Databases

9

Advanced Databases: NoSQL databases

Database systems 2

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DB EVOLUTION

1990-2000

’70→’90

- 1970-72: Relational model (P. Chen)
- 1974-77: Two major RDBMS prototypes
  - Ingres (UCB - Berkeley) – QUEL language → Ingres (later Postgres), MS SQL Server, Sybase
  - System R (IBM) – SEQUEL language → DB2, Oracle, Allbase (HP)
- 1976: Entity-Relationship Model (P. Chen)
- 1980s: SQL standard
- 1990s:
  - Object Oriented Databases (OODB)
  - Object-relational Databases (ORDB)
  - Object-Relational Mapping (ORM) – most popular
- Mid ‘90: WEB! Client-server DBMSs
  - Internet DB connectors (Front Page, Active Server Pages, JDBC, Java Servlet, Dream Weaver, ColdFusion, Enterprise Java Beans, and Oracle Developer 2000)
- 1998: XML

‘90 - New needs

- Complex objects
  - complex aggregations
  - non-numerical information — images, spatial data, temporal series, …
  - pre-defined and user-defined types (with reuse)

- Complex operations
  - customized on the type of information — e.g., multimedia or user-defined types
  - long-lived transactions

→ Supported by OO programming languages

- BUT: Object-oriented application development and relational data management use two incompatible models

→ IMPEDANCE MISMATCH PROBLEM!

