01

Introduction

Notice

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Bibliography

- **Many examples and images are extracted and adapted from:**
  - Guy Harrison. Next Generation Databases: NoSQL, NewSQL and Big Data. Apress, 2015.

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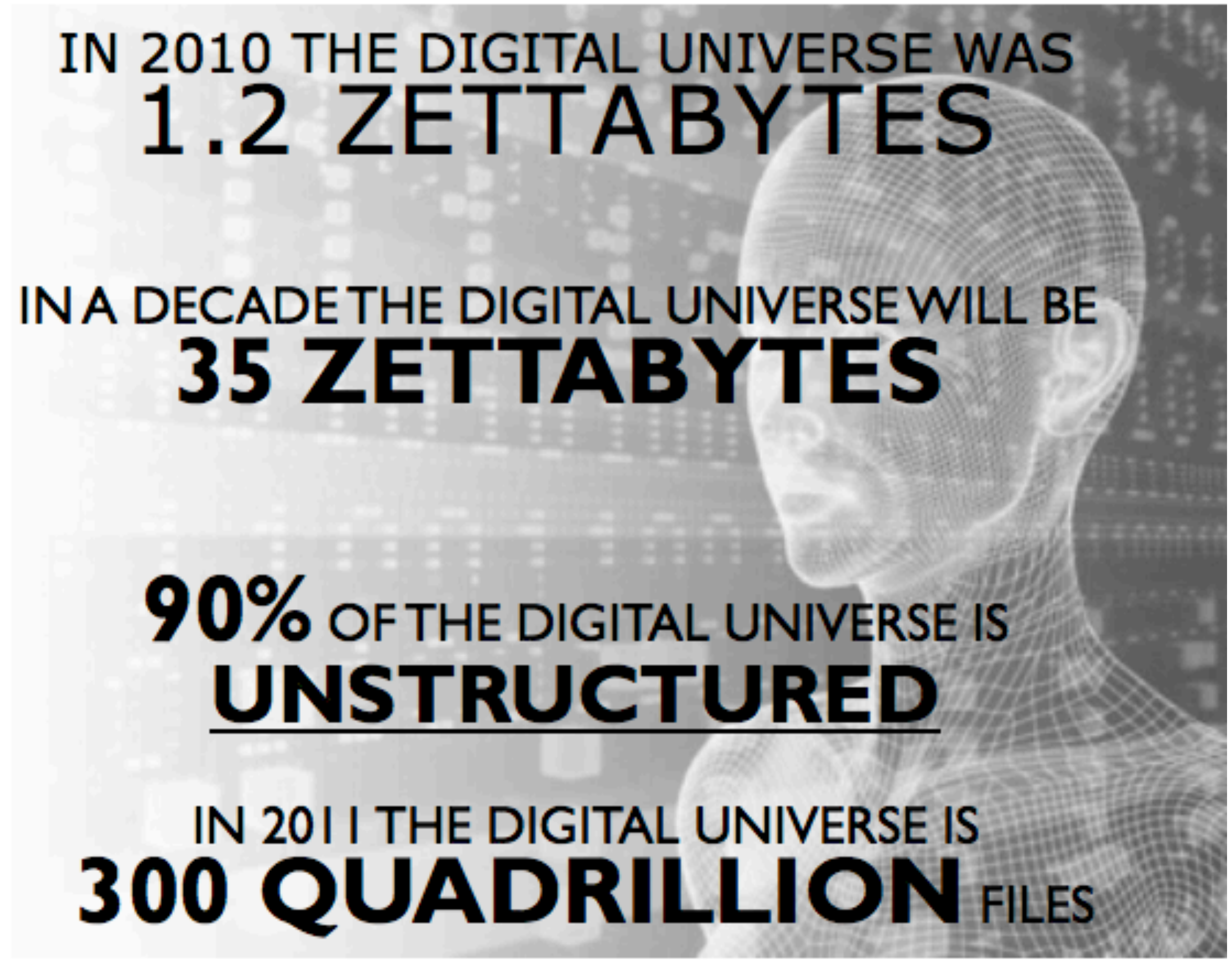
Big Data

The (Big)Data Era

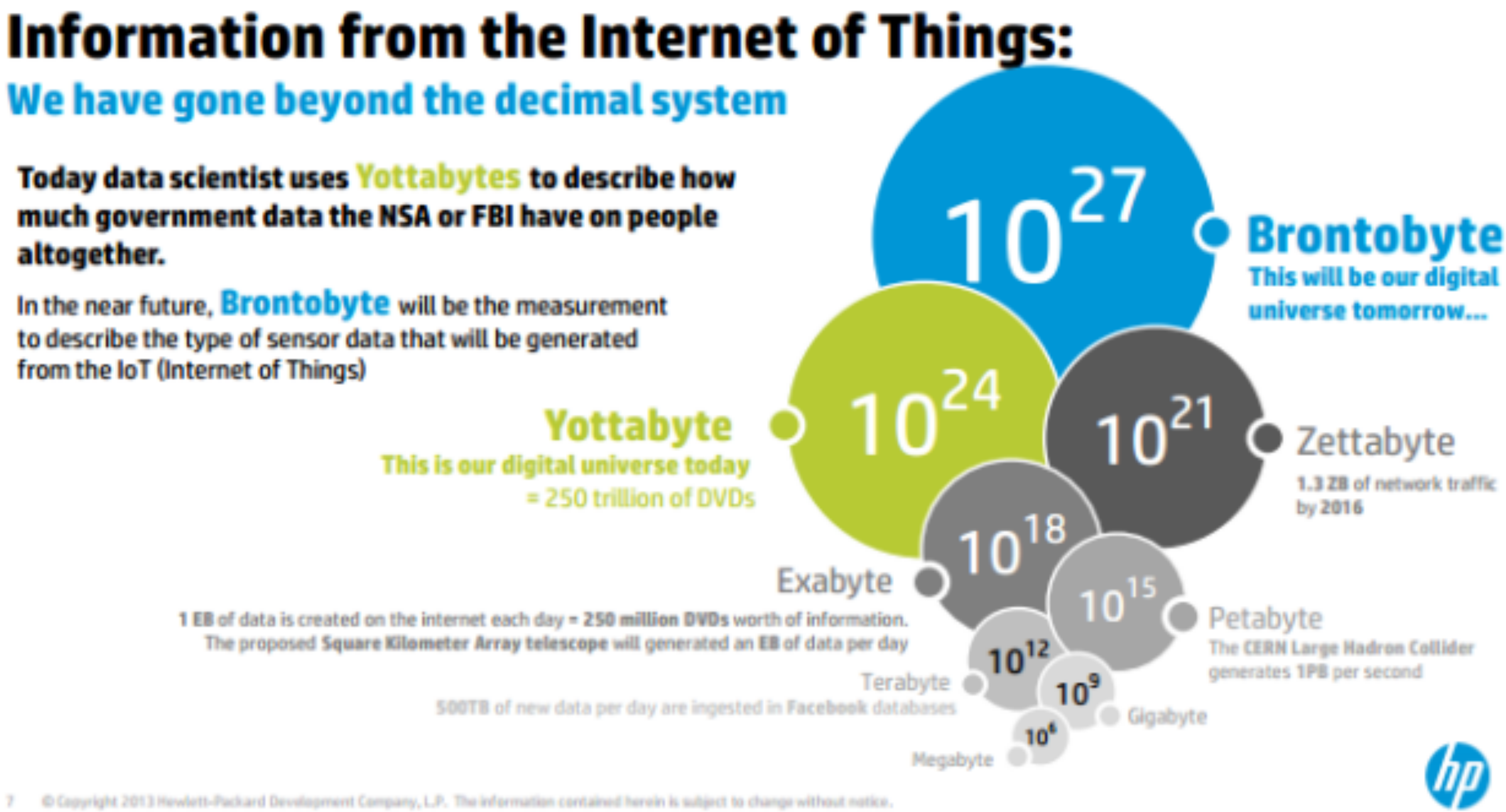
The Economist, Feb 25, 2010



WIRED The New York Times Bloomberg Businessweek Forbes WALL STREET JOURNAL

Introduction to Analytics and Big Data – Hadoop

The (Big)Data Era



The (Big)Data Era

Multiples of bytes V·T·E

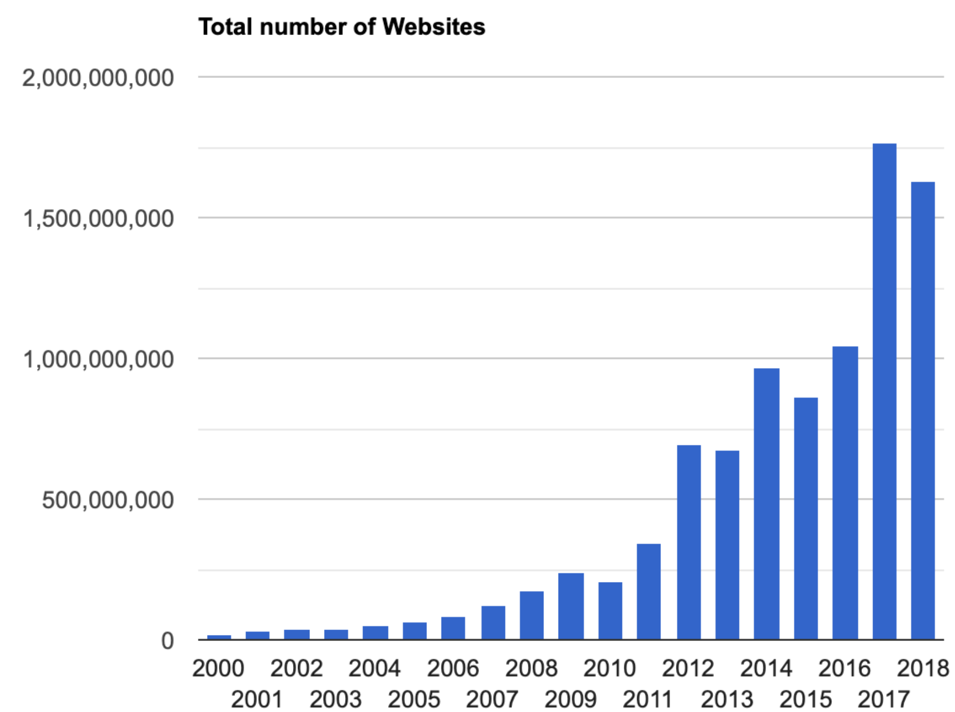
Decimal			Binary				
Value	Metric		Value	IEC		JEDEC	
1	B	byte	1	B	byte	B	byte
1000	kB	kilobyte	1024	KiB	kibibyte	KB	kilobyte
1000^2	MB	megabyte	1024^2	MiB	mebibyte	MB	megabyte
1000^3	GB	gigabyte	1024^3	GiB	gibibyte	GB	gigabyte
1000^4	TB	terabyte	1024^4	TiB	tebibyte	–	
1000^5	PB	petabyte	1024^5	PiB	pebibyte	–	
1000^6	EB	exabyte	1024^6	EiB	exbibyte	–	
1000^7	ZB	**zettabyte**	1024^7	ZiB	zebibyte	–	
1000^8	YB	yottabyte	1024^8	YiB	yobibyte	–	

The (Big)Data Era

- **The current Internet is estimated to hold 4.7 billion web pages (March 2016)**
- **There are over 1.5 billion websites on the world wide web today. Of these, less than 200 million are active.**

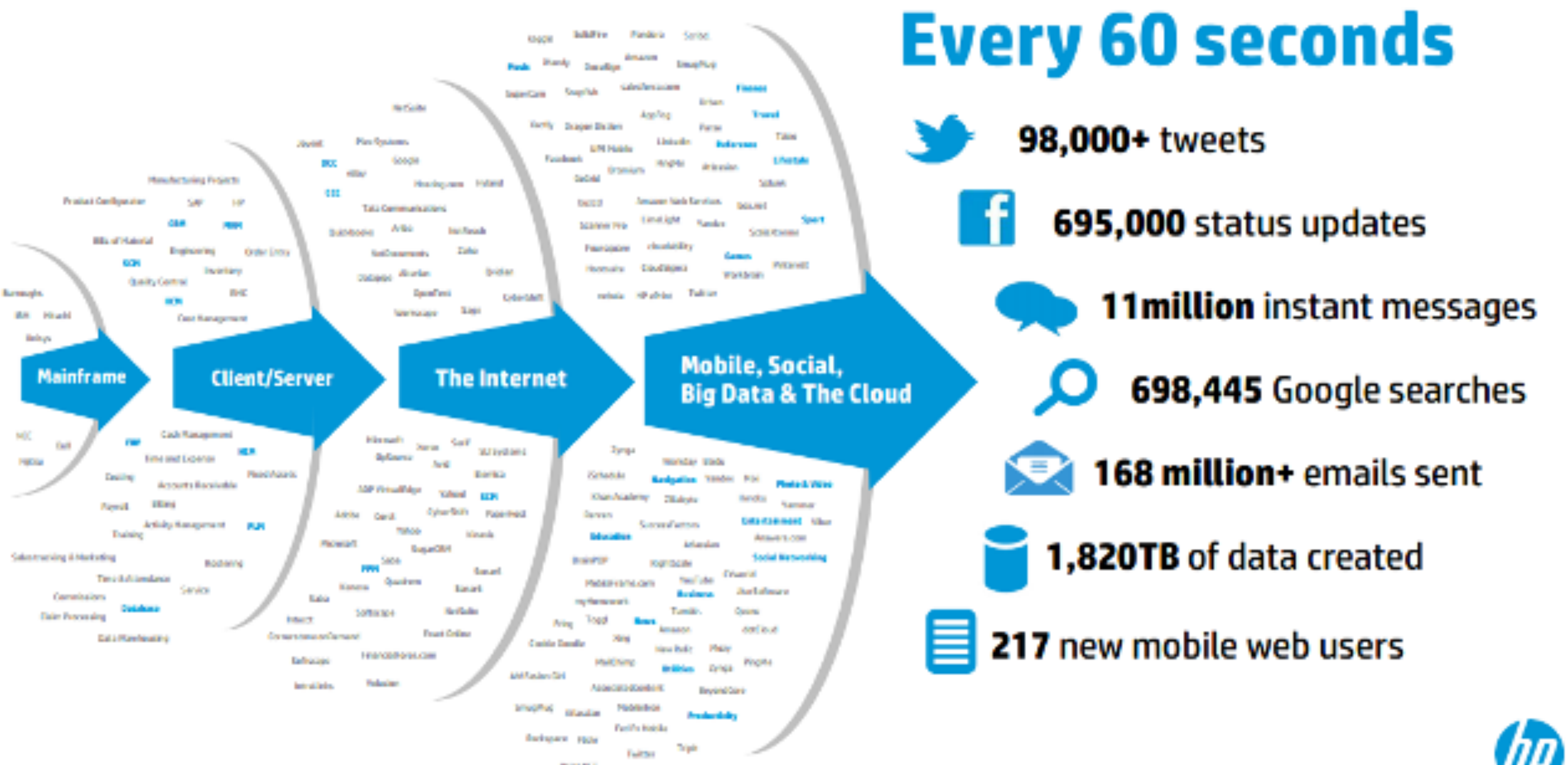
75% of websites
today are not active

internetlivestats



- **In 2014 the Internet it was estimated to have a capacity of 10^24 bytes, i.e. 1 000 000 exabytes**
- **Cisco estimates the traffic in 2016 to be around 1.1 zetabytes, and to double by**

From where the DATA comes?



Data producers

- **Everything and everyone is producing data nowadays**
  - Users in the Internet
  - Mobile users (mobile devices, photos/videos, tweets)
  - Science and researchers
  - Industries (plants, cars, connected devices)
  - Computers monitoring processes, and producing data
  - Sensors (e.g. IoT, remote sensors, satellites)

Data producers by activity area

Retail

- CRM – Customer Scoring
- Store Siting and Layout
- Fraud Detection / Prevention
- Supply Chain Optimization

Advertising & Public Relations

- Demand Signaling
- Ad Targeting
- Sentiment Analysis
- Customer Acquisition

Financial Services

- Algorithmic Trading
- Risk Analysis
- Fraud Detection
- Portfolio Analysis

Media & Telecommunications

- Network Optimization
- Customer Scoring
- Churn Prevention
- Fraud Prevention

Manufacturing

- Product Research
- Engineering Analytics
- Process & Quality Analysis
- Distribution Optimization

Energy

- Smart Grid
- Exploration

Government

- Market Governance
- Counter-Terrorism
- Econometrics
- Health Informatics

Healthcare & Life Sciences

- Pharmaco-Genomics
- Bio-Informatics
- Pharmaceutical Research
- Clinical Outcomes Research

Big Data Characteristics

- **Volume**
- **Variety**
- **Velocity**
- **Variability**
- **Veracity**

Big data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization.

