

University of Udine

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# Data Management for Big Data

*Introduction to Big Data and NoSQL*

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# Big Data

# Big Data

## What is Big Data?

Big data are beyond the usual limits of traditional databases, and are characterized by one or more of the properties:

- huge *Volume*
- high *Variety*
- acquired at high *Velocity*

Gartner analyst Doug Laney introduced the 3Vs concept in a 2001 MetaGroup research publication: "*3D data management: Controlling data volume, variety and velocity*"

# Volume

Volume basically means the size of stored data, which may derive from human actions or can be machine-generated.

Sometimes the volume of data is so massive that they cannot be stored in their entirety, but have to be compressed/transformed online, as soon as they arrive (e.g., scientific sensor data).

Sometimes data can be stored using traditional RDBMS, while other times this choice may end up being too expensive in terms of cost or time ↵ NoSQL solutions, Hadoop.

# Volume (Orders Of Magnitude)

IBM 350 disk storage  
(1956, 3.75 MB)

Walmart's DW  
(1992, 1 TB)

1 year of CERN's  
LHC data (15 PB)

Quantities of bytes						
Common prefix				Binary prefix		
Name	Symbol	Decimal	Binary	Name	Symbol	Binary
		SI	JEDEC			IEC
kilobyte	KB/kB	$10^3$	$2^{10}$	kibibyte	KiB	$2^{10}$
megabyte	MB	$10^6$	$2^{20}$	mebibyte	MiB	$2^{20}$
gigabyte	GB	$10^9$	$2^{30}$	gibibyte	GiB	$2^{30}$
terabyte	TB	$10^{12}$	$2^{40}$	tebibyte	TiB	$2^{40}$
petabyte	PB	$10^{15}$	$2^{60}$	pebibyte	PiB	$2^{60}$
exabyte	EB	$10^{18}$	$2^{60}$	exbibyte	EiB	$2^{60}$
zettabyte	ZB	$10^{21}$	$2^{70}$	zebibyte	ZiB	$2^{70}$
yottabyte	YB	$10^{24}$	$2^{80}$	yobibyte	YiB	$2^{80}$

In 2016, it was estimated that all the Internet data amounted to 1.3 ZB

# Variety

Differences between formats and the absence of a common structure are a typical characteristic of big data.

Structured, semi-structured, and unstructured data.

Data may come from different sources. Considering the web it may come from humans, like *user-generated content*, or it can be machine-generated, such as *logs, packet traces, etc.*

Heterogeneity of formats, structures and sources make it difficult to process and store such data using traditional tools.

# Velocity

Data acquired via sensors, or scientific instruments, may come at a high speed.

Some data have to be stored or analyzed as soon as they arrive, since they are transient (e.g., logs, data streams).

For companies that rely upon fast-generated data it is also important to exploit/analyze such data as fast as possible.

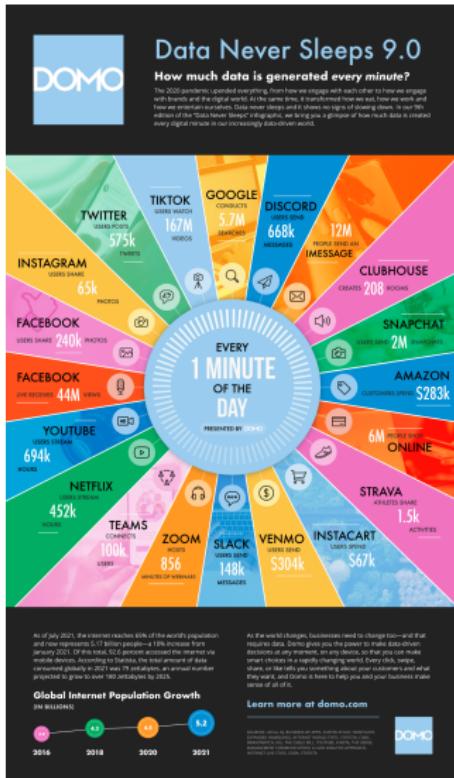
*"Just in its 1st phase, the SKA telescope will produce some 160 TB of raw data per second that the supercomputers will need to handle."*

<https://www.skatelescope.org/frequently-asked-questions/>





# Velocity



# Velocity

Data *velocity* is rarely a static metric.

