Data Management in Large-Scale Distributed Systems

NoSQL Databases

Thomas Ropars

thomas.ropars@univ-grenoble-alpes.fr

http://tropars.github.io/

2019

References

- The lecture notes of V. Leroy
- The lecture notes of F. Zanon Boito
- Designing Data-Intensive Applications by Martin Kleppmann
  - Chapter 7

In this lecture

- Motivations for NoSQL databases
- ACID properties and CAP Theorem
- A landscape of NoSQL databases

Agenda

Introduction

Why NoSQL?

Transactions, ACID properties and CAP theorem

Data models

NoSQL databases design and implementation

Common patterns of data accesses

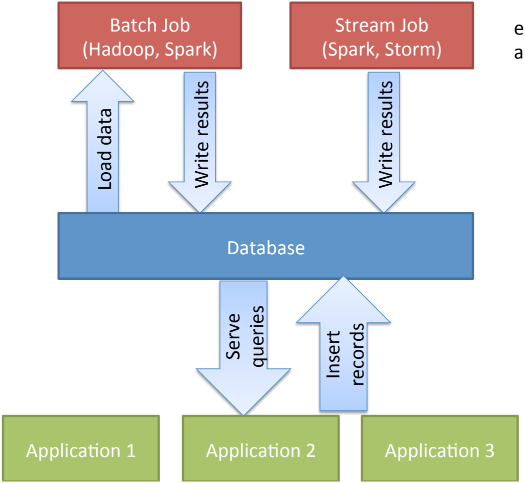
Large-scale data processing

- Batch processing: Hadoop, Spark, etc.
- Perform some computation/transformation over a full dataset
- Process all data

Selective query

- Access a specific part of the dataset
- Manipulate only data needed (1 record among millions)
- Main purpose of a database system

Processing / Database Link



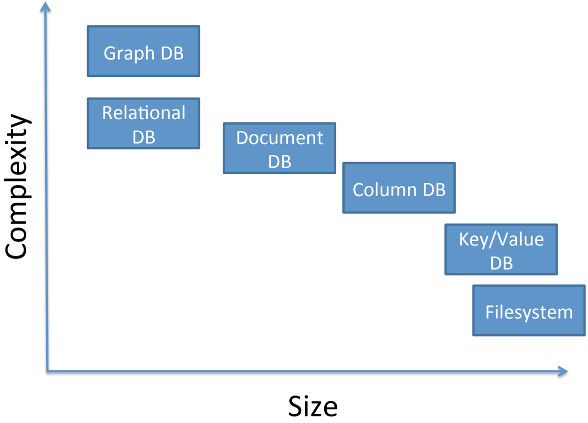
e.g. sentiment analysis

e.g. Twitter trends page

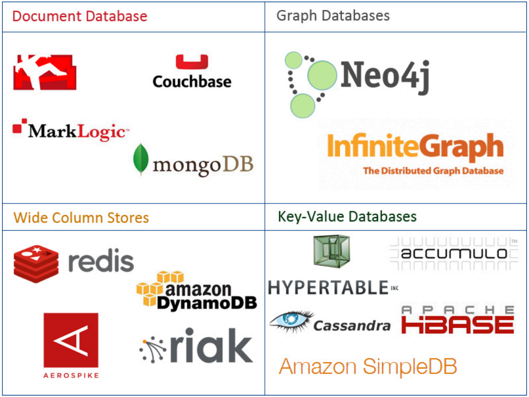
Different types of databases

- So far we used HDFS
  - A file system can be seen as a very basic database
  - Directories / files to organize data
  - Very simple queries (file system path)
  - Very good scalability, fault tolerance …
- Other end of the spectrum: Relational Databases
  - SQL query language, very expressive
  - Limited scalability (generally 1 server)

Size / Complexity



The NoSQL Jungle



@cloudtxt http://www.aryannava.com

Agenda

Introduction

Why NoSQL?