[Gartner's definition]

"Big Data is data that exceeds the processing capacity of conventional database systems. The data is too big, moves too fast, or does not fit the structures of your database architectures. To gain value from this data, you must choose an alternative way to process it". (Dumbill, 2013)

Big Data: Volume

- **(Gandomi & Haider, 2015):**
  - **Volume** is a characteristic which indicates the magnitude of data
  - **Data size** is relative and **varies according to the periodicity and the type of data**. It is impractical to define a specific threshold for Big Data volume, as different types of data require different technologies to deal with it (e.g., tabular data and video data)
- **(Krishnan, 2013):**
  - **Volume characterizes the amount of data that is continuously generated.**
- **(Zikopoulos & Eaton, 2011):**
  - **The main cause for the ever increasing volume is the fact that we currently store all our interactions with the majority of services available in our world.**

Big Data: Variety

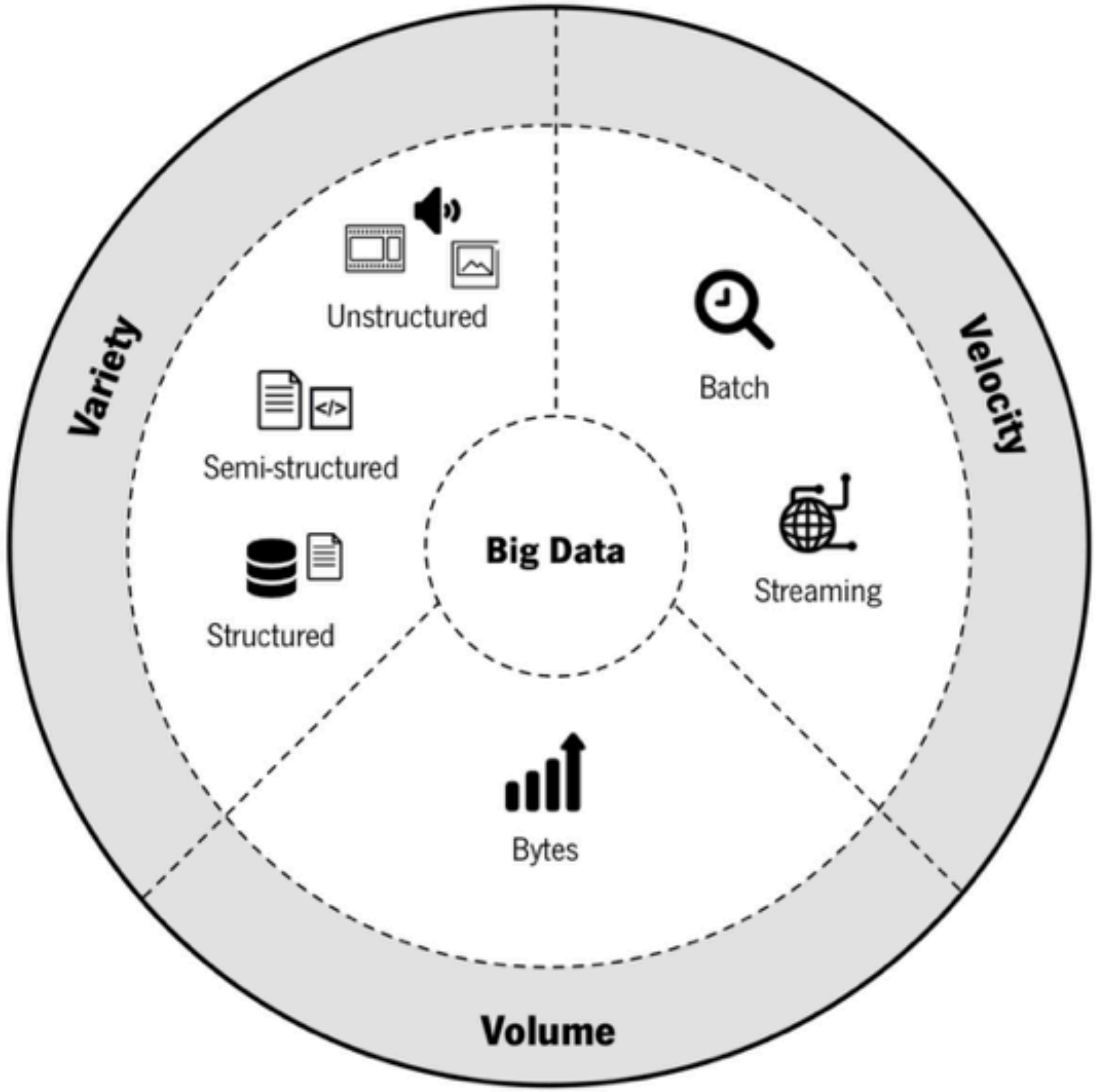
- **(Gandomi & Haider, 2015) - Data can be classified as:**
  - **structured** (e.g., transactional data, spreadsheets, relational databases;
  - **semi-structured** (e.g., web server logs and Extensible Markup Language - XML);
  - **unstructured** (e.g., social media posts, audio, video, images);

Big Data: Velocity

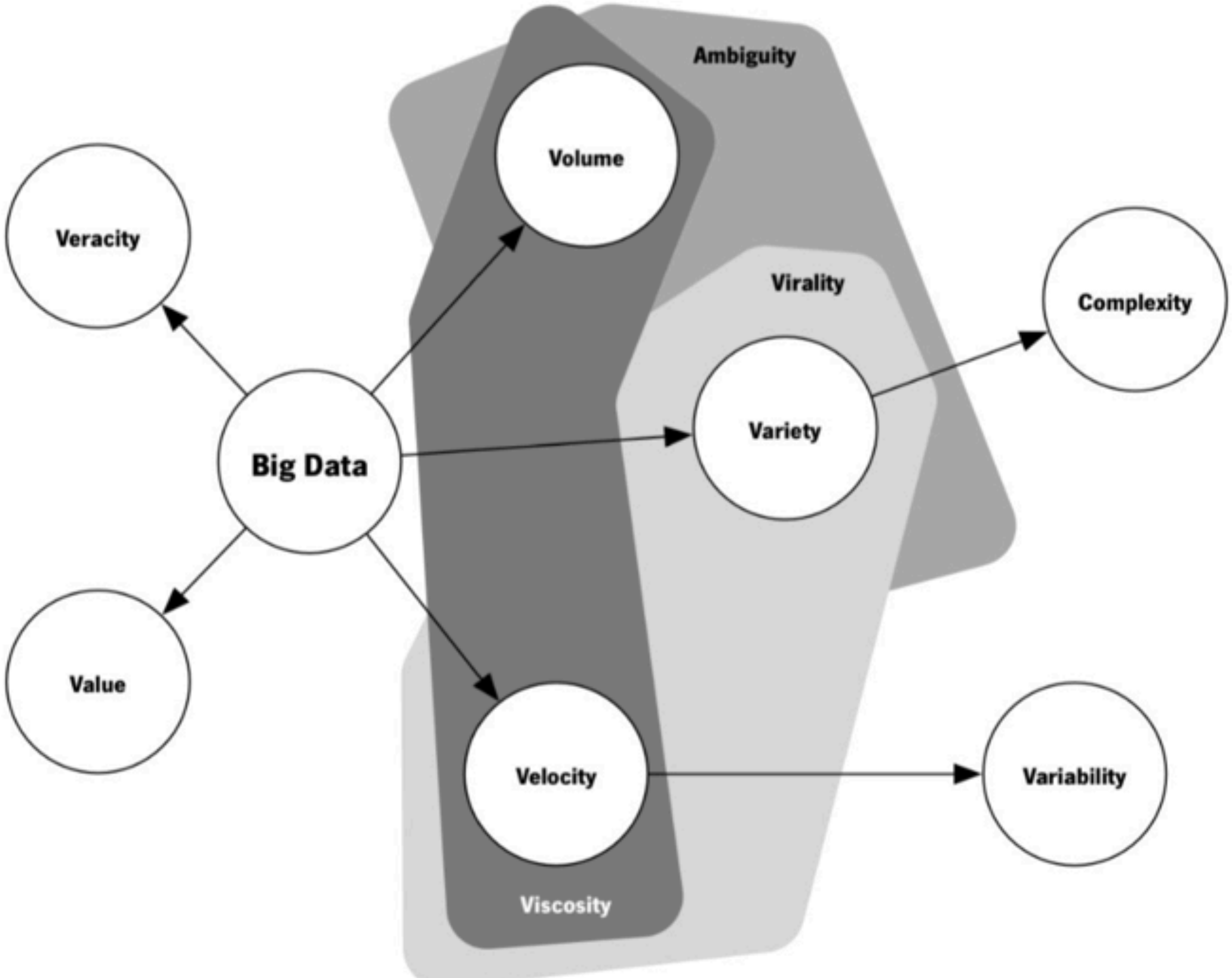
- **(Gandomi & Haider, 2015) - Velocity, referring either to**
  - **the rate at which data is generated or**
  - **to the speed of analysis and decision support.**

- **Data can be generated at different rates, ranging from batch to real-time (streaming)**

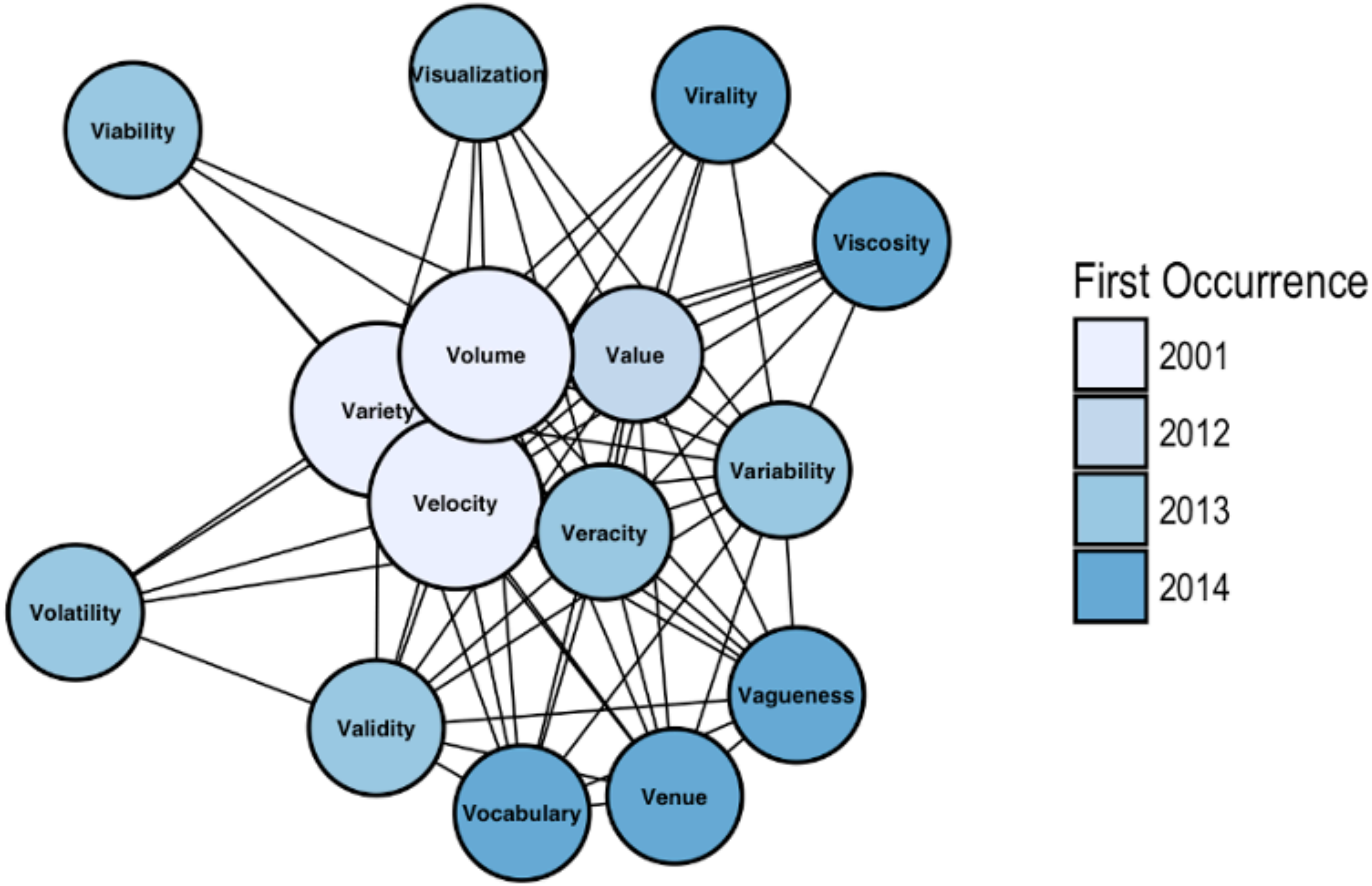
Big Data Characteristics



Big Data Characteristics

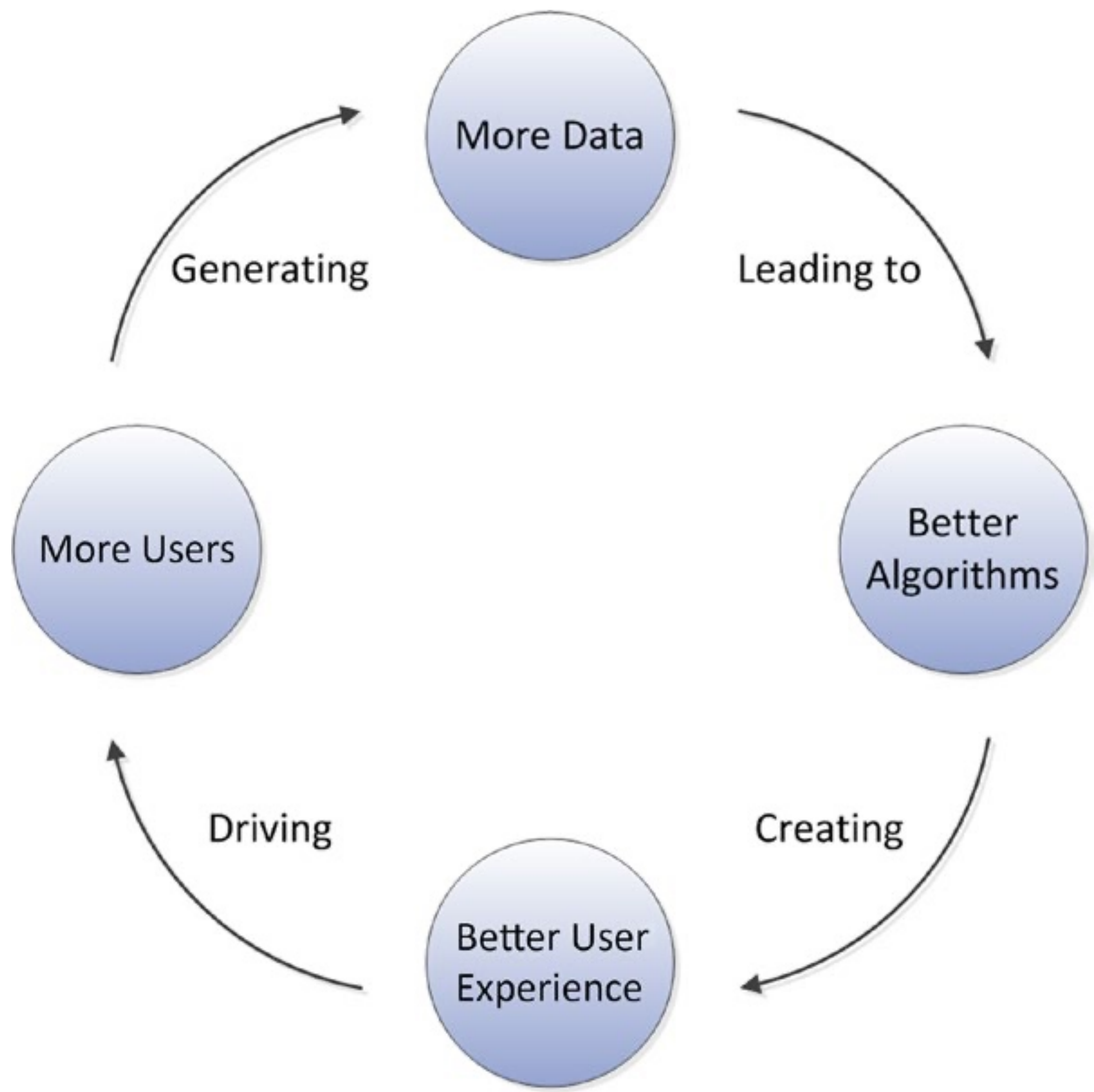


The never ending story



The 42 V's of Big Data and Data Science (Tom Shafer, April 1st 2017)

The virtuous cycle of big data



Big Data Impacts

- **Digital footprint (produced anyways for free)**
- **n = N (no sampling, but potential bias)**
- **Data-fusion (unstructured and incomplete)**
- **Real-time (dynamic)**
- **Machine Learning (no need for theory)**

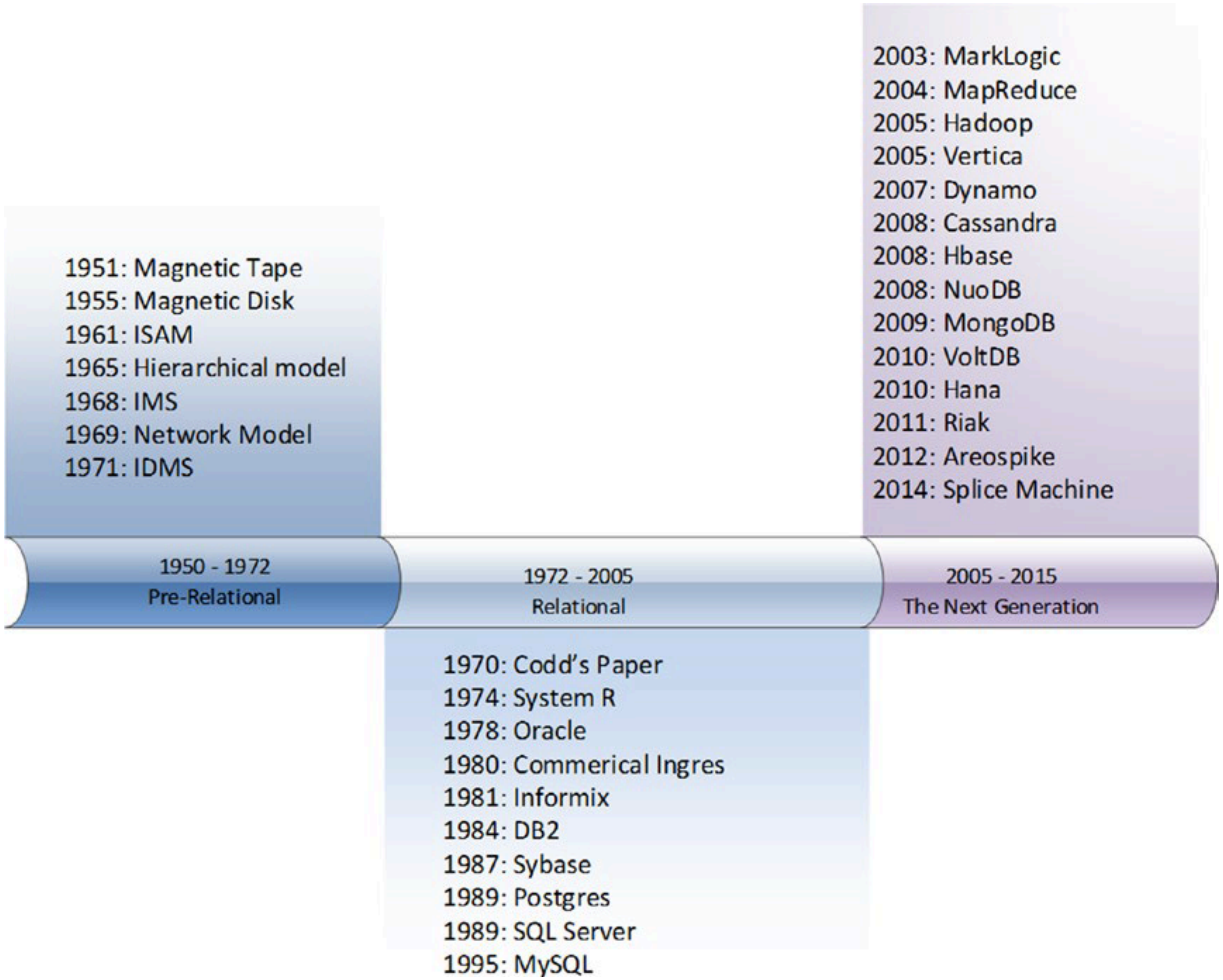
[What is Big Data]