Internal and external changes to a system and to the context in which it operates can have a considerable impact on the rate at which data have to be managed.

Variable velocity, coupled with large volume, requires data stores to handle **sustained levels** of high read and write loads, and also **peaks**.

- **Volume:** scale of the data
- **Variety:** different forms of data
- **Velocity:** e.g., analysis of streaming data
- **Variability:** changes in the characteristics of the data
- **Value:** revenues, hypotheses that may arise from the data
- **Veracity:** trustworthiness, origin and reputation



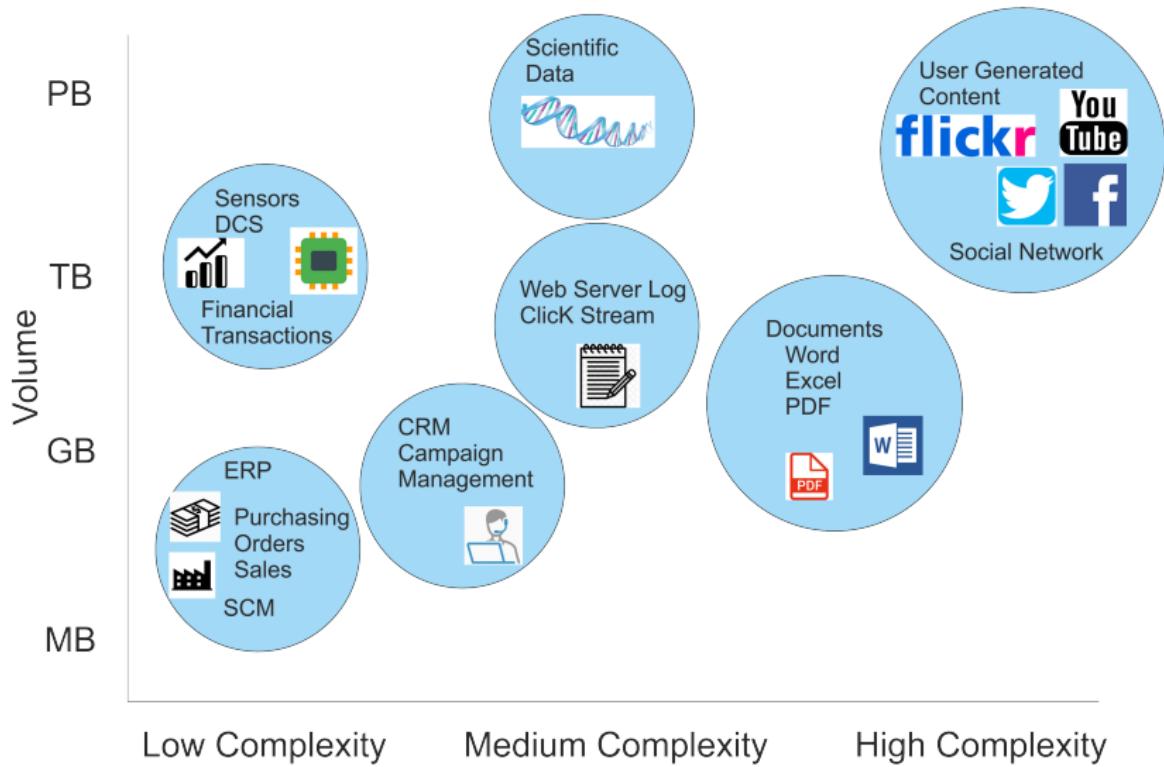
# Big Data

## And Even More Vs...

- **7 Vs:** <https://impact.com/marketing-intelligence/7-vs-big-data/>
- **10 Vs:** [tdwi.org/articles/2017/02/08/10-vs-of-big-data.aspx](https://tdwi.org/articles/2017/02/08/10-vs-of-big-data.aspx)
- **17 Vs:** <https://www.irjet.net/archives/V4/i9/IRJET-V4I957.pdf>
- **42 Vs:** <https://www.kdnuggets.com/2017/04/42-vs-big-data-data-science.html>