Transactions, ACID properties and CAP theorem

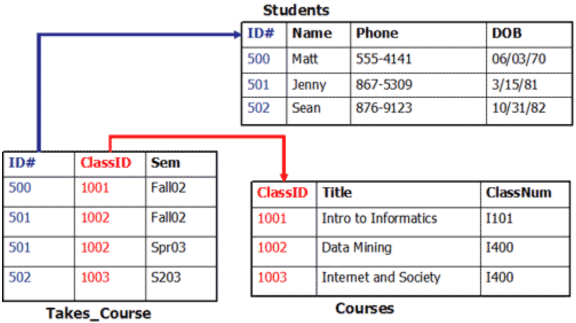
Data models

NoSQL databases design and implementation

Relational databases

SQL

- Born in the 70's – Still heavily used
- Data is organized into relations (in SQL: tables)
- Each relation is an unordered collection of tuples (rows)



Students

ID#	Name	Phone	DOB
500	Matt	555-4141	06/03/70
501	Jenny	867-5309	3/15/81
502	Sean	876-9123	10/31/82

ID#	ClassID	Sem
500	1001	Fall02
501	1002	Fall02
501	1002	Spr03
502	1003	S203

Takes_Course

ClassID	Title	ClassNum
1001	Intro to Informatics	I101
1002	Data Mining	I400
1003	Internet and Society	I400

Courses

About SQL

Advantages

- Separate the data from the code
    - High-level language
    - Space for optimization strategies
- Powerful query language
    - Clean semantics
    - Operations on sets
- Support for transactions

Motivations for alternative models

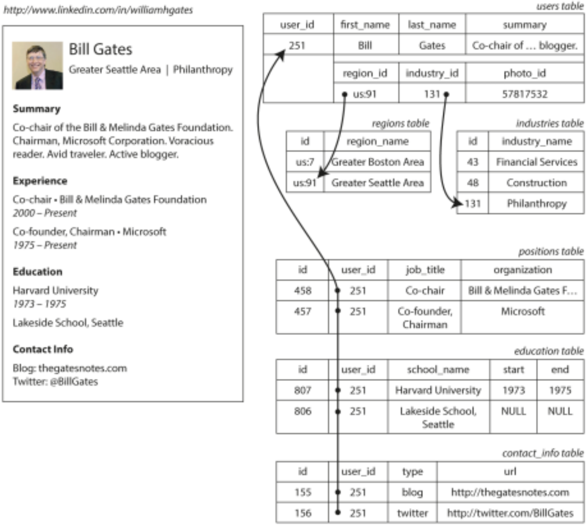
see https://blog.couchbase.com/nosql-adoption-survey-surprises/

Some limitations of relational databases

- Performance and scalability
  - Difficult to partition the data (in general run on a single server)
  - Need to scale up to improve performance
- Lack of flexibility
  - Will to easily change the schema
  - Need to express different relations
  - Not all data are well structured
- Few open source solutions
- Mismatch between the relational model and object-oriented programming model

Illustration of the object-relational mismatch

Figure by M. Kleppmann



http://www.linkedin.com/in/williamhgates

Bill Gates

Greater Seattle Area | Philanthropy

Summary

Co-chair of the Bill & Melinda Gates Foundation. Chairman, Microsoft Corporation. Voracious reader. Avid traveler. Active blogger.

Experience

Co-chair • Bill & Melinda Gates Foundation
2000 – Present

Co-founder, Chairman • Microsoft
1975 – Present

Education

Harvard University
1973 – 1975

Lakeside School, Seattle

Contact Info

Blog: thegatesnotes.com
Twitter: @BillGates

users table

user_id	first_name	last_name	summary
251	Bill	Gates	Co-chair of … blogger.

region_id	industry_id	photo_id
us:91	131	57817532

regions table

id	region_name
us:7	Greater Boston Area
us:91	Greater Seattle Area

industries table

id	industry_name
43	Financial Services
48	Construction
131	Philanthropy

positions table

id	user_id	job_title	organization
458	251	Co-chair	Bill & Melinda Gates F…
457	251	Co-founder, Chairman	Microsoft

education table

id	user_id	school_name	start	end
807	251	Harvard University	1973	1975
806	251	Lakeside School, Seattle	NULL	NULL

contact_info table

id	user_id	type	url
155	251	blog	http://thegatesnotes.com
156	251	twitter	http://twitter.com/BillGates

Figure: A CV in a relation database

Illustration of the object-relational mismatch

Figure by M. Kleppmann

```
{
  "user_id":251,
  "first_name": "Bill",
  "last_name": "Gates",
  "summary": "Co−chair of the Bill & Melinda Gates; Active blogger.",
  "region_id": "us:91",
  "industry_id": 131,
  "photo_url": "/p/7/000/253/05b/308dd6e.jpg",
  "positions": [
    {"job_title": "Co−chair", "organization": "Bill & Melinda Gates
          Foundation"},
    {"job_title": "Co−founder, Chairman", "organization": "Microsoft"}
  ],
  "education": [
    {"school_name": "Harvard University", "start": 1973, "end": 1975},
    {"school_name": "Lakeside School, Seattle", "start": null, "end": null}
  ],
  "contact_info": {
    "blog": "http://thegatesnotes.com",
    "twitter": "http://twitter.com/BillGates"
  }
}
```

Figure: A CV in a JSON document

About NoSQL

What is NoSQL?