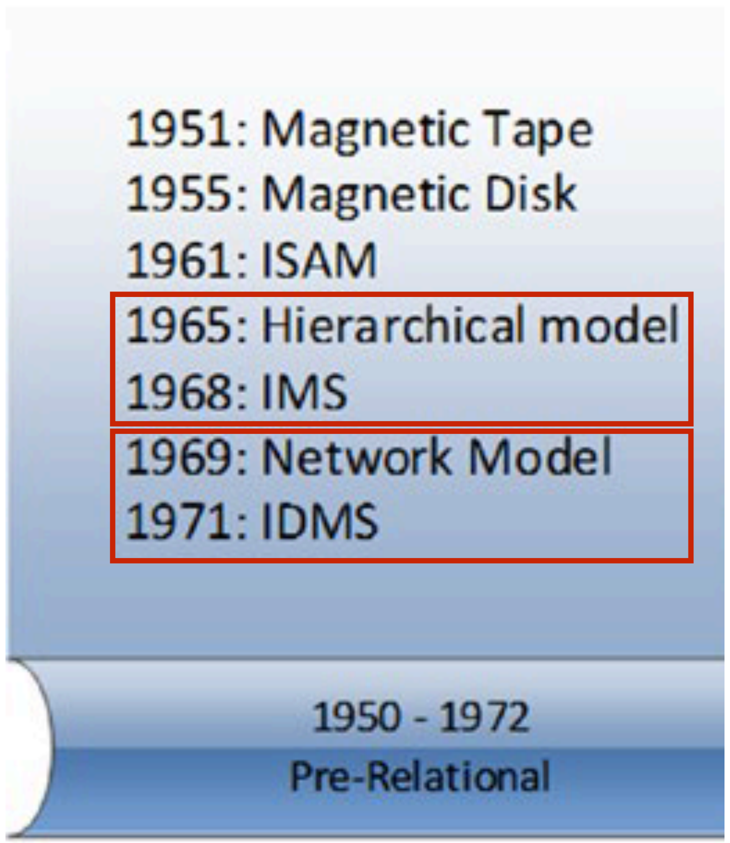
- **Digital footprint** (produced anyways for free)
- **n = N** (no sampling, but potential bias)
- **Data-fusion** (unstructured and incomplete)

Source: Hilbert, M. (2015). Big Data for Development: A Review of Promises and Challenges. *Development Policy Review*.

Database Systems Evolution

Three database revolutions

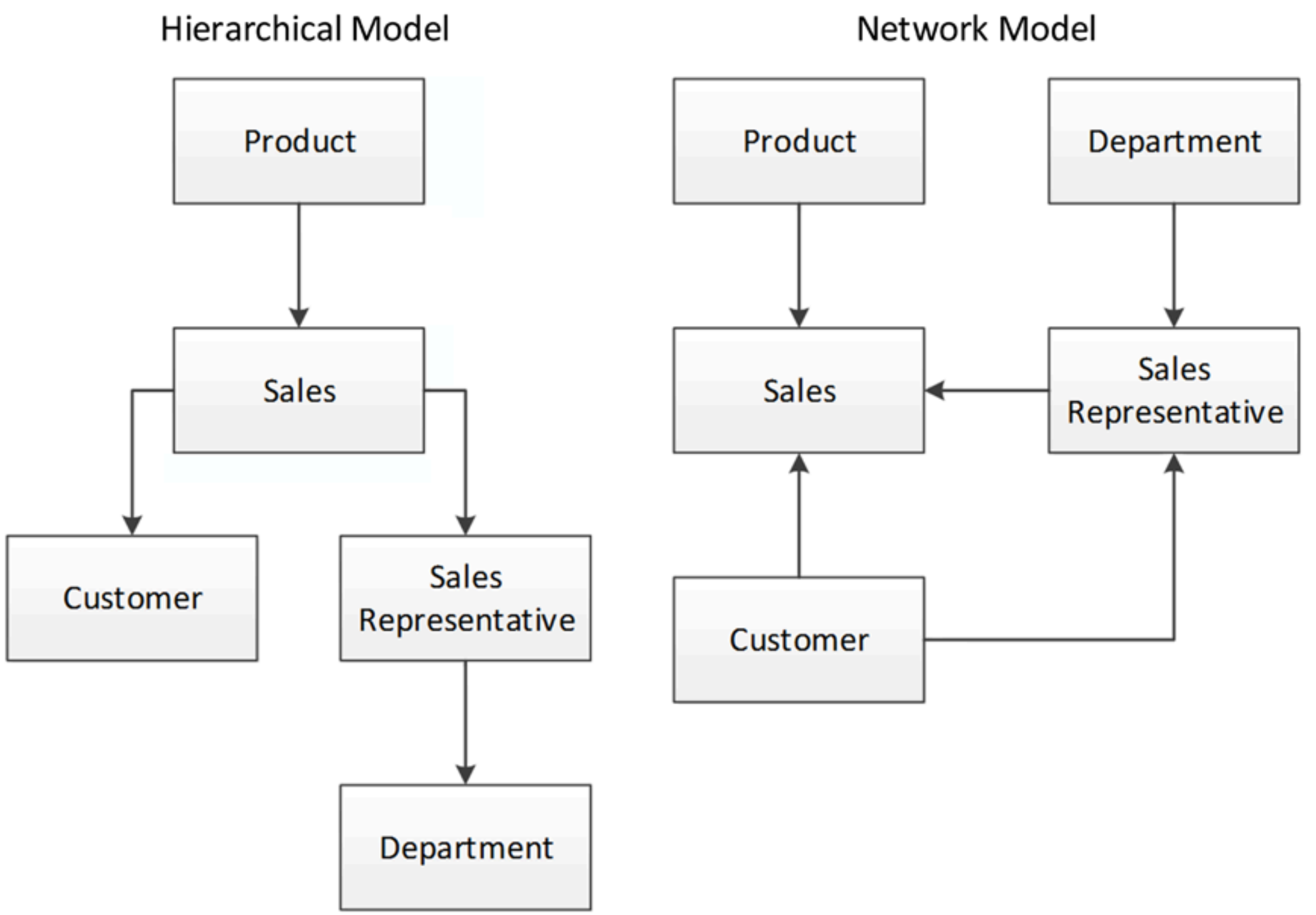




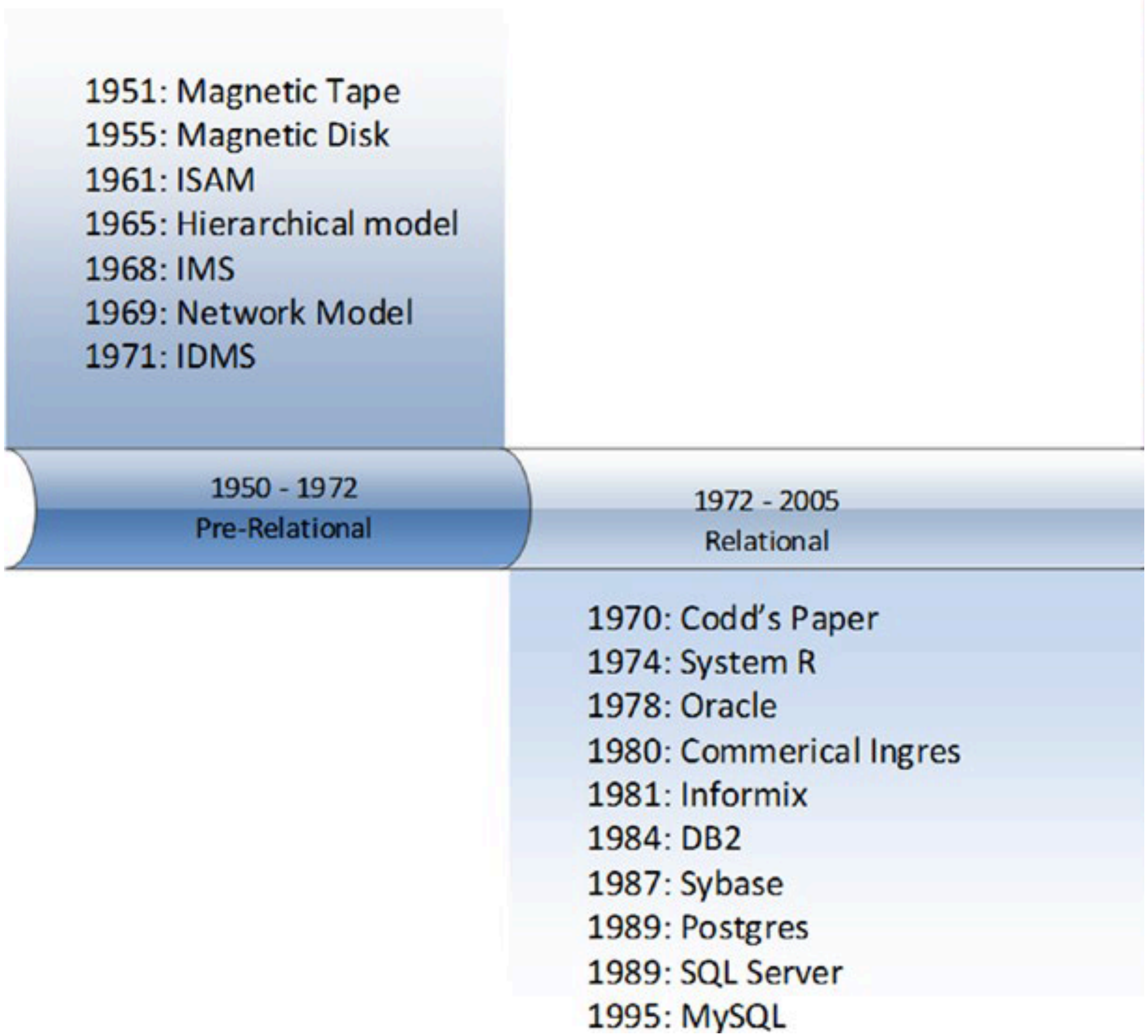
Index Sequential Access Method

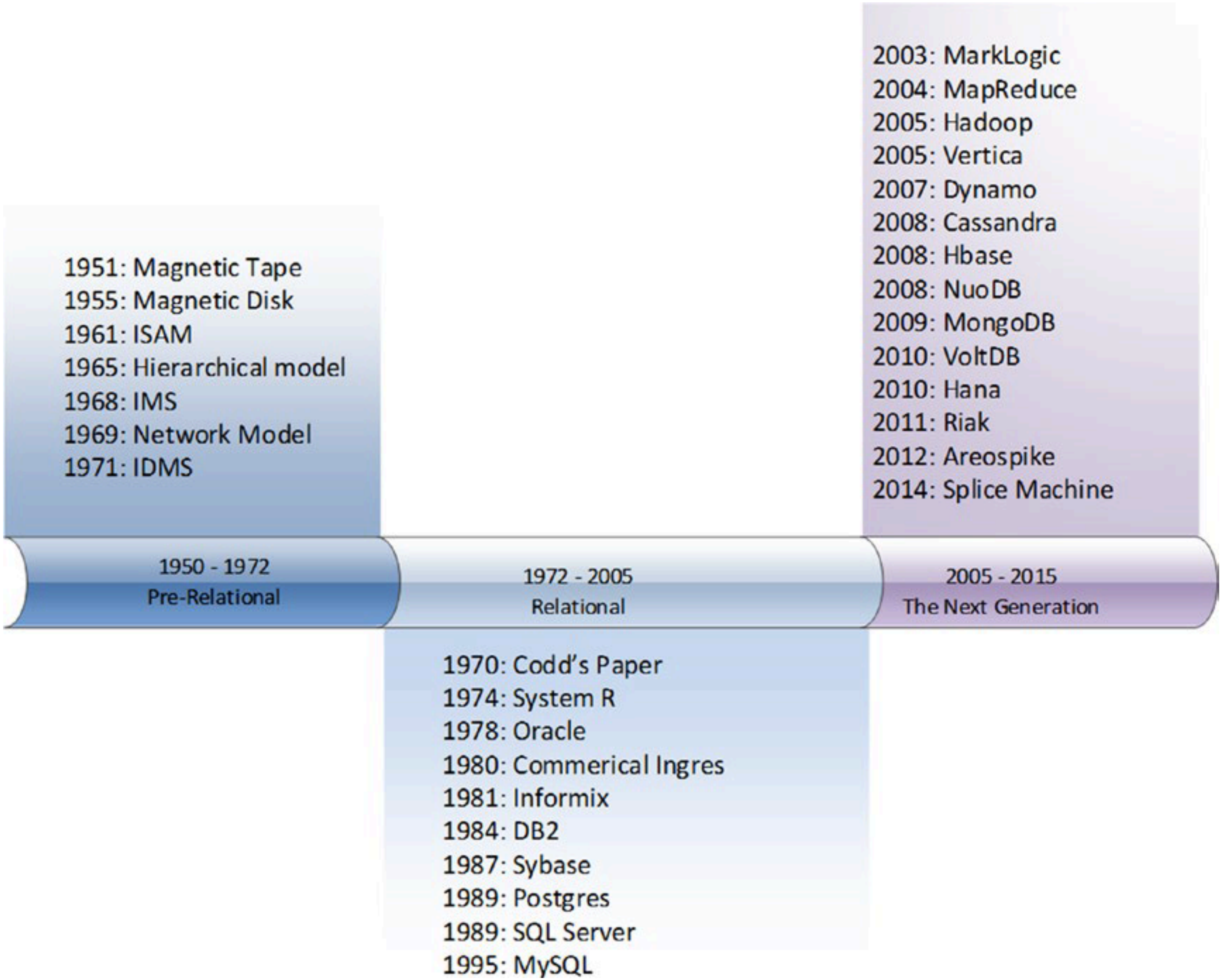
First database revolution

IMS (IBM)



- Mainframe computers
- Enforce Schema and access path
- Inflexible
- Record at a time processing
- Reporting written in procedural languages (COBOL)

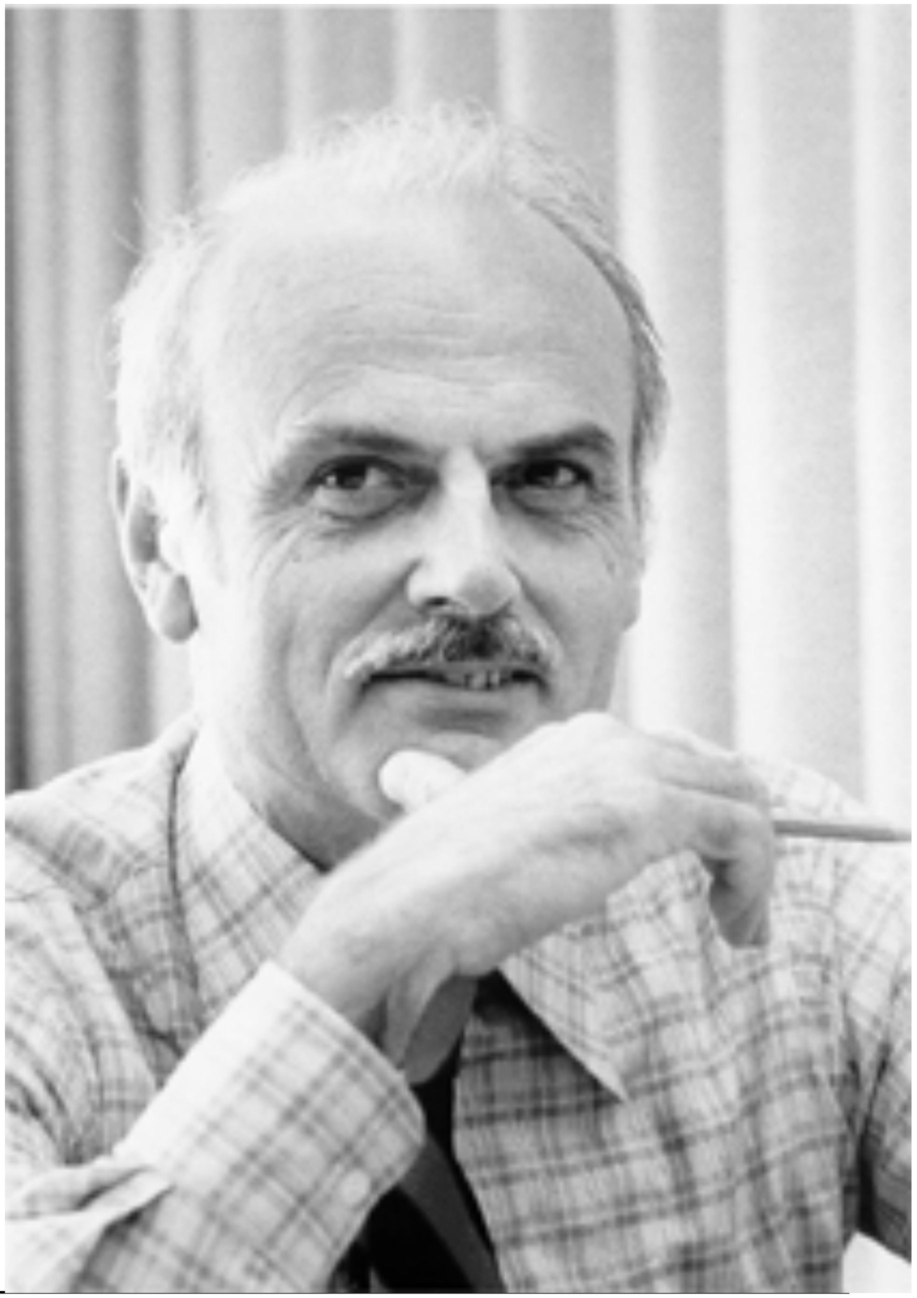

1951: Magnetic Tape
1955: Magnetic Disk
1961: ISAM
1965: Hierarchical model
1968: IMS
1969: Network Model
1971: IDMS
1950 - 1972
Pre-Relational
1972 - 2005
Relational
1970: Codd's Paper
1974: System R
1978: Oracle
1980: Commerical Ingres
1981: Informix
1984: DB2
1987: Sybase
1989: Postgres
1989: SQL Server
1995: MySQL