# Big Data

## Classification by Volume and Complexity



Data from the Web plays a big role in big data realm, and are characterized by volume, variety and velocity. Examples:

- HTML pages (in any language)
- Tweets
- Social network content (Facebook, LinkedIn, etc.)
- Forum comments and blog posts
- Documents in several formats: XML, PDF, Word, Excel, etc.

# Big Data Use Cases

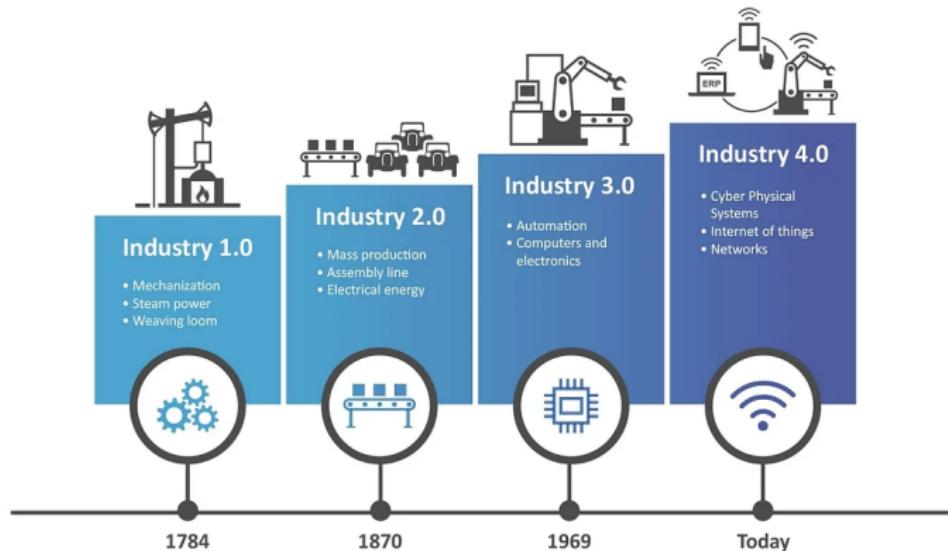
## Internet of Things

The Internet Of Things (IoT) is about (daily life) objects that are equipped with sensors and connectivity, acting as sources of data

- the concept can involve both industry and consumer products (like connected automobiles, machinery, etc.)
- data can be used for tasks such as surveillance, predictive maintenance, or performance enhancement in general
- if objects are attached to people even human behaviour and well-being can be analyzed

# Big Data Use Cases

## Industry 4.0



# Big Data

## Challenges and Opportunities

Big data come with challenges and opportunities:

- *business*: big data give companies the opportunity to develop new business models so to get advantages with respect to competitors
- *technology*: size and complexity of big data require adequate solutions
- *financial aspects*: several use cases show that exploiting big data may lead to economic benefits. To this end, it is also important evaluate the costs involved with their management (e.g., cloud solutions)
- *privacy*: who owns the data?

# NoSQL

# What is NoSQL?

The term NoSQL (Not only SQL) refers to data stores that are **not relational databases**, rather than explicitly describing what they are.

A possible (rather general) definition: “*Next Generation DBs mostly addressing some of the points: being non-relational, distributed, open source and horizontally scalable*”.

NoSQL storage technologies have very **heterogeneous** operational, functional, and architectural characteristics.

NoSQL proposals have been developed starting from 2009 trying to address new challenges that emerged in that decade.

# The Rise of NoSQL

Most enterprise level applications used to run on top of relational databases (MySQL, PostgreSQL, etc).