- A hashtag
  - NoSQL approaches were existing before the name became famous
- No SQL
- New SQL
- Not only SQL
  - Relational databases will continue to exist alongside non-relational datastores

About NoSQL

A variety of NoSQL solutions

- Key-Value (KV) stores
- Wide column stores (Column family stores)
- Document databases
- Graph databases

Difference with relational databases

There are several ways in which they differ from relational databases:

- Properties
- Data models
- Underlying architecture

Agenda

Introduction

Why NoSQL?

Transactions, ACID properties and CAP theorem

Data models

NoSQL databases design and implementation

About transactions

The concept of transaction

- Groups several read and write operations into a logical unit
- A group of reads and writes are executed as one operation:
  - The entire transaction succeeds (commit)
  - or the entire transaction fails (abort, rollback)
- If a transaction fails, the application can safely retry

About transactions

The concept of transaction

- Groups several read and write operations into a logical unit
- A group of reads and writes are executed as one operation:
  - The entire transaction succeeds (commit)
  - or the entire transaction fails (abort, rollback)
- If a transaction fails, the application can safely retry

Why do we need transactions?

- Crashes may occur at any time
  - On the database side
  - On the application side
  - The network might not be reliable
- Several clients may write to the database at the same time

ACID

ACID describes the set of safety guarantees provided by transactions

- Atomicity
- Consistency
- Isolation
- Durability

Having such properties make the life of developers easy, but:

- ACID properties are not the same in all databases
    - It is not even the same in all SQL databases
- NoSQL solutions tend to provide weaker safety guarantees
    - To have better performance, scalability, etc.

ACID: Atomicity

Description

- A transactions succeeds completely or fails completely
  - If a single operation in a transaction fails, the whole transaction should fail
  - If a transaction fails, the database is left unchanged
- It should be able to deal with any faults *in the middle* of a transaction
- If a transaction fails, a client can safely retry

In the NoSQL context:

- Atomicity is still ensured

ACID: Consistency

Description

- Ensures that the transaction brings the database from a valid state to another valid state
    - Example: Credits and debits over all accounts must always be balanced
- It is a property of the application, not of the database
    - The application cannot enforce application-specific invariants
    - The database can check some specific invariants
        - A foreign key must be valid

In the NoSQL context:

- Consistency is (often) not discussed

ACID: Durability

Description

- Ensures that once a transaction has committed successfully, data will not be lost
  - Even if a server crashes (flush to a storage device, replication)

In the NoSQL context:

- Durability is also ensured

ACID: Isolation

Description

- Concurrently executed transactions are isolated from each other
  - We need to deal with concurrent transactions that access the same data
- Serializability
  - High level of isolation where each transaction executes as if it was the only transaction applied on the database
    - As if the transactions are applied *serially*, one after the other
  - Many SQL solutions provide a lower level of isolation

In the NoSQL context:

- **What about the CAP theorem?**

The CAP theorem

3 properties of databases

- Consistency
  - What guarantees do we have on the value returned by a read operation?
  - It strongly relates to Isolation in ACID (and not to consistency)
- Availability
  - The system should always accept updates
- Partition tolerance
  - The system should be able to deal with a partitioning of the network

Comments on CAP theorem

- Was introduced by E. Brewer in its lectures (beginning of years 2000)
- Goal: discussing trade-offs in database design

What does the CAP theorem says?

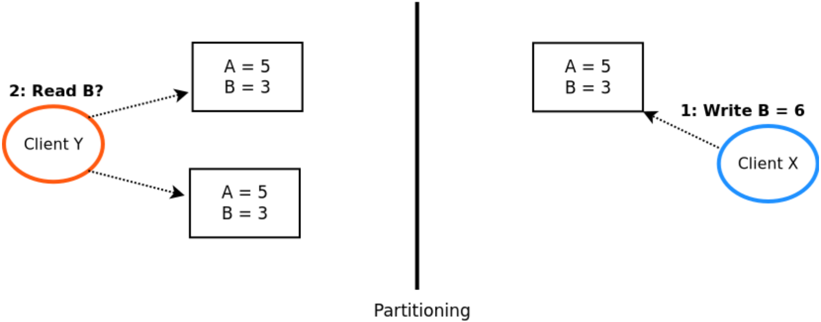
The theorem

It is impossible to have a system that provides Consistency, Availability, and partition tolerance.