2003: MarkLogic
2004: MapReduce
2005: Hadoop
2005: Vertica
2007: Dynamo
2008: Cassandra
2008: Hbase
2008: NuoDB
2009: MongoDB
2010: VoltDB
2010: Hana
2011: Riak
2012: Areospike
2014: Splice Machine
1951: Magnetic Tape
1955: Magnetic Disk
1961: ISAM
1965: Hierarchical model
1968: IMS
1969: Network Model
1971: IDMS
1950 - 1972
Pre-Relational
1972 - 2005
Relational
2005 - 2015
The Next Generation
1970: Codd's Paper
1974: System R
1978: Oracle
1980: Commerical Ingres
1981: Informix
1984: DB2
1987: Sybase
1989: Postgres
1989: SQL Server
1995: MySQL

Second database revolution

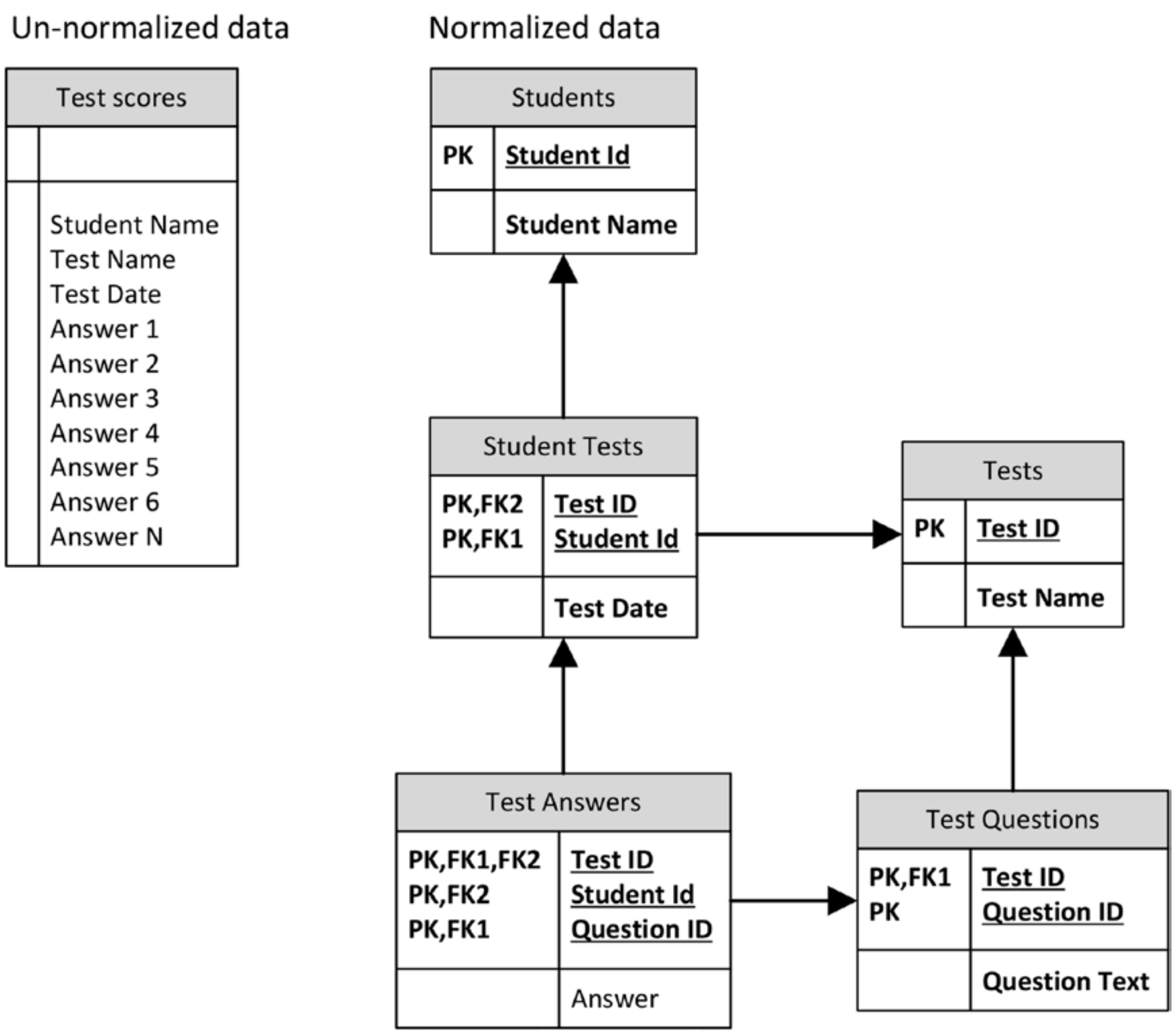
Edgar F. Codd realized at the end of 1960s that existing database systems:

- Were **hard** to use
- Lacked a theoretical foundation
- Mixed logical and physical implementations



Codd, E. F. (1970). "A relational model of data for large shared data banks" (PDF). Communications of the ACM. 13 (6): 377–387. doi:10.1145/362384.362685.

Data normalization



Relational theory defines

- Tuples
- Relations
- Constraints
- Algebra (operations)

Data should be normalized

Commercial database systems

- IBM started the development of a prototypical relational database system in 1974
- Relational databases gained importance in the 1980s with the advent of minicomputers
  - First release of Oracle in 1979
  - Mid 1980s the benefits were clear, namely SQL for reporting and analytics
  - Gained the "Database Wars" by the end of the 1980s
  - In the 1990s client-server computing was introduced and fitted well with RDBMs

Commercial database systems

- Three major characteristics of RDBMs:
  - Codd's relational model
  - SQL language
  - ACID transaction model
    - **Atomic**: The transaction is indivisible—either all the statements in the transaction are applied to the database or none are.
    - **Consistent**: The database remains in a consistent state before and after transaction execution.
    - **Isolated**: multiple transactions can be executed by one or more users simultaneously, one transaction should not see the effects of other in-progress transactions.
    - **Durable**: changes are expected to persist

OLTP systems

Operational Systems (most - OLTP)

- **OLTP – On Line Transaction Processing**
  - **Systems that support the running activities of the organization**
  - **Examples:**
    - Point of sale in stores;
    - ATM and Bank operations
    - e-commerce (amazon, iTunes, etc)
- **Some characteristics:**
  - **Thousand of operations per second**
  - **Repeated operations dealing with small amounts of data (insert, update, remove)**
  - **Real Time**

DW and OLAP systems

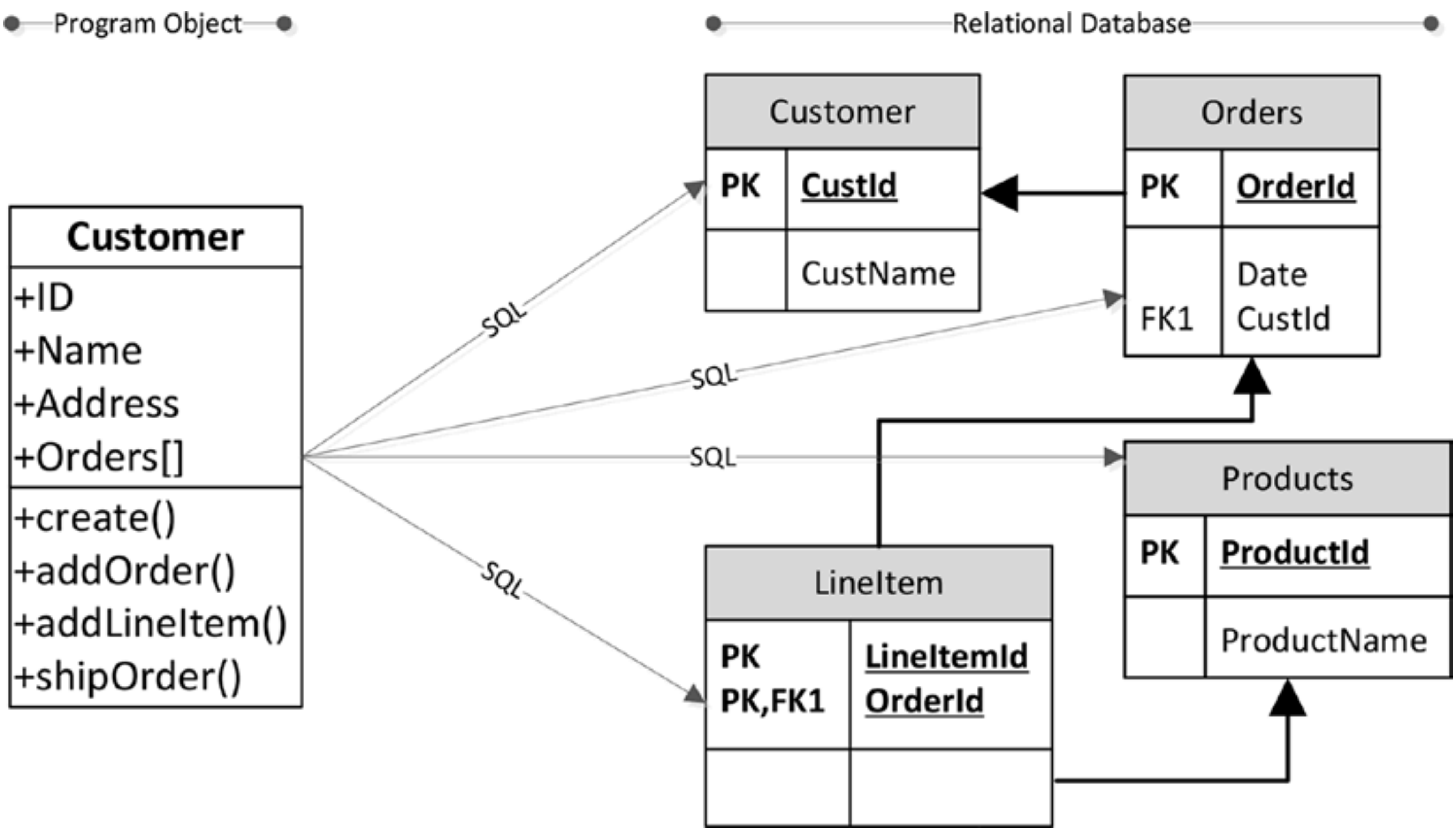
- **OLAP – On Line Analytical Processing**
  - Systems that provide the users the necessary capabilities to analyze many and different aspects of organization activities and its performance.
  - Examples
    - How well certain product is selling in different regions? How well is the evolution in the market from its introduction?
    - Which are the top ten selling product in each region? and globally?
- **Some characteristics:**
  - Small number of queries (per day), when compared with OLTP systems
  - Large amount of data processed in each query, in order to obtain a small output.
  - It is hard to predict the queries and in general they are much more diverse, when compared with OLTP systems
  - Reading and processing data but no writing.

Multidimensional Design

Object oriented programming

- **OO programming resulted in productivity gains in the IT sector**
- **OO was a serious challenge to RDBMS due to representation mismatch of the models**
- **OO is akin to network models**
- **Could lead to performance problems…**

Multiple SQL queries required



Object oriented DBMS

- **OODBMs did not succeed in the market**
- **Big RDBMs vendors introduced these features in their products (that were rarely used)**
- **This was a programmers' issue and introduced problems for the business data consumers**
- **Compromise attained with Object Relational Mapping frameworks**
- **RDBMs mastered the scene till mid 2000s**

- **Complex Data Types: Spatial, XML, JSON**

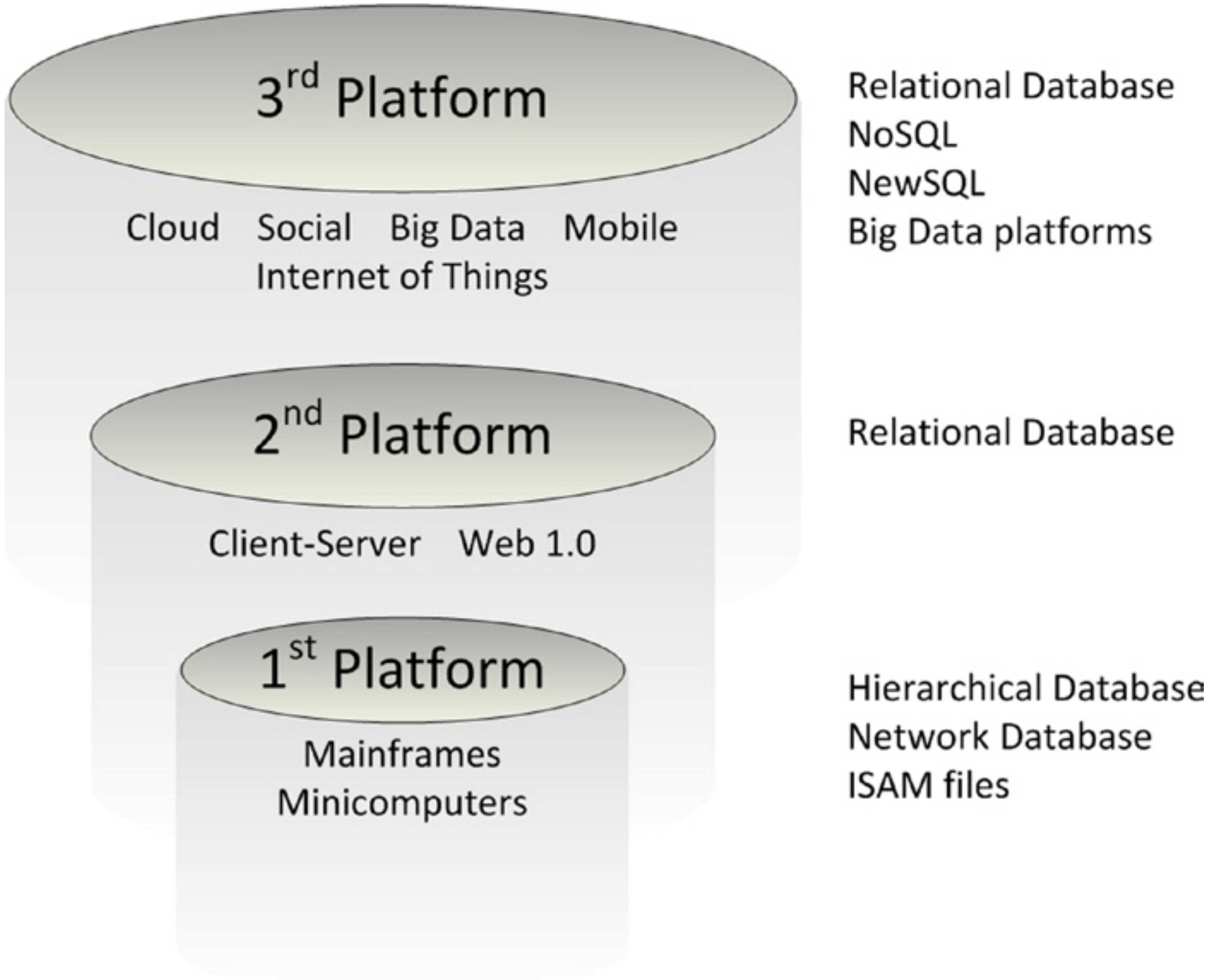
Third Database revolution

- **Massive web-scale applications required new advancements in database technology**
  - **To represent and process search engine indexes: Hadoop, Elasticsearch**
  - **To handle massive online e-commerce (e.g. Amazon): DynamoDB**
  - **Cloud computing: AWS and DynamoDB**
  - **XML and JSON storage: document databases (e.g. CouchDB, MongoDB)**
- **NoSQL databases:** Distributed Non-Relational Database Management System" (DNRDBMS)
  - **Reject constraints of the relational model in particular strict consistency and schemas**
- **NewSQL databases:** The End of an Architectural Era (It's Time for a Complete Rewrite)
  - **Enhanced or modified the fundamental principles: relational model or ACID transactions (**
- **BigData systems: Hadoop ecosystem, including Spark**

Modeling the data

- **Relational databases most of the times are not appropriate for supporting big data applications because:**
  - Huge amounts of data (volume)
  - High frequency generation (velocity)
  - The structure constantly evolving and changing, storing everything (variety)
  - Mash-up of data from different sources
  - Need to explore data links that often require joins
  - High-availability requirements of Web 2.0
  - Difficult to scale horizontally
- **Motivates the NoSQL movement:**
  - **"non SQL", "non relational" or "not only SQL"**