Over the years data got bigger in volume, started to change more rapidly, and to be in general more structurally varied than those commonly handled with traditional RDBMS.

As the *volume* of data increases dramatically, so does query execution time, as a consequence of the size of tables involved and of an increased number of JOIN operations (*join pain*).

# Benefits of NoSQL

High volume and high heterogeneity data:

- RDBMS: capacity and constraints at their limits
- NoSQL are specifically designed for this scenario

Elastic Scaling:

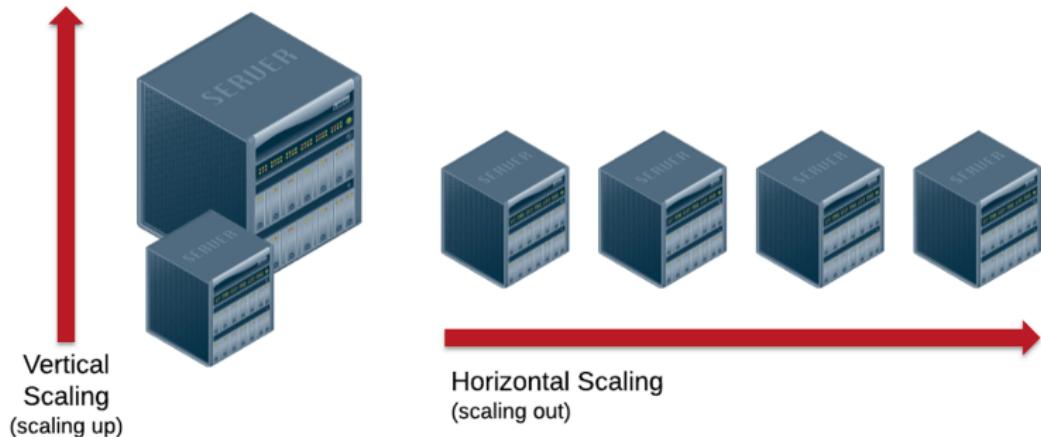
- RDBMS scale up: bigger load  $\Rightarrow$  bigger server
- NoSQL scale out: distribute data across multiple nodes, adding/removing them seamlessly

DBA Specialists:

- RDBMS require highly trained experts to monitor DB
- NoSQL require less management: automatic repair and simpler data models

# Benefits of NoSQL

## Vertical vs horizontal scaling



# Drawbacks of NoSQL

Several default constraints of RDBMS are not supported at the database level (e.g., foreign keys).

If not properly managed, the absence of a fixed structure may become an issue.

The design process is not as straightforward and consolidated as in the relational model.

Lack of SQL (though there are some SQL-inspired languages).

Often, lack of one or more ACID properties.