How it should be understood:

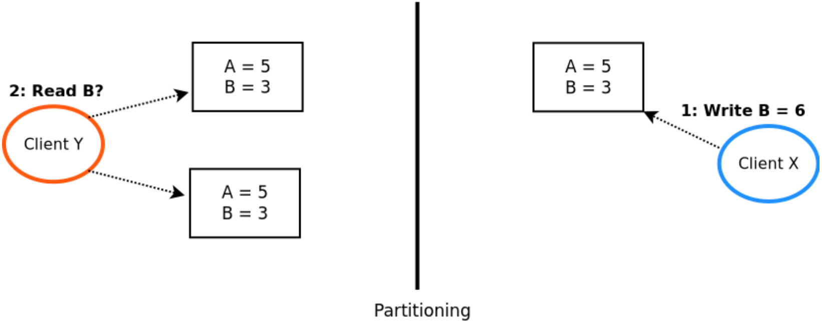
- Partitions are unavoidable
  - It is a fault, we have no control on it
- We need to choose between availability and consistency
  - In the CAP theorem:
    - Consistency is meant as *linearizability* (the strongest consistency guarantee)
    - Availability is meant as *total availability*
  - In practice, different trade-offs can be provided

The intuition behind CAP



- Let inconsistencies occur? (No C)
- Stop executing transactions? (No A)

The intuition behind CAP



- Let inconsistencies occur? (No C)
- Stop executing transactions? (No A)

Note that in a centralized system (non-partitioned relational database), no need for Partition tolerance

- We can have Consistency and Availability

The impact of CAP on ACID for NoSQL

source: E. Brewer

The main consequence

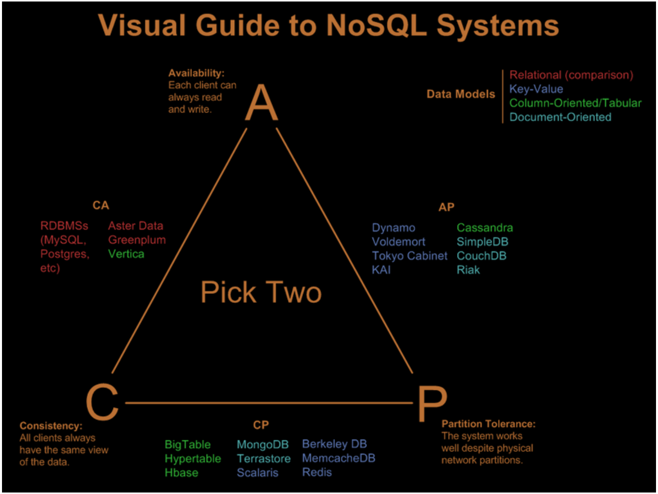
- No NoSQL database with strong Isolation

Discussion about other ACID properties

- Atomicity
  - Each side should ensure atomicity
- Durability
  - Should never be compromised

A vision of the NoSQL landscape

Source: https://blog.nahurst.com/visual-guide-to-nosql-systems



To be read with care:

- Solutions often provide a trade-off between CP and AP
- A single solution may often a different trade-off depending on how is is configured.
- **We don't pick two !**

Agenda

Introduction

Why NoSQL?

Transactions, ACID properties and CAP theorem

Data models

NoSQL databases design and implementation

Agenda

Introduction

Why NoSQL?

Transactions, ACID properties and CAP theorem

Data models

NoSQL databases design and implementation

Additional references

Mandatory reading

- *Bigtable: A Distributed Storage System for Structured Data.*, F. Chang et al., OSDI, 2006.
- *Cassandra: a decentralized structured storage system* ., A. Lakshman et al., SIGOPS OS review, 2010.

Suggested reading

- `http://martin.kleppmann.com/2015/05/11/please-stop-calling-databases-cp-or-ap.html`, M. Kleppmann, 2015.
- `https://jvns.ca/blog/2016/11/19/a-critique-of-the-cap-theorem/`, J. Evans, 2016.