IDC's "three platforms" model: three waves of DB Techs



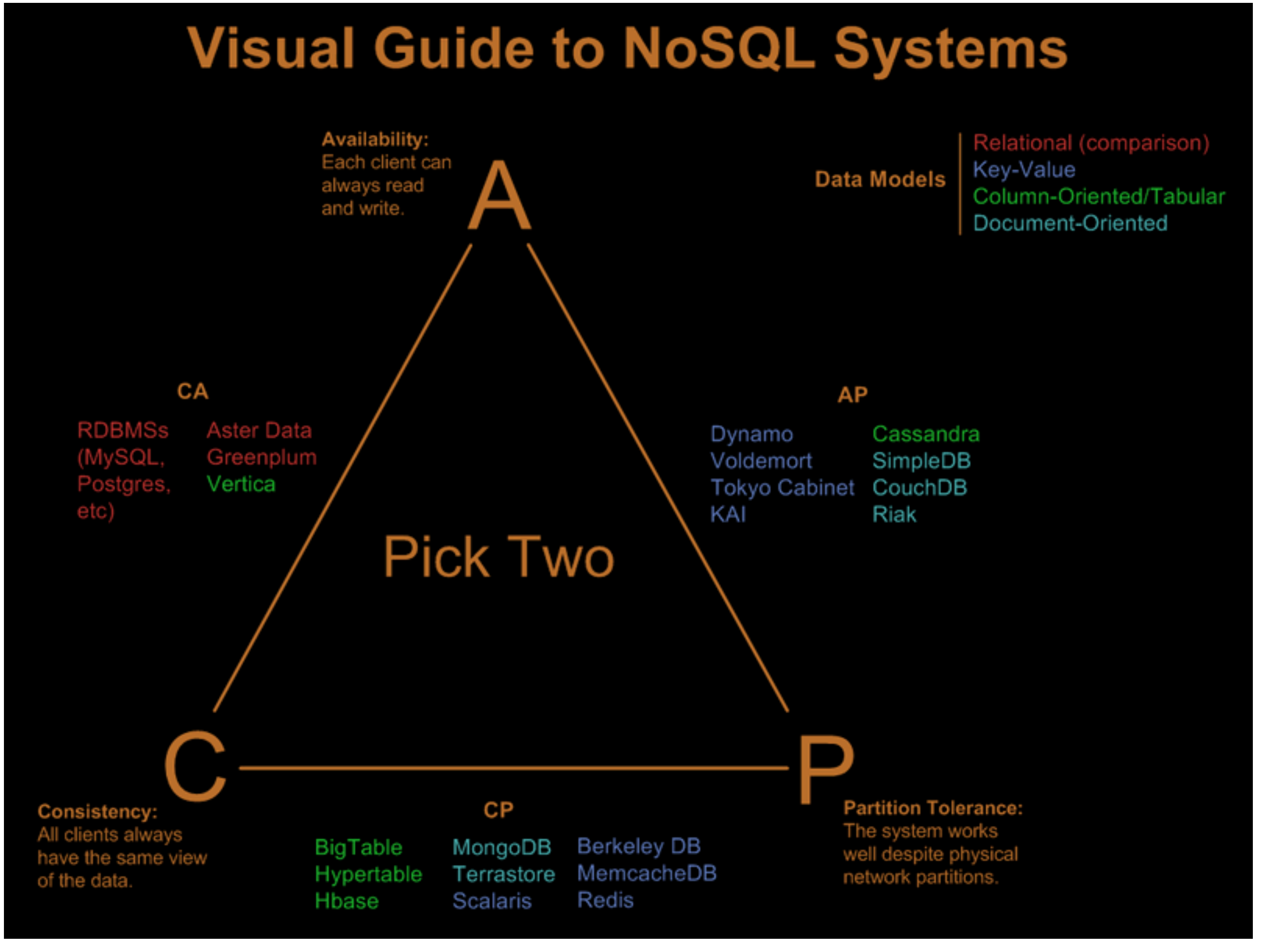
Brewer's CAP theorem

- It is **impossible** for a **distributed computer system** to **simultaneously** provide **all three** of the following guarantees:
  - Consistency (every read receives the most recent write or an error)
  - Availability (every request receives a response, without guarantee that it contains the most recent version of the information)
  - Partition tolerance (the system continues to operate despite arbitrary partitioning due to network failures)

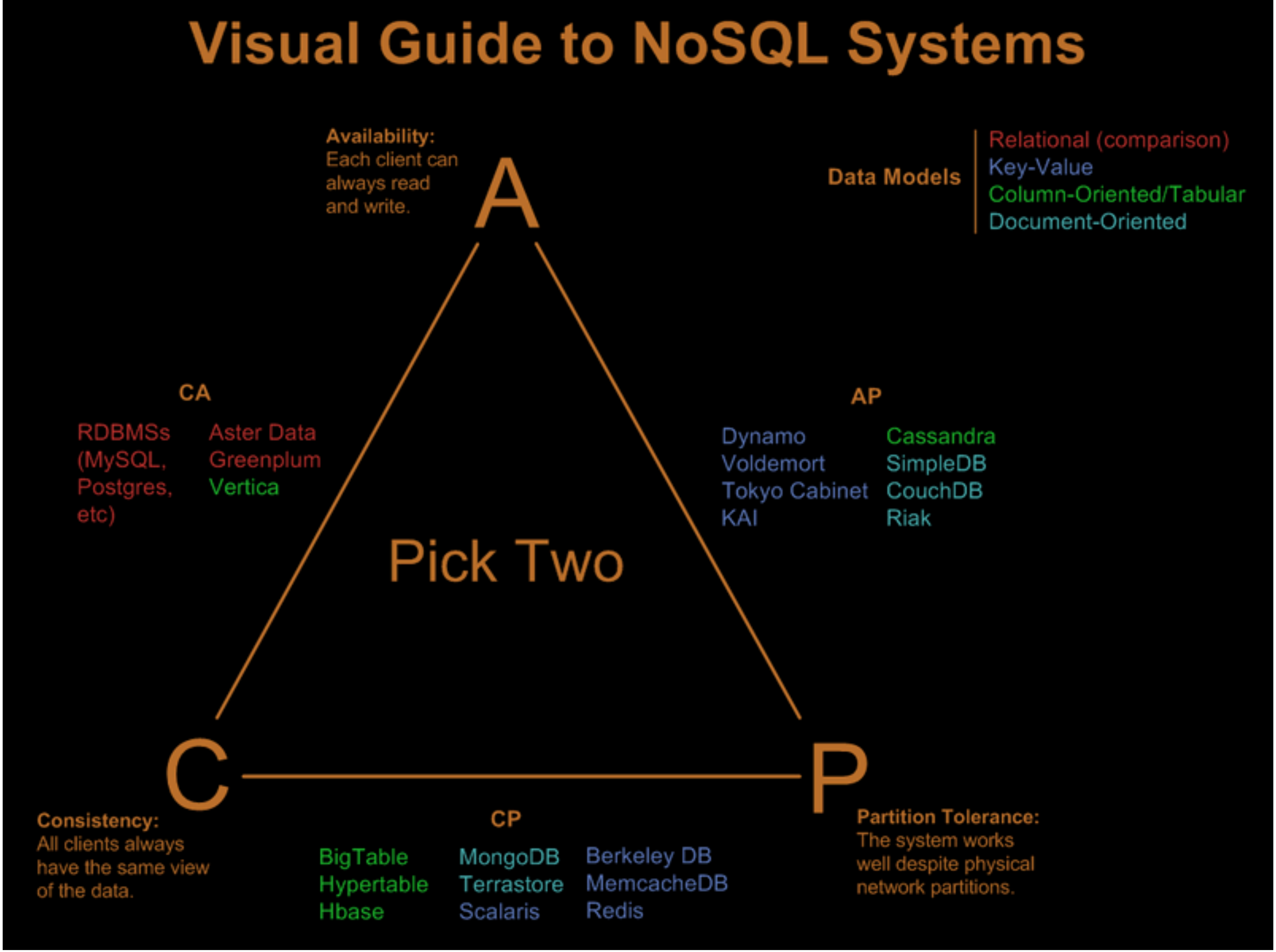
Essential for horizontal scalability

- Since network failures are unavoidable **one has to choose between consistency and availability**.
- **The CAP theorem is for failures!**

Brewer's CAP theorem



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



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

Abadi’s PACELC theorem

- **In order to guarantee availability under partitioning, one has to replicate data**
- **As soon as a DBMS replicates data, a tradeoff between consistency and latency arises. But when replicating data over a WAN, there is no way around the consistency/latency tradeoff.**
- **If there is a partition (P), how does the system trade off availability and consistency (A and C); else (E), when the system is running normally in the absence of partitions, how does the system trade off latency (L) and consistency (C)?**

http://cs-www.cs.yale.edu/homes/dna/papers/abadi-pacelc.pdf

Abadi's PACELC theorem

- **The default versions of Dynamo, Cassandra, and Riak are PA/EL systems: <u>if a partition occurs</u>, they give up consistency for availability, and under normal operation they give up consistency for lower latency.**
  - Giving up both Cs in PACELC makes the design simpler; once a system is configured to handle inconsistencies, it makes sense to give up consistency for both availability and lower latency.
- **Fully ACID systems such as VoltDB/H-Store and Megastore are PC/EC: they refuse to give up consistency, and will pay the availability and latency costs to achieve it. BigTable and related systems such as HBase are also PC/EC.**

http://cs-www.cs.yale.edu/homes/dna/papers/abadi-pacelc.pdf

Abadi's PACELC theorem

- **MongoDB can be classified as a PA/EC system. In the baseline case, the system guarantees reads and writes to be consistent.**
- **PNUTS is a PC/EL system. In normal operation, it gives up consistency for latency; however, if a partition occurs, it trades availability for consistency.**

http://cs-www.cs.yale.edu/homes/dna/papers/abadi-pacelc.pdf

ACID versus BASE

- **Atomicity**
- **Consistency**
- **Isolation**
- **Durability**

Consistency

Availability

- Basically-Available
- Soft-state
- Eventual Consistency

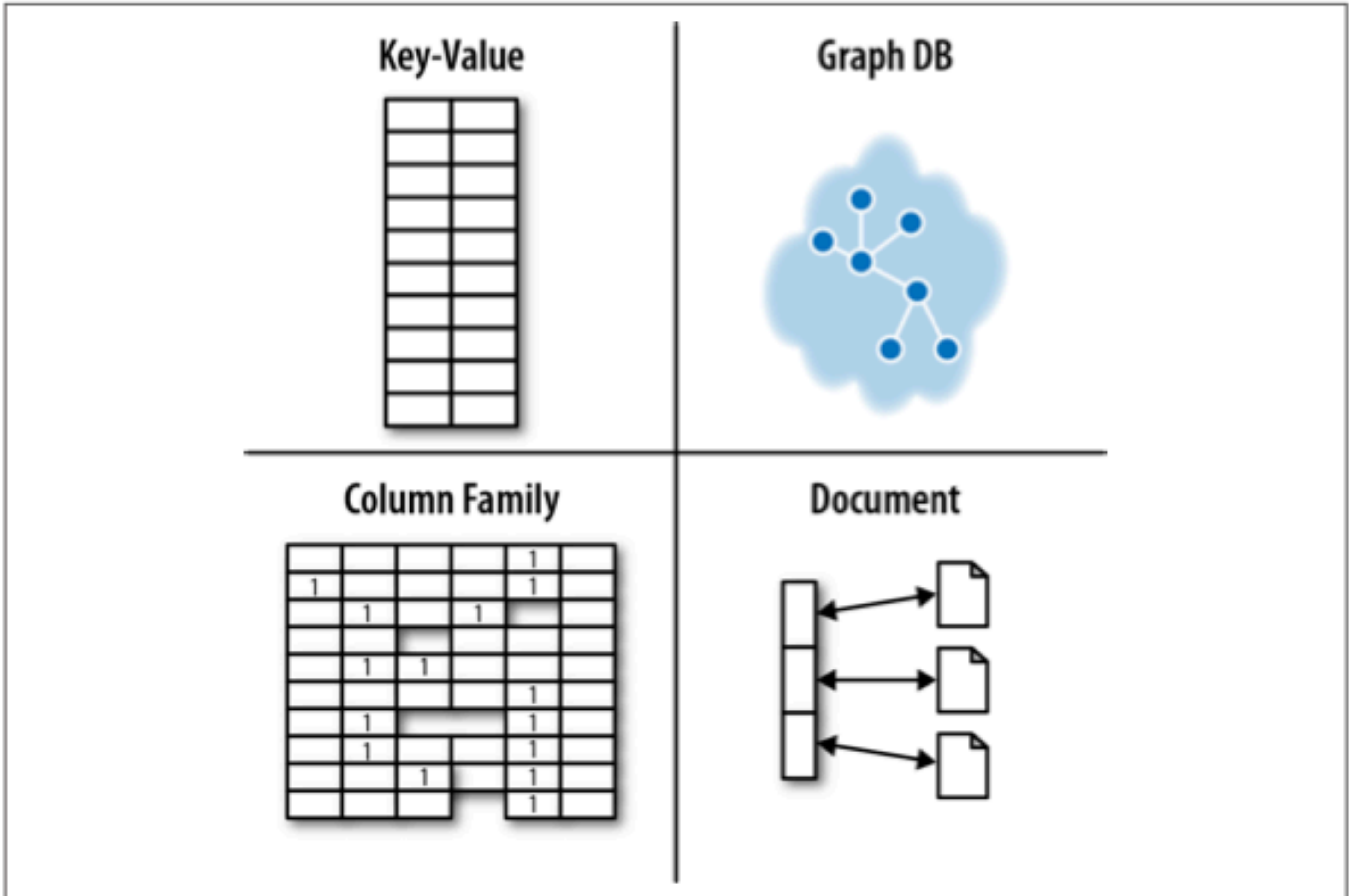
Consistency Models

- **Strict consistency**: A read will always return the most recent data value.
- **Causal consistency**: Reads may not return the most recent value, but will not return values "out of sequence." This implies that if one session created updates A, B, and C, another session should never see update C without also being able to see update B.
- **Monotonic consistency**: In this mode, a session will never see data revert to an earlier point in time. Once we read a data item, we will never see an earlier version of that data item.
- **Read your own writes**: This is a form of eventual consistency in which you are at least guaranteed to see any operations you executed.
- **Eventual consistency**: The system may be inconsistent at any point in time, but all individual operations will eventually be consistently applied. If all updates stop, then the system will eventually reach a consistent state.
- **Weak consistency**: The system makes no guarantee that the system will ever become consistent—if, for instance, a server fails, an update might be lost.