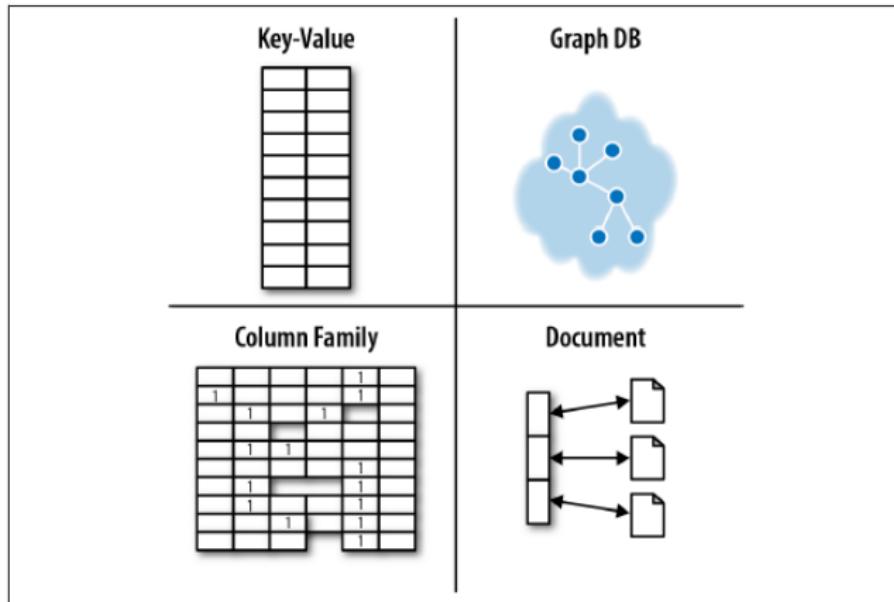
# BASE Properties

In order to better support the characteristics of the novel kinds of data, NoSQL systems rely on the BASE properties instead:

- *Basically available* The store appears to be accessible most of the time (for instance, tolerance to node failures)
- *Soft state* Stores do not need to be write-consistent, nor do different replicas have to be mutually consistent all the time
- *Eventual consistency* The system eventually exhibits consistency at some later point

Of course, this kind of relaxed consistency would be a problem, for instance, in a banking database. In other cases, it is perfectly acceptable, e.g., for social networks.

# The NoSQL Quadrant



# Key/Value Stores

Key/value stores are based on the concept of *associative array* (i.e., dictionary, or map), a data structure that contains couples of <key, values>; the key is used to access the values.

E.g., in a database storing personal data, keys could be the SSN of customers, while values their phone numbers.

Operations allowed over an associative array are:

- *Add*: add an element to the array
- *Remove*: remove an element from the array
- *Modify*: change the value associated to a key
- *Find*: search for a value by the key

# Key/Value Store - Focus

Key/values stores offer just the add/remove/modify/find operations on data, which nevertheless are executed at a fixed (fast) computational cost, thanks to the associative array.

Some typical relational operations, such as complex filters and JOINS are not possible (unless a custom script is written).

Also, important RDBMS functionalities like foreign keys are not supported.

Key/value stores are very simple pertaining to their data model, but they can be extremely sophisticated regarding horizontal scalability.

# Key/Value Store - Focus

Array "emp\_name":

[<XA13, John Doe>, <XZ42, Mary Jane>, <XG56, Jhonny  
Donny>, ...]

Array "emp\_department":

[<XA13, Physics>, <XZ42, Physics>, <XG56, Computer  
Science>, ...]

Array "emp\_salary":

[<XA13, 45000>, <XZ42, 50000>, <XG56, 52000>, ...]

Array "dept\_budget":

[<Physics, 950000>, <Computer Science, 780000>, ...]

# Key/Value Store - Examples

Use cases:

- Storage of profiles, preferences and configurations
- Storage of multimedia objects
- Storage of machinery or sensors data

Exemplary DBMSs:

- **Berkeley DB** is a high performance key/value database from Oracle Inc., with implementations in C, Java and XML/C++
- **Project Voldemort** is a (LinkedIn-born) distributed key/value store based on Berkeley DB, designed for performance and fault protection
- **Redis** (in-memory database): <https://redis.io/>
- **Aerospike**: <https://aerospike.com/>

# Document-oriented Databases

Document databases store, retrieve and manage document oriented information, also known as semi-structured data.

Documents do not have a fixed structure, nonetheless they contain **tags** or other markers to separate semantic elements and enforce hierarchies of records and fields within the data. Therefore, they can be considered as a kind of **self-describing structure**.