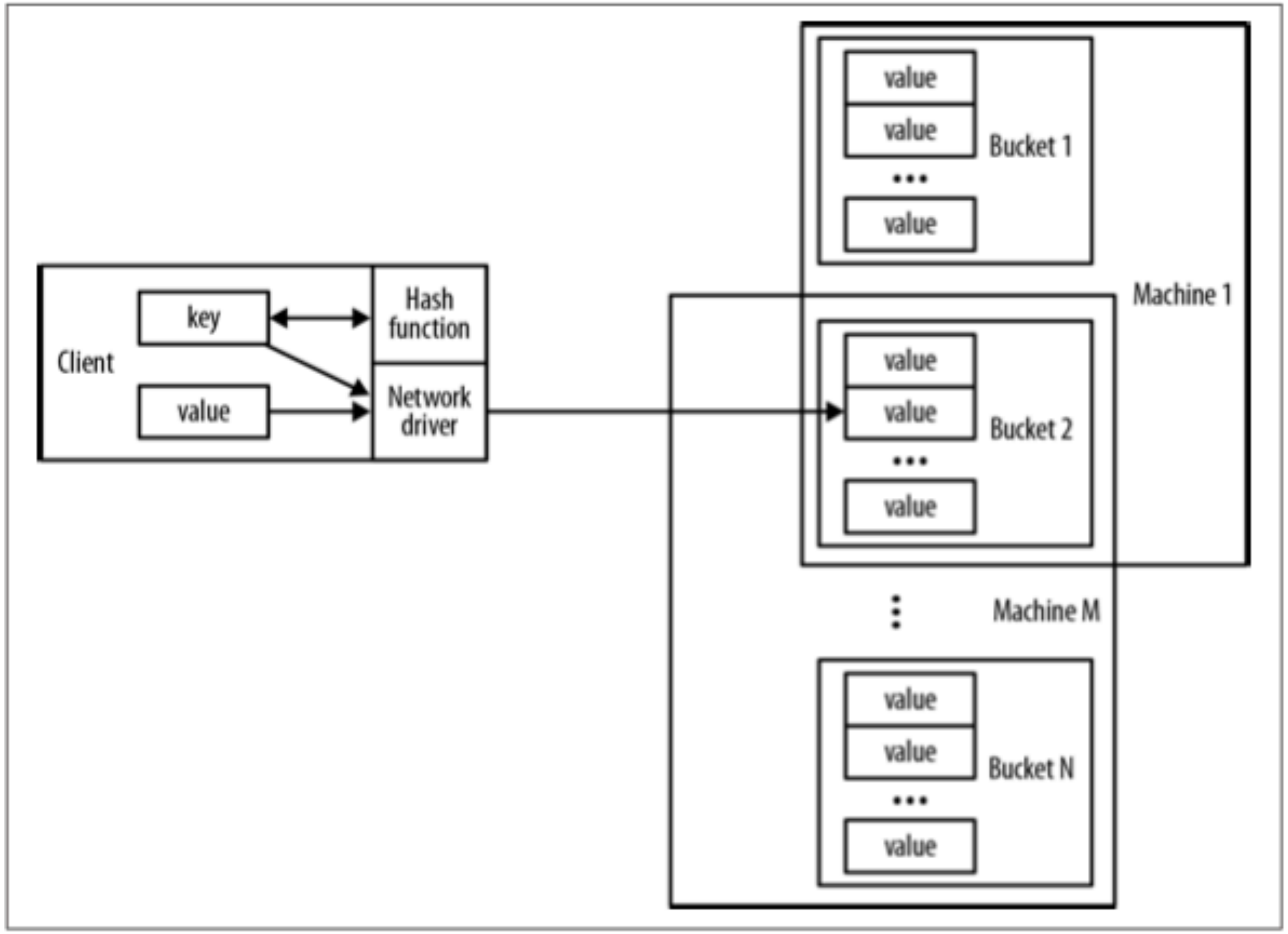
No SQL Quadrants

NoSQL quadrants

https://en.wikipedia.org/wiki/NoSQL



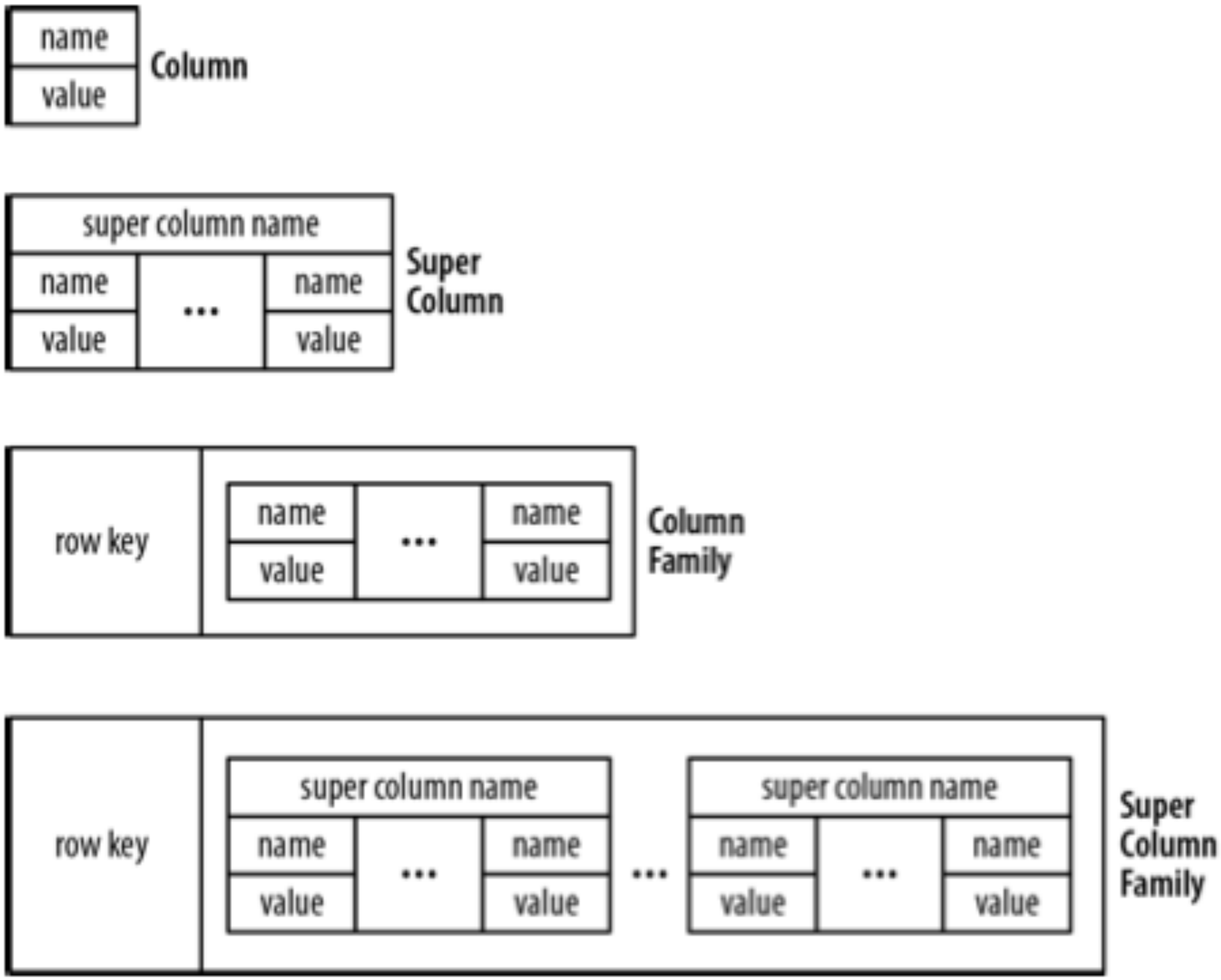
Key-value stores



Amazon DynamoDB

redis

Column oriented



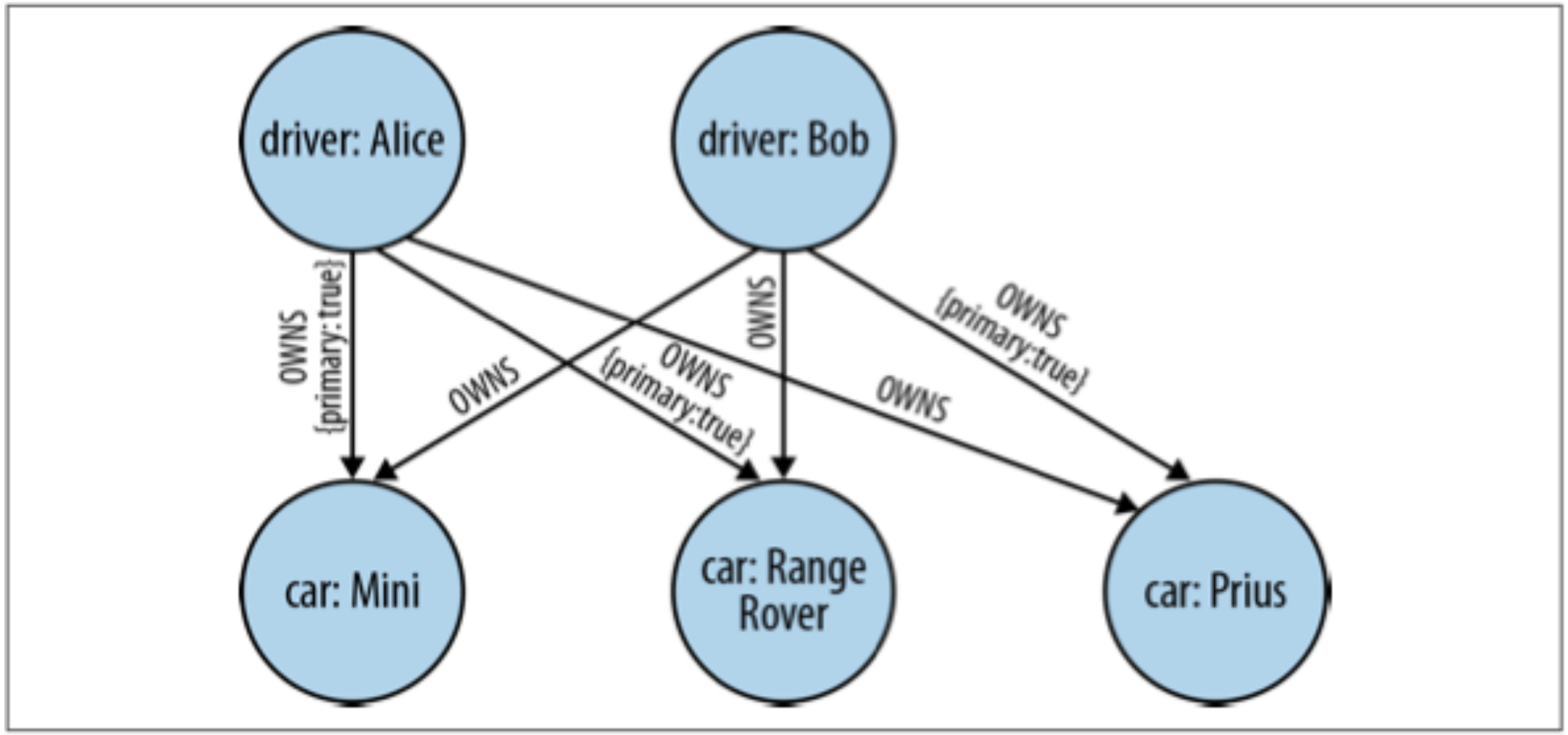
Document Stores

```
{
  _id: <ObjectId1>,
  username: "123xyz",
  contact: {
              phone: "123-456-7890",
              email: "xyz@example.com"
            },
  access: {
             level: 5,
             group: "dev"
           }
}
```

Embedded sub-document (contact)

Embedded sub-document (access)

Graph databases



neo4j

Apache Jena

AllegroGraph

Main lesson

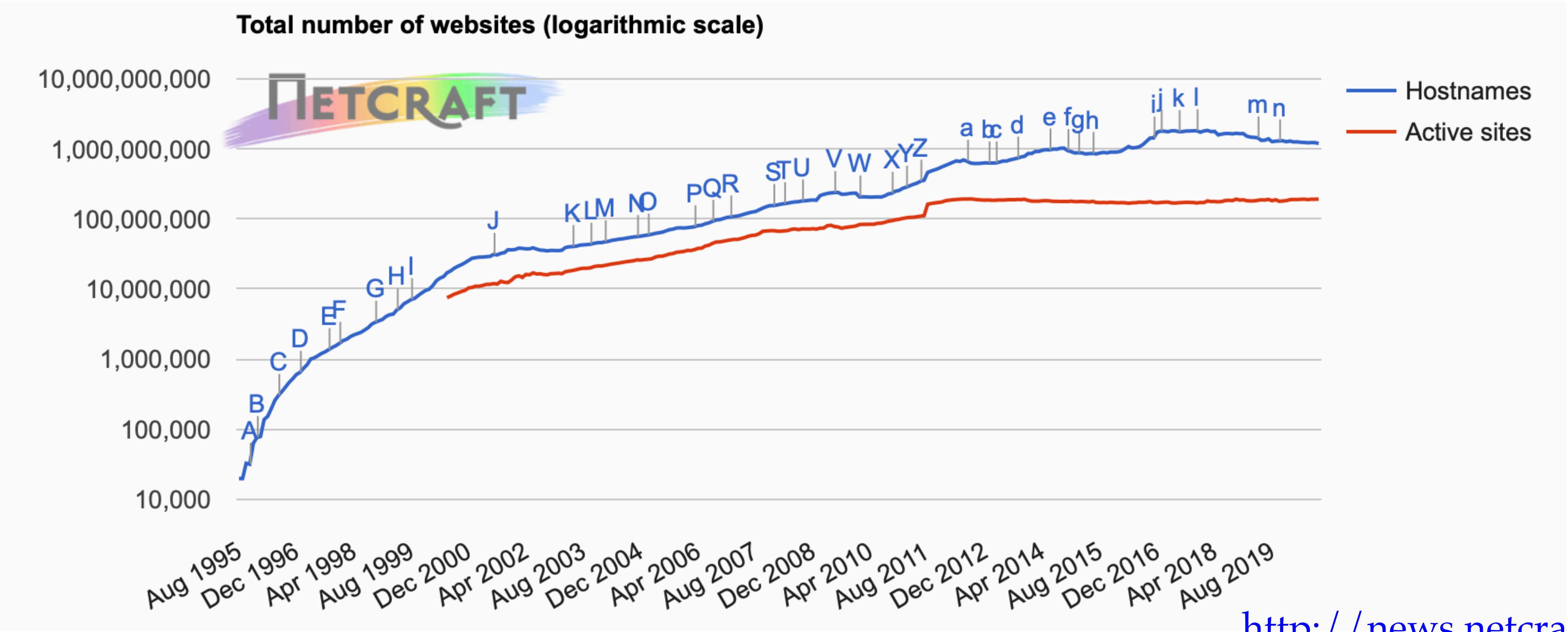
There are no silver-bullet solutions, in most of the cases you will end with a RDBMs but occasionally not.

One Size doesn't fit all!!!

The Semantic Web Vision

The World Wide Web

- The **World Wide Web changed the ways knowledge and information are shared**
- From this point of view, the World Wide Web has been a success supported mostly in the existence of amazing **search engines**.
- The uncontrolled exponential growth of the Web brought new challenges...



http://news.netcraft.com/

Web 1.0 and 2.0 jargon

- Web 1.0
  - A huge portal of documents, in which information can be retrieved
  - Directories
  - Too static and read-only

≈ 2005

- Web 2.0
  - The social web
  - Document (and information) sharing
  - Collaboration
  - User-centered

http://news.netcraft.com/

Daily use of the WWW

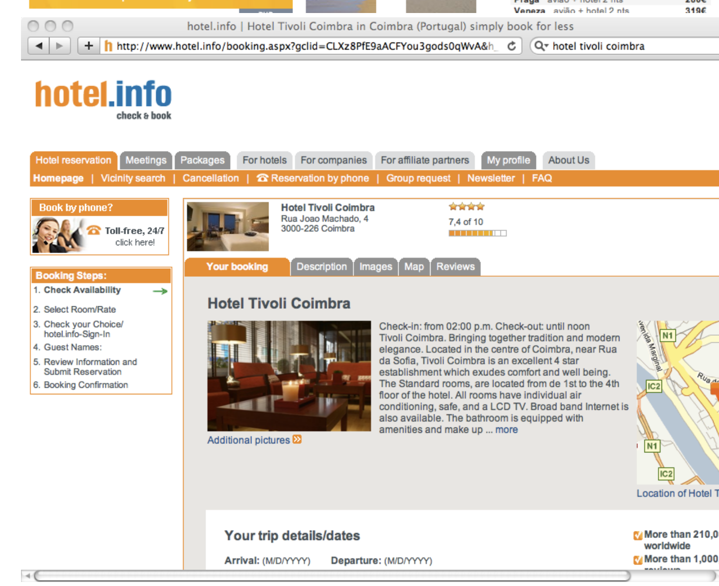
Web of **Documents**

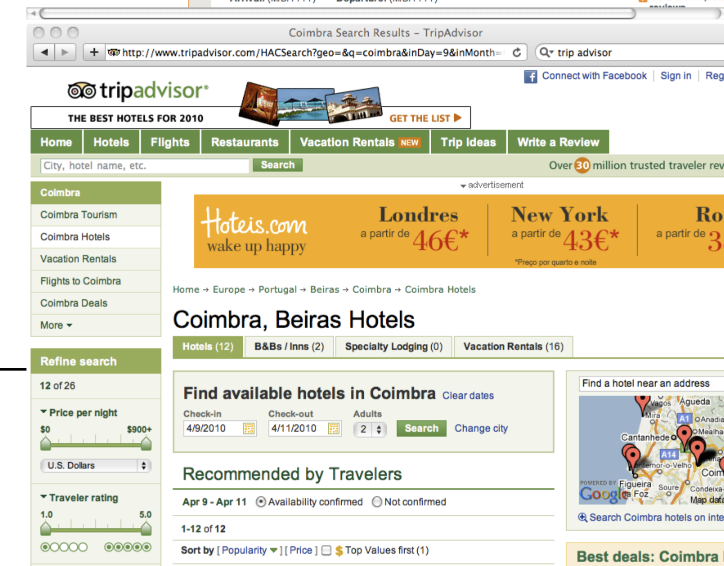
- Most of today's **Web content** is **designed** and appropriate for **human consumption**
- Even Web content that is generated automatically is usually then processed and **presented without the original structural information** (e.g. from databases)
- Typical Web usage of today needs people
  - for seeking and making use of information,
  - searching for and getting in touch with other people,
  - reviewing catalogues of online stores and ordering products by filling out forms, …

- **A Web in machines, for humans' usage**

Planning a trip

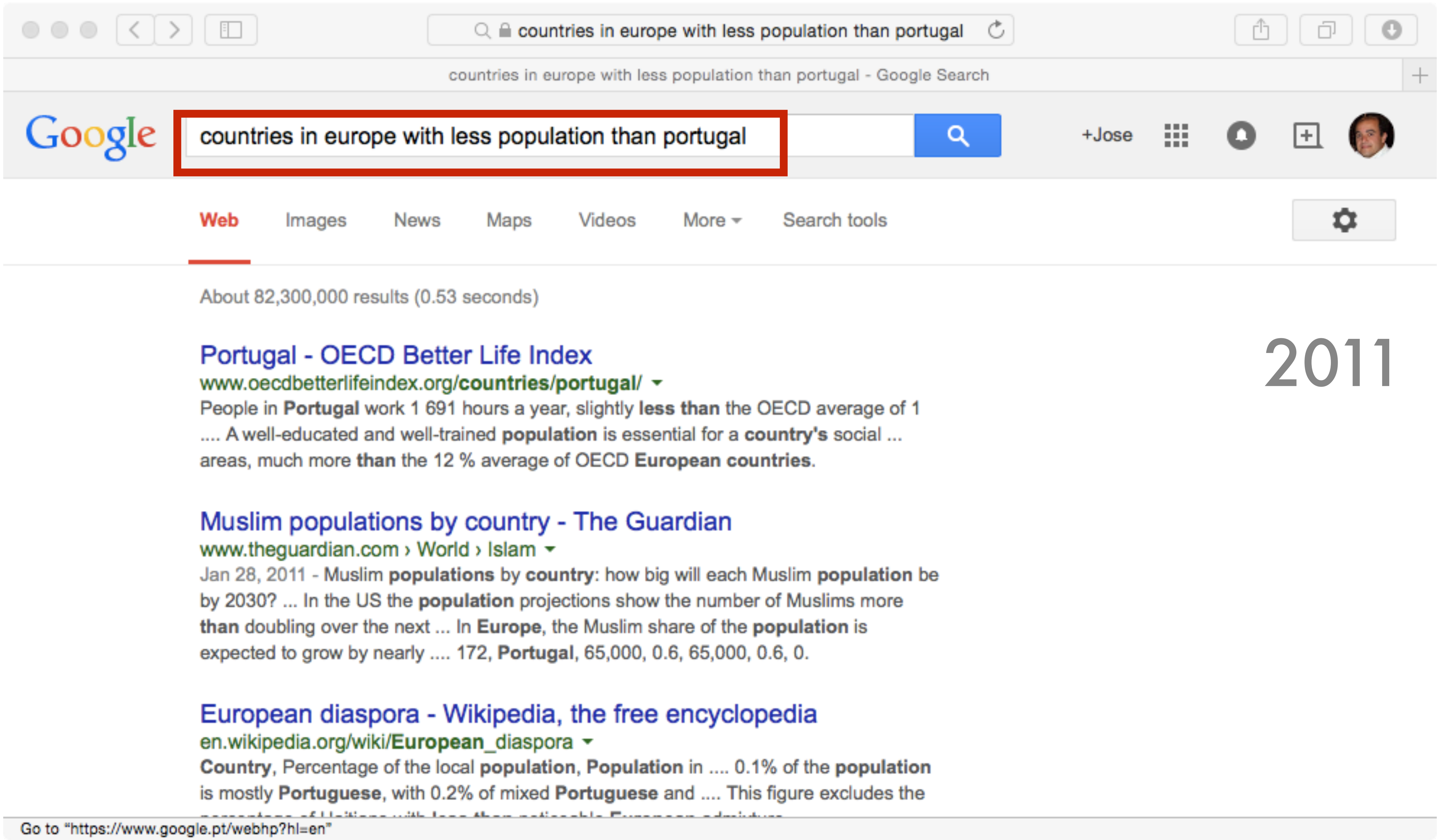
- One has to consult several sites, with different styles, purposes, languages, ...
- Mentally integrate the data and understand it
- Apply personal preferences





- How could we do a program to perform such a task?
- Note that those pages most likely are already based in structured data, but one can't access it (easily)

Querying the Web



2011

Querying the Web

2016

countries in europe with less population than portugal

Tudo | Notícias | Imagens | Mapas | Vídeos | Mais | Ferramentas de pesquisa

Cerca de 38 700 000 resultados (0,40 segundos)

Area and population of European countries - Wikipedia, the free ...
https://en.wikipedia.org/.../Area_and_population_of_European_c... ▾ Traduzir esta página
This is a list of countries and territories in Europe by population density. ... The data for Portugal includes the Madeira Islands. ... inland water bodies (lakes, reservoirs, rivers) and therefore the population densities stated here may be lower.