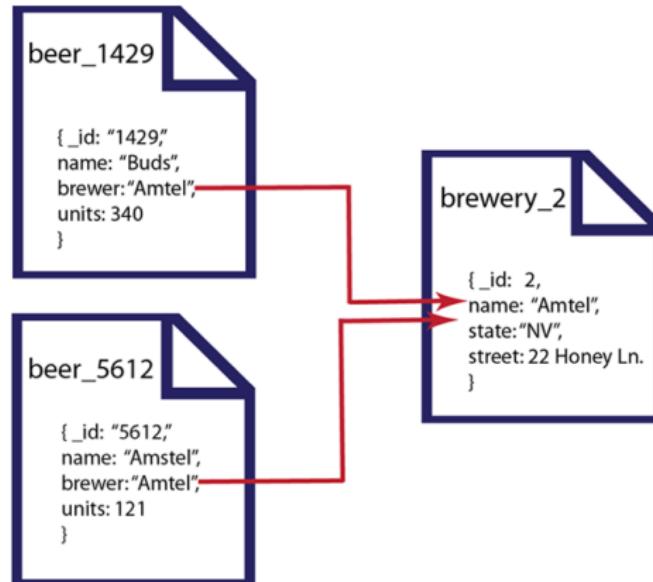
Documents can be encoded into formats like XML and JSON.

Document stores represent a step up with respect to key-value stores, defining a structure over keys and values, thus allowing the users to operate on the internal document structure.

# Document example

```
<Phone campaign>
  <Survey ID = 1>
    <Name> John Easter </Name>
    <Question ID = 1> yes </Question>
    <Question ID = 2> yes </Question>
    <Question ID = 2.1> 5 </Question>
    <Question ID = 2.2> 7 </Question>
    <Question ID = 3> no </Question>
  </Survey>
  <Survey ID = 2>
    <Name> Mary Christmas </Name>
    <Question ID = 1> yes </Question>
    <Question ID = 2> no </Question>
    <Question ID = 3> yes </Question>
    <Question ID = 3.1> yes </Question>
    <Note> The person seems to be rather interested in the offered product </Note>
  </Survey>
</Phone campaign>
```

# Document example



Custom scripts are required to perform JOIN operations or to enforce data consistency between documents

# Documents and relationships

Relationships are represented by nesting documents: “*Data that is accessed together should be stored together*”

USERS						
ID	first_name	last_name	cell	city	latitude	longitude
1	Leslie	Yepp	8125552344	Pawnee	39.170344	-86.536632

HOBBIES			JOB HISTORY			
ID	user_id	hobby	ID	user_id	job_title	year_started
10	1	scrapbooking	20	1	Deputy Directory	2004
11	1	eating waffles	21	1	City Councilor	2012
12	1	working	22	1	Director, National Parks Service, Midwest Branch	2014

```
{  
  "_id": 1,  
  "first_name": "Leslie",  
  "last_name": "Yepp",  
  "cell": "8125552344",  
  "city": "Pawnee",  
  "location": [ -86.536632,  
               39.170344 ],  
  "hobbies": [  
    "scrapbooking",  
    "eating waffles",  
    "working"  
  ],  
  "jobHistory": [  
    {  
      "title": "Deputy Director",  
      "yearStarted": 2004  
    },  
    {  
      "title": "City Councillor",  
      "yearStarted": 2012  
    },  
    {  
      "title": "Director, National Parks Service, Midwest Branch",  
      "yearStarted": 2014  
    }  
  ]  
}
```

The core operations that a document-oriented database supports for documents are similar to other databases, and are named as CRUD:

- *Creation*: of a new document
- *Retrieval*: based on key, content, or metadata
- *Update*: the content or metadata of the document
- *Deletion*: of a document

Typical use cases: similar to key-value stores, but more complex data can be handled (product data management, inventory).

→ **MongoDB** is an example of a document-oriented database.

# Column-oriented Stores

The roots of colum-store DBMSs can be traced back in the 1970s.

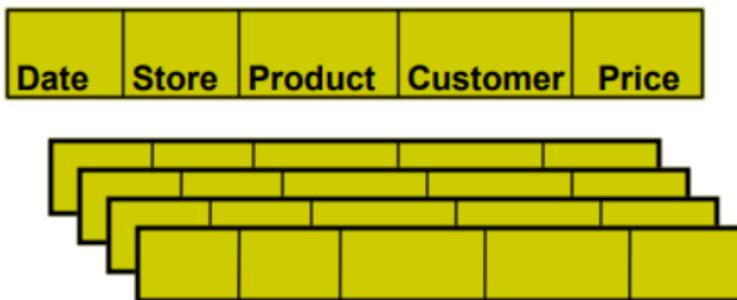
However, due to market needs and non favorable-technology trends it was not until the 2000s that they took off.

A column-oriented DBMS stores each database table column separately, in different disk locations, or even different machines.

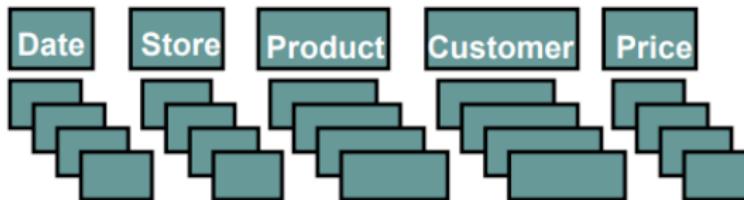
Values belonging to the same column are packed together, as opposed to traditional DBMSs that store entire rows one after the other.

# Rows vs Columns

## row-store



## column-store



# Rows vs Columns

In a classical relational database each field is stored adjacent to the next in the same block on the hard drive:

```
512,Seabiscuit,Book,10.95,201712241200,goodreads.com  
513,Bowler,Apparel,59.95,201712241200,google.com  
514,Cuphead,Game,20.00,201712241201,gamerassaultweekly.com
```

In a columnar database, blocks on the disk for the above data might look like this:

```
512,513,514  
Seabiscuit,Bowler,Cuphead  
Book,Apparel,Game  
10.95,59.95,20.00  
201712241200,201712241200,201712241201  
goodreads.com,google.com,gamerassaultweekly.com
```

# Column Store Pros

Column stores are beneficial when the typical application is reading a subset of columns, or performing **aggregate functions** over them (AVG, MIN, MAX, ...).

They offer efficient storing capabilities due to an easier **compression of data**, which is performed by column (columns have a low information entropy).

Columnar databases are **very scalable**, and well suited for *massively parallel processing* (MPP), which involves having data partitioned and spread across a large cluster of machines.

# Column Store Cons

The main drawbacks of column-based stores are related to write operations and tuple (re)construction.

Newly inserted tuples have to be **broken down** to their component attributes, and each attribute must be written separately.

Also tuple construction is considered problematic, since information about a logical entity is stored in multiple locations, which brings an **overhead** for queries that access many attributes from an entity.

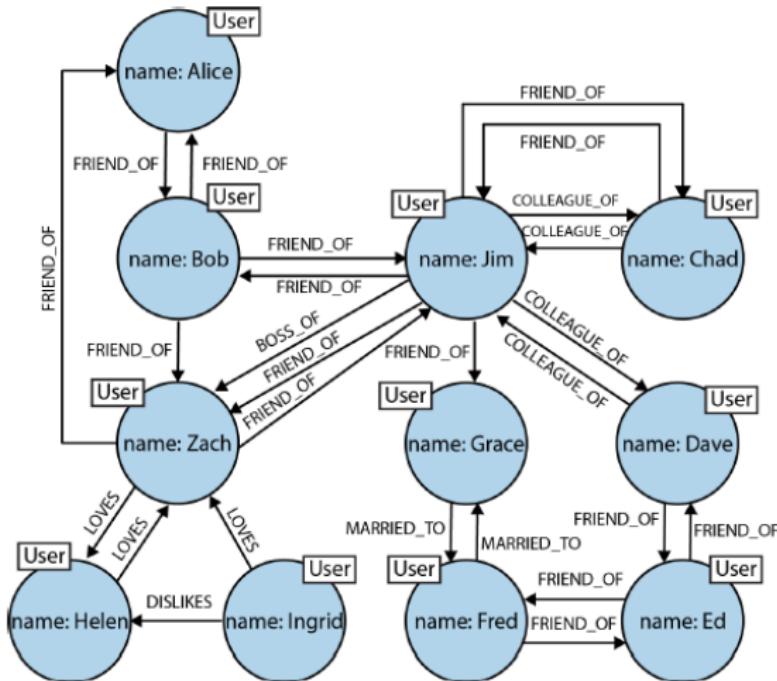
→ **Cassandra** is an example of a column store database.