Portugal - Wikipedia, the free encyclopedia
https://en.wikipedia.org/wiki/Portugal ▾ Traduzir esta página
Location of Portugal (dark green). – in Europe (green & dark grey) – in the European Union ... It is the westernmost country of mainland Europe. .... of Celts invaded Portugal from Central Europe and inter-married with the local populations, ... a century later in 1031 into no less than 23 small kingdoms, called Taifa kingdoms.

European Union statistics - Wikipedia, the free encyclopedia
https://en.wikipedia.org/wiki/European_Union_statistics ▾ Traduzir esta página
Statistics in the European Union are collected by Eurostat (European statistics body). ... The least densely populated country is Finland. Population figures in the table below are from 2006 or 2007 estimates. The highest and lowest figures in each ...

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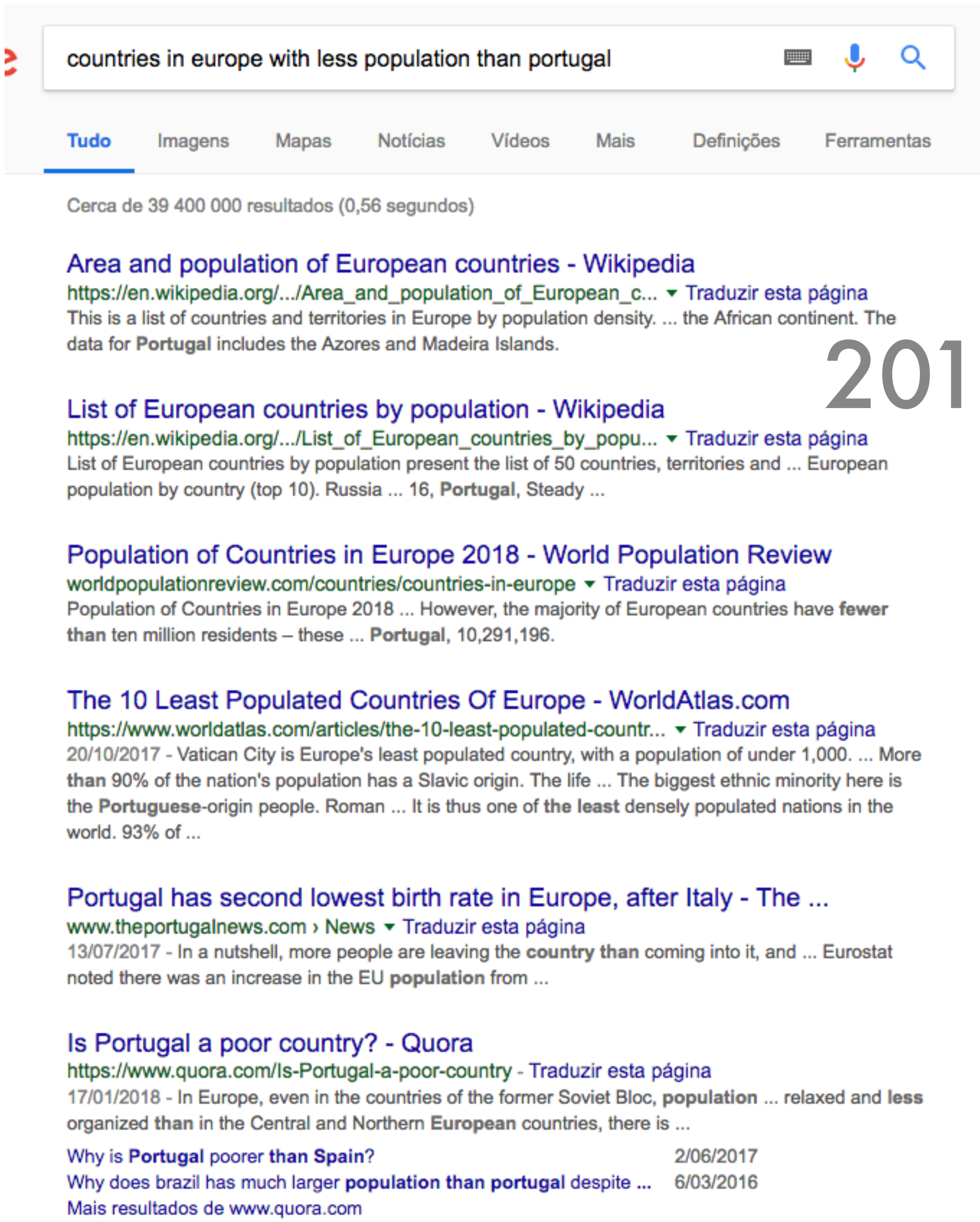

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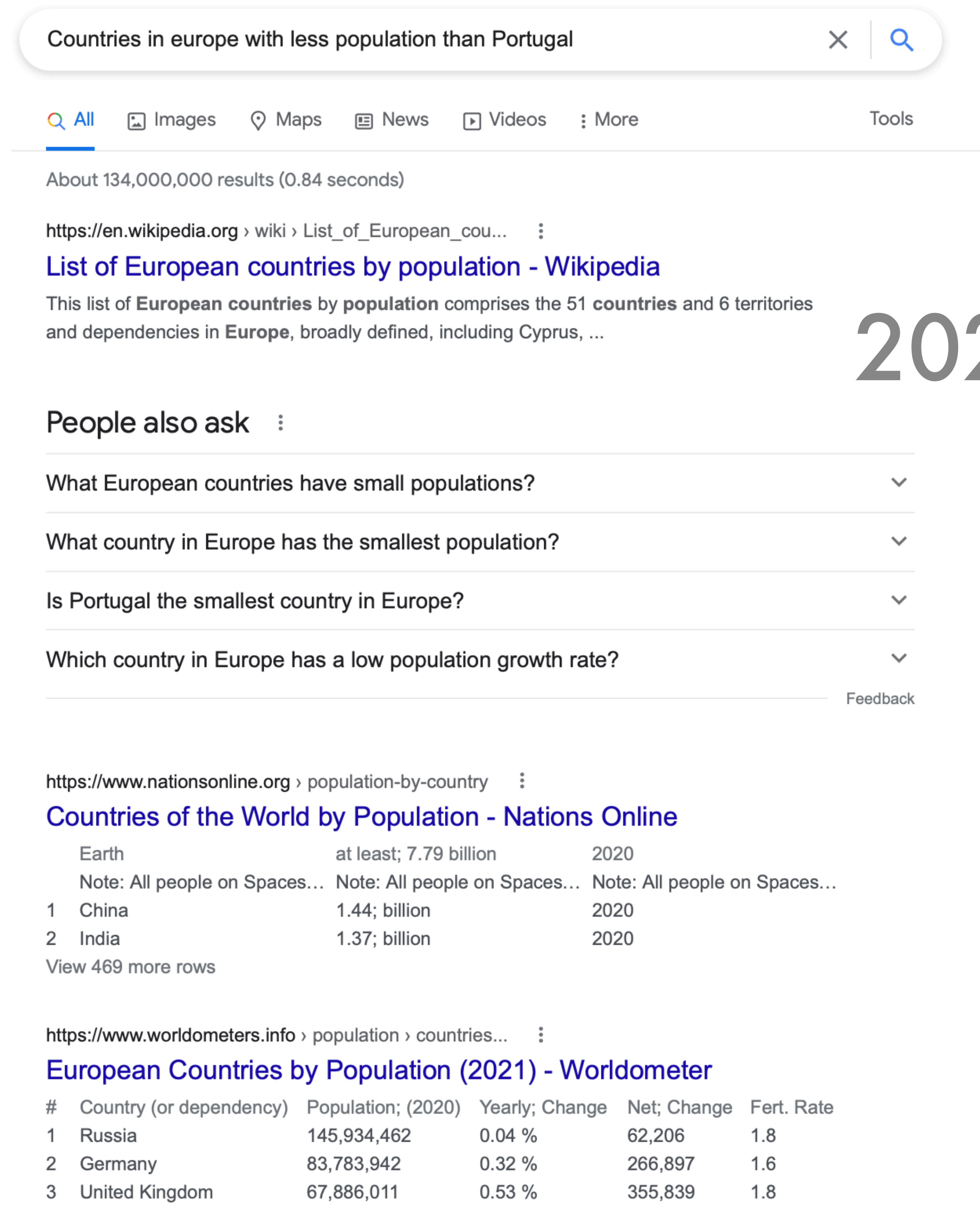

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1	Russia	145,934,462	0.04 %	62,206	1.8
2	Germany	83,783,942	0.32 %	266,897	1.6
3	United Kingdom	67,886,011	0.53 %	355,839	1.8

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- Monaco (37,000)
- Liechtenstein (37,000)
- Andorra (78,000)
- Iceland (331,000)
- Malta (425,000)
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Europe Population 2021

748,787,739

Europe is a subcontinent that comprises the westernmost peninsula of Eurasia. It's usually divided from Asia by the watershed divides of the Ural River, the Caspian and Black Seas, the Caucasus and Ural Mountains and waterways that connect the Black and Aegean Seas together. The continent's estimated 2016 population is over 738 million.

Europe is the second-smallest continent by surface area and covers 10.18 million square kilometers (3.93 million square miles), or 2% of the Earth's surface and 6.8% of the world's land area. There are approximately 50 countries in Europe. The largest by size is Russia with 40% of the continent, and Vatican City is the smallest.

Europe is the third most populous continent behind Asia and Africa. Its population in 2016 is estimated at 738 million, which accounts for 11% of the world's population. The continent is currently growing at a rate of 0.3%. Europe has been in a decline for some time and its population is aging rapidly in most countries.

Most Populous Countries

By far the most populous country in Europe is Russia, which is actually located in both Europe and Asia. Russia's population of 143 million is almost equal to the combined populations of the 2nd and

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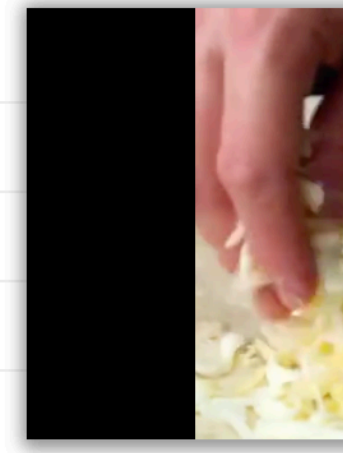
% of World Pop

Density 32.52



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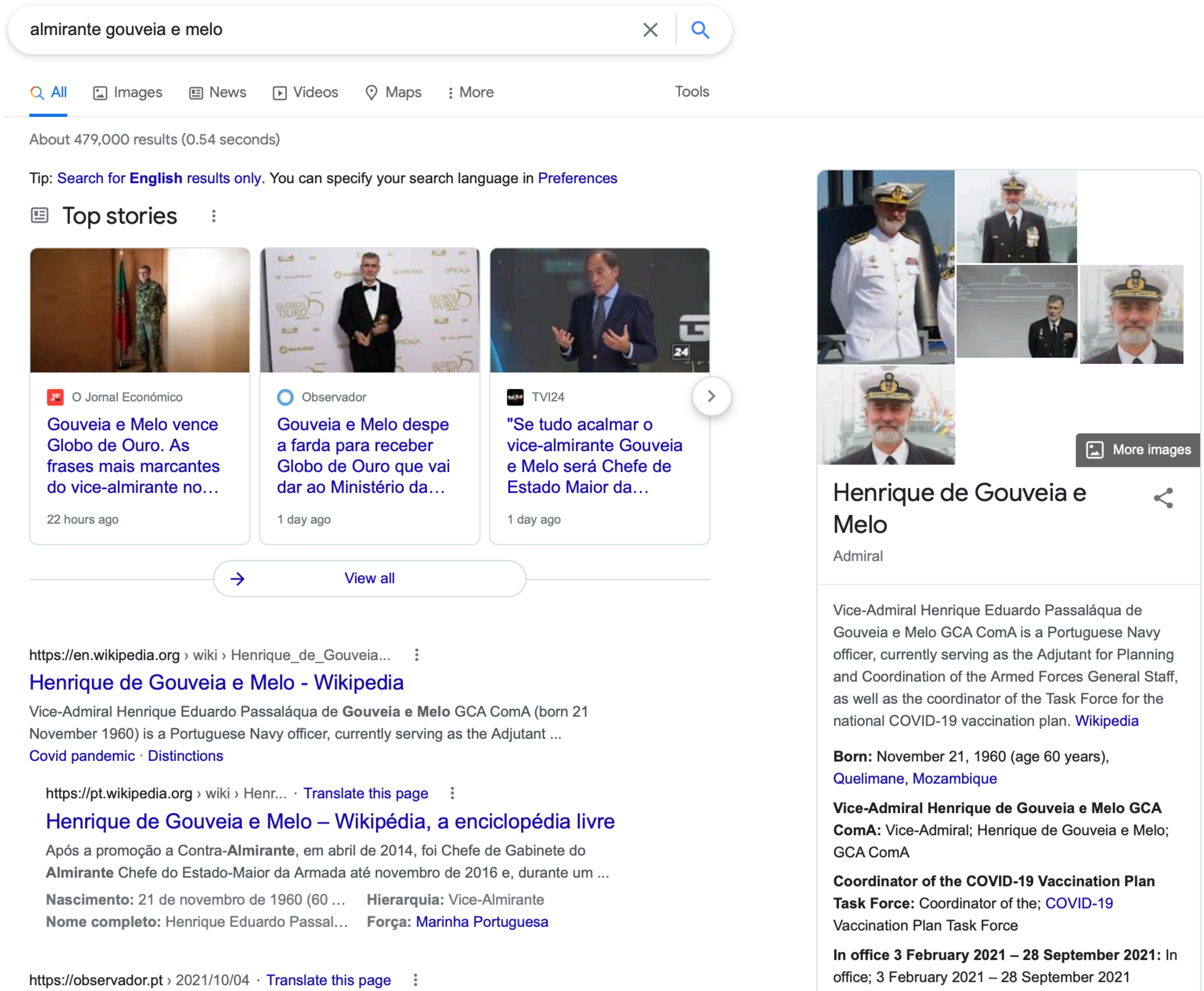

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Born: November 21, 1960 (age 60 years), Quelimane, Mozambique

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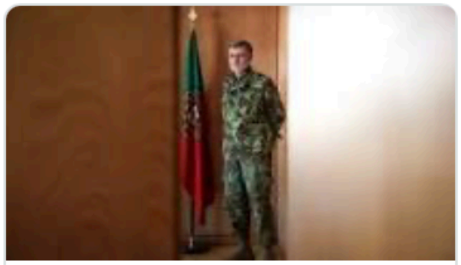

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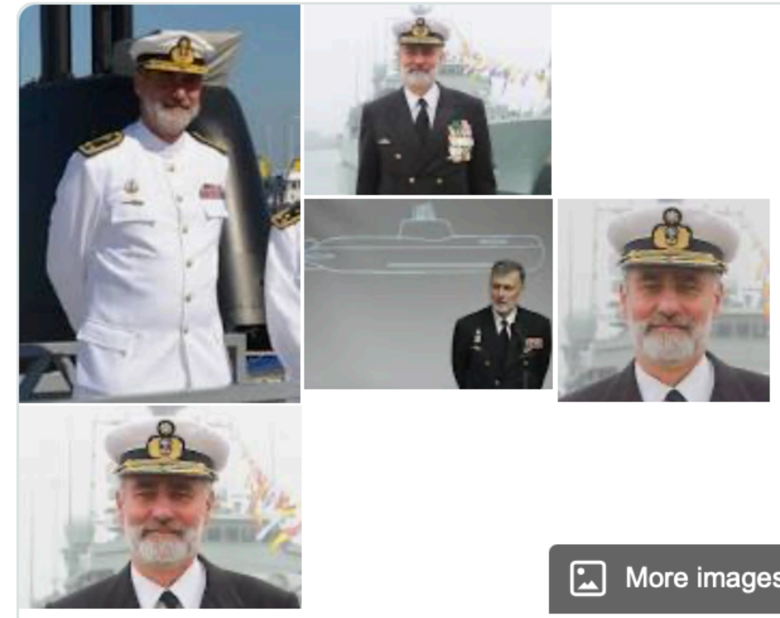

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Founders: Steve Jobs, Steve Wozniak, Ronald Wayne Trending

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Recognized regional language: Mirandese

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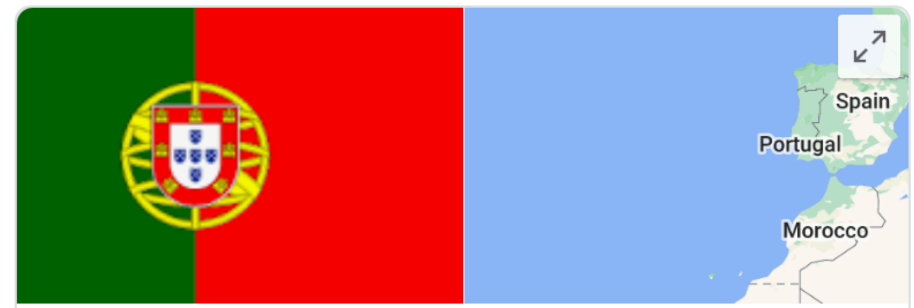

Portugal

Country

Portugal is a southern European country on the Iberian Peninsula, bordering Spain. Its location on the Atlantic Ocean has influenced many aspects of its culture: salt cod and grilled sardines are national dishes, the Algarve's beaches are a major destination and much of the nation's architecture dates to the 1500s–1800s, when Portugal had a powerful maritime empire. — Google

President: Marcelo Rebelo de Sousa Trending

Capital: Lisbon

Dialing code: +351

Population: 10.31 million (2020) World Bank

Minimum wage: 740.83 EUR per month (Jun 2020) Eurostat

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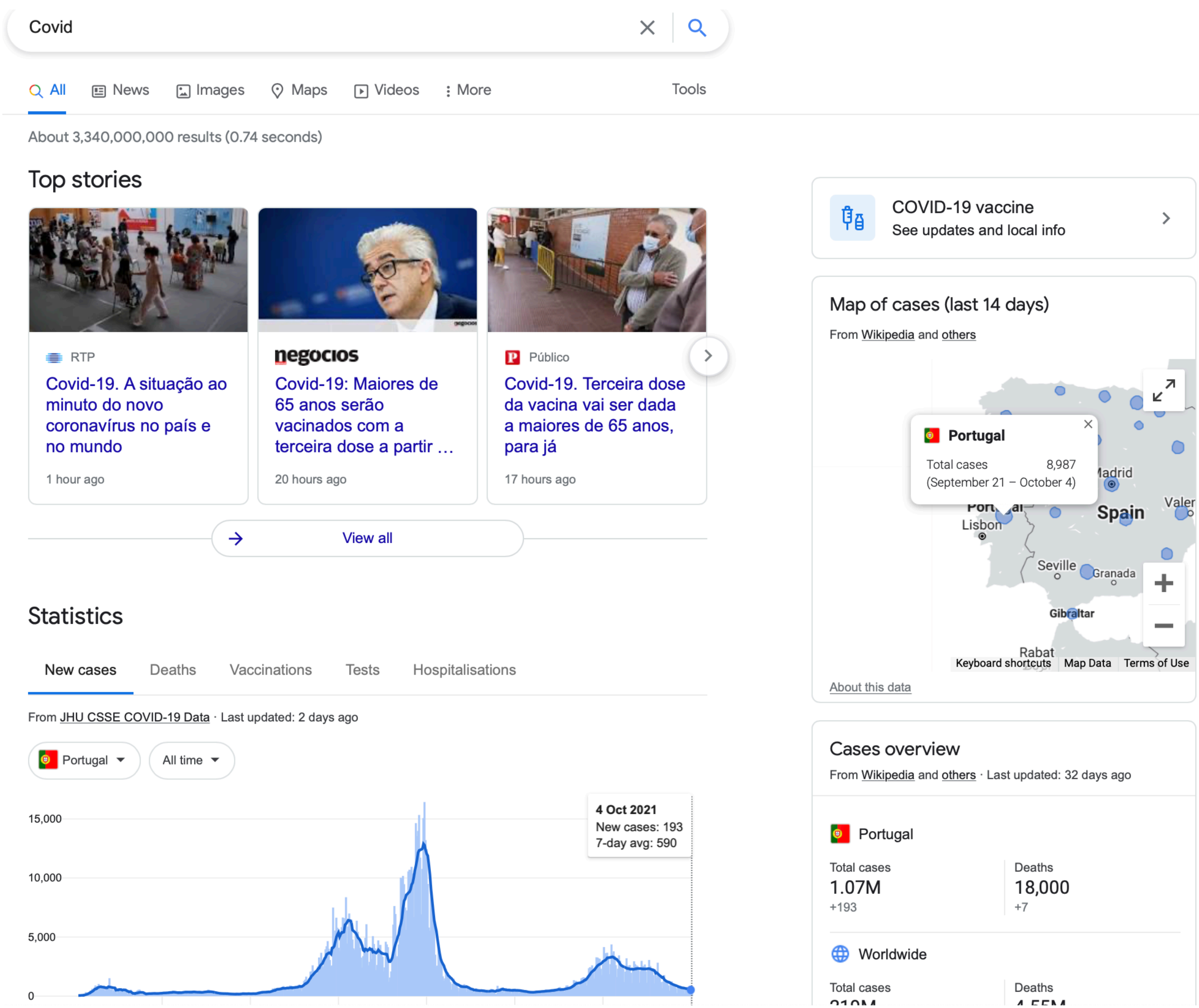

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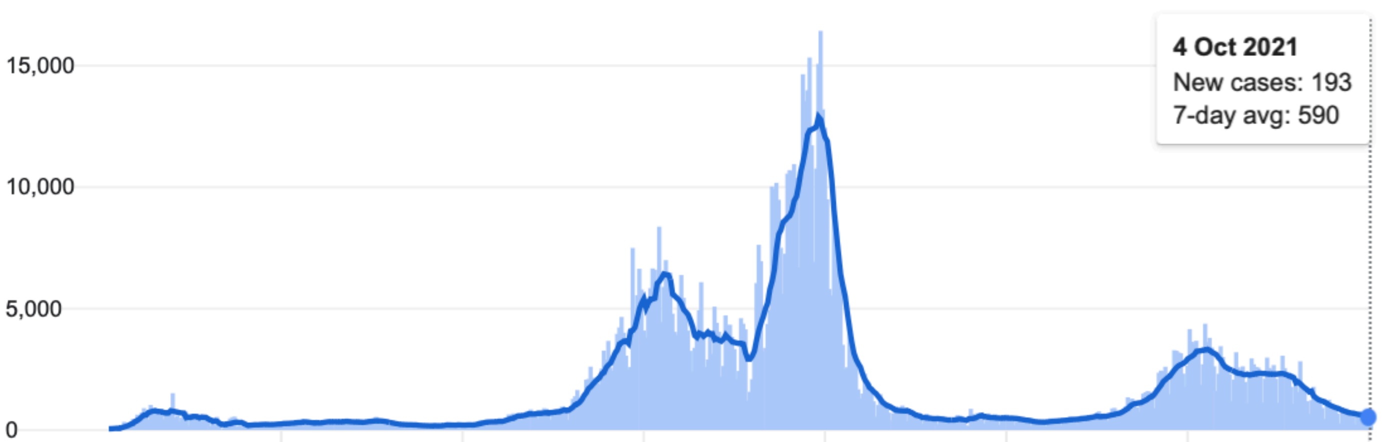

COVID-19 vaccine

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Map of cases (last 14 days)

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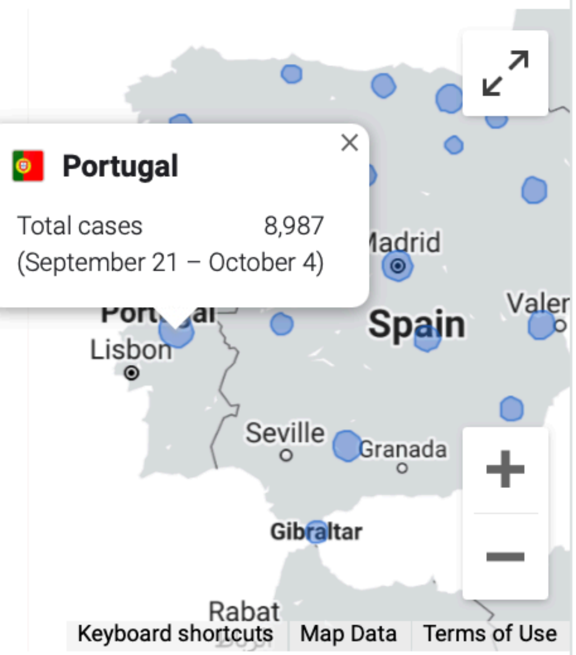

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Portugal

Total cases	Deaths
1.07M	18,000
+193	+7

Worldwide

Total cases	Deaths
219M	4.55M

Querying the Web

- **Search engines are great!**
  - for keyword search
  - improving its “understanding” capabilities for more complex “natural language” queries
- **What if we want to make more elaborate queries?**
  - Similar to what you may do in databases.
- **What about very specialized queries?**
  - E.g. in specific domains (e.g. protein structures)
  - Again similar to those to databases.

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"I have a dream for the Web [in which computers] become capable of analyzing all the data on the Web – the content, links, and transactions between people and computers. A 'Semantic Web', which should make this possible, has yet to emerge, but when it does, the day-to-day mechanisms of trade, bureaucracy and our daily lives will be handled by machines talking to machines. The 'intelligent agents' people have touted for ages will finally materialize." Tim Berners-Lee, 1999

A Web of Data

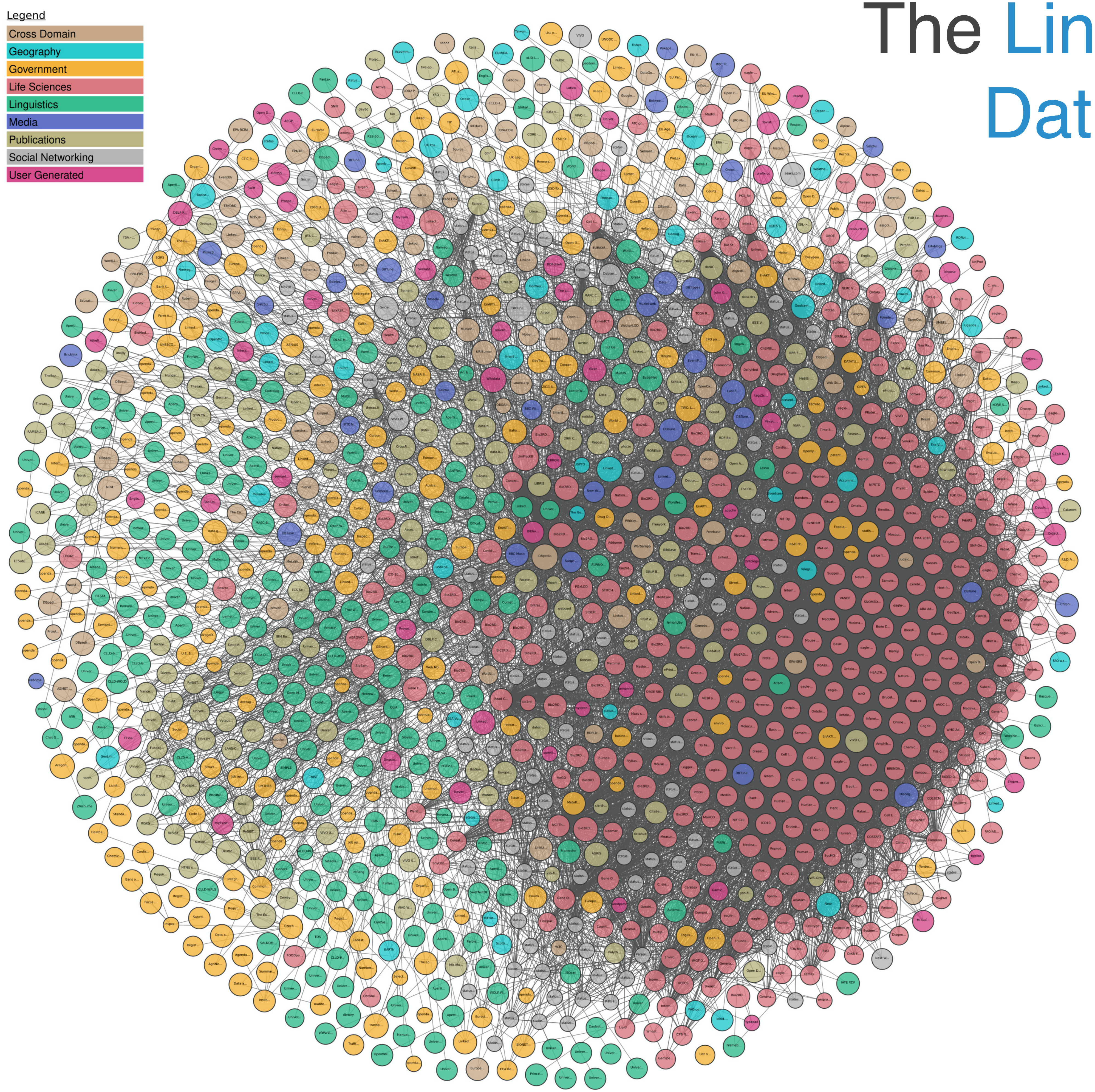
- What we need is a Web of (raw) Data?
- Use the linked data in the same way we do with linked documents
  - be able to link data independently of presentation
  - use the data to query it, present it, mine it
  - have data in a machine processable format

RDF and RDF Schema

Linked Open Data

SPARQL

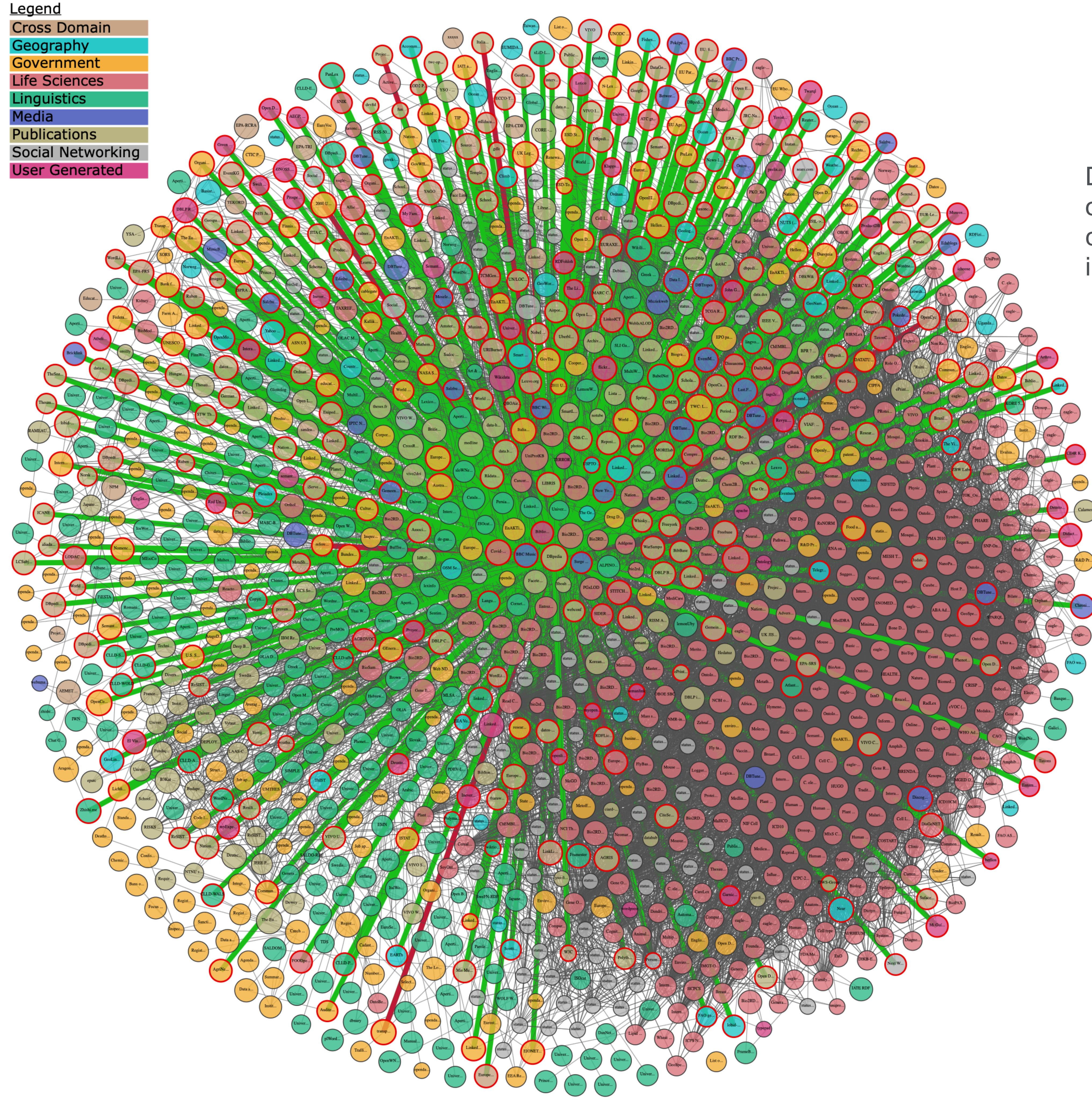
The Linked Open Data Cloud



The Linked Open Data Cloud

Legend

- Cross Domain
- Geography
- Government
- Life Sciences
- Linguistics
- Media
- Publications
- Social Networking
- User Generated



DBpedia

DBpedia is a project whose objective is to extract structured content from Wikipedia's information.

Further Reading and Summary

Q&A

Further Reading and Summary

- **What you should know:**
  - A first understand of what is BigData, its main characteristics, and the main challenges
  - Understand the examples of digital footprint from the second video Martin Hilbert
  - What is about the CAP theorem and its implications
  - understand the NoSQL quadrants and the motivation for each one