# Graph Databases

A graph database is a database that uses graph structures for semantic queries with *nodes* (possibly of different kinds), *edges*, and *properties* to represent and store data.

Graph databases can naturally represent certain kinds of semi-structured, **highly interconnected data**, such as those present in social networks, or in geospatial and biotech applications.

# Graph Example



# Graph Databases – Why

Of course, the previous graph could be modeled using other kinds of NoSQL approaches, as well as RDBMSs.

Nevertheless, the resulting databases would be very difficult to query, update, and populate.

On the contrary, graph databases can easily answer to queries such as:

- what is the shortest path connecting node X with node Y?
- what are the friends of *Billy*?
- what are the friends of friends of *Billy*?

In native implementations, nodes have **direct pointers** connecting them, so the navigation time is independent from the graph size.

# Examples of Graph Databases

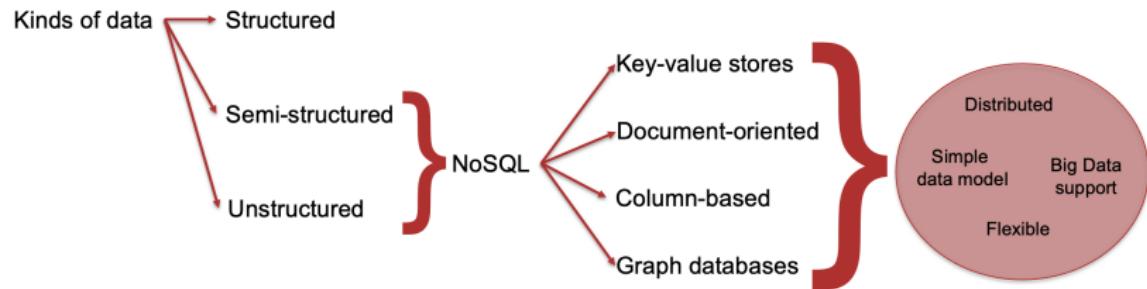
**Neo4J** is a very performing, native, open source property graph database that guarantees ACID properties offering scalability up to billions of nodes.

- Online sandbox: <https://neo4j.com/sandbox/>

**AllegroGraph** is a closed source triplestore, designed to store RDF triples; it supports ACID properties.

**ArangoDB** is a multi-model, open source, database system that supports three data models (key/value, documents, graphs).

# Recap



# The twilight zone: NewSQL

- In recent years there has been a progressive (**re**)**approach between relational solutions and NoSQL**, with the birth of the so-called NewSQL
- NewSQL DBMSs try to combine the performances of NoSQL with the data guarantees offered by relational DBs
- For example, there are NoSQL systems that support transactions (Neo4j), and others that offer languages inspired by SQL, although generally less powerful than the latter (Cassandra's CQL)
- Conversely, relational DBMSs allow, today, to store semi-structured data inside tables, thanks to the JSON and JSONB formats, while others allow to store time series data generated quickly and in large quantities (TimescaleDB)

# Bibliography

Stavros Harizopoulos, Daniel Abadi, Peter Boncz (2009),  
Column-Oriented Database Systems, VLDB 2009 Tutorial

Ian Robinson, Jim Webber & Emil Eifrem, Graph Databases  
Second Edition, O'Reilly Media, Inc.

Big Data Management and NoSQL Databases Lecture 7.  
Column-family stores, Doc. RNDr. Irena Holubova, Ph.D.

Andrew Pavlo, Matthew Aslett (2016), What's really new with  
NewSQL?, ACM Sigmod Record, 45(2), 45-55