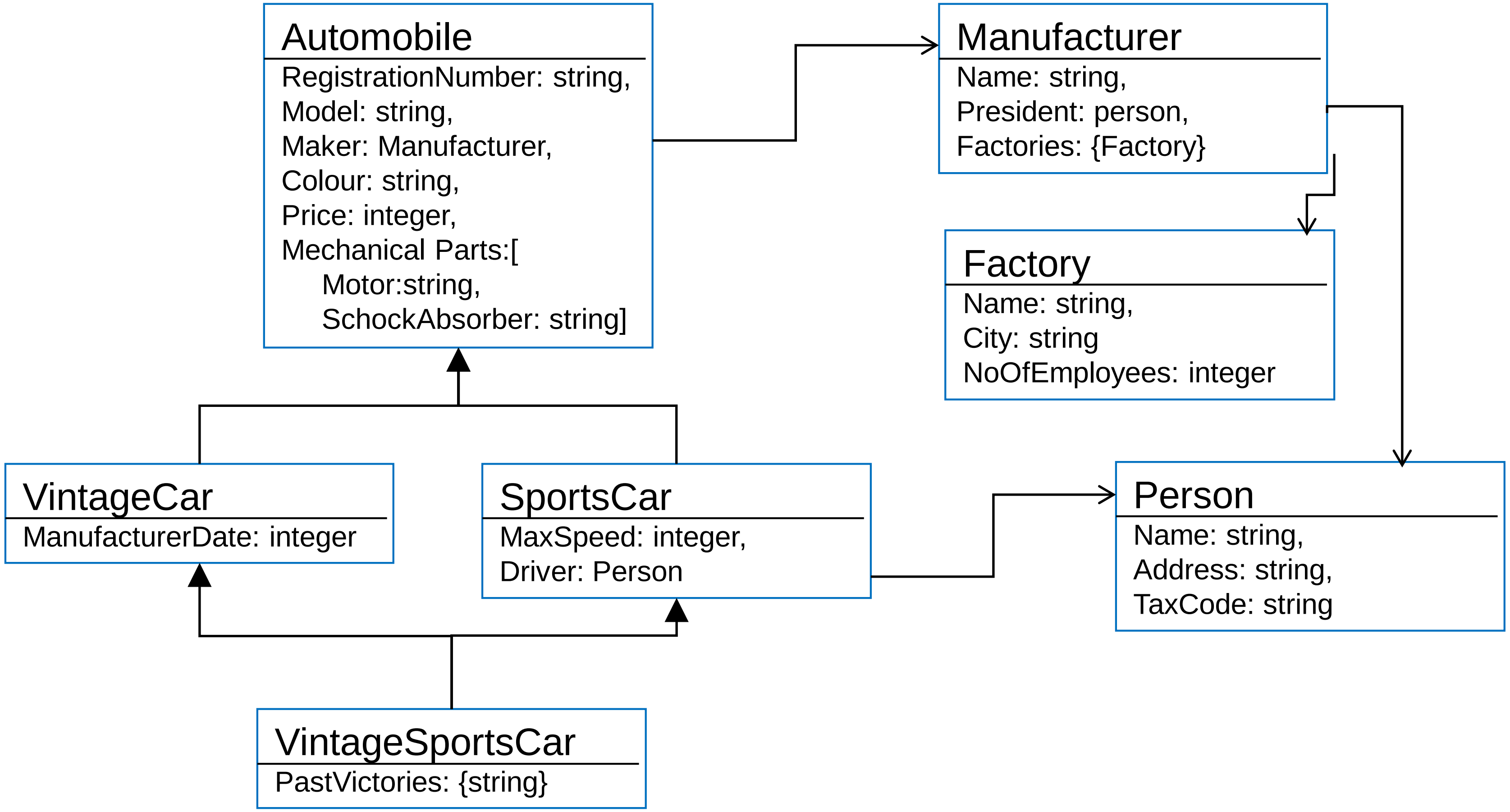
ODBMS Technology

- First generation of ODBMS: it is represented by *persistent* object programming languages
  - offer only some of the services of DBMSs, with no support for queries
- Second generation of ODBMS: manage and store persistent objects → offer a greater number of DBMS services and typically offer support for queries
- Two main ODBMS solutions
  - OODBMS (*Object-Oriented*): a *revolutionary* solution, with respect to RDBMS
  - ORDBMS (*Object-Relational*): an evolutionary solution, with respect to RDBMS

OODBMS

- Data represented as objects
  - object identity
  - attributes and methods
  - references, relationships, associations
- Extensible type hierarchy
  - user-defined types, abstract data types
  - single or multiple inheritance
  - overloading, overriding, late binding
- Declarative language for ad hoc purposes (ODL, OQL)
- Binding for object-oriented programming language

OODBMS - Example



OODBMS - Example of ODL schema

```
interface Automobile
  {extent Automobiles key RegistrationNumber}
  { attribute string RegistrationNumber;
    attribute string Model;
    attribute string Colour;
    attribute integer Price
    attribute structure MechanicalParts
    { string Motor,
      string ShockAbsorber};
    relationship <Manufacturer> Maker
      inverse Manufacturer::Builds;
    Automobile init (in string RegistrationNumber_par,
                     in string Model_par,
                     in string Colour_par,
                     in integer Price_par);
    void Increase (in integer Amount) raises(ExcessivePrice); }

interface VintageCar: Automobile
  {attribute integer ManufacturerDate}
```

Complex structure

Bidirectional relationships

Methods

inheritance

OODBMS - OQL by examples

- Find the registration numbers of the vintage cars built at Maranello and driven by Fangio:

Path expressions

```
select x.RegistrationNumber
from x in VintageSportsCar
where x.Driver.Name = "Fangio“ and "Maranello" in x.Maker.Factories.Name
```

- Find the names of the manufacturers who sell sports cars at a price higher than 200000; for each of them, list the city and number of employees of the factories:

Nested structure

```
select distinct struct(Name: x.Maker.Name,
                       Fact: (select struct (Cit: y.City,
                                             Emp: y.NoOfEmployees)
                              from y in Factory
                              where y in x.Maker.Factories))
from x in SportsCar
where x.Price > 200000
```

Commercial OODBMS

- Objectivity/DB (C++/Java/Smalltalk/Python/SQL++ interfaces)
- ObjectStore PSE Pro for Java
- Versant (C++/Java/Smalltalk)
- O2 (C++/Java)
- db4o (Java/.NET)

- Language-Integrated Query (LINQ), Microsoft .NET has a similar syntax

ORDBMS

- Relational model extended
  - Nested relations
  - References
  - Sets
  - Row types, abstract types
  - Functions
- Declarative language extended
- Fundamental impedance mismatch remains

Object-Relational databases (ORDBMSs)

- Revision of
  - Data model (non-1NF)
  - Query language

    → SQL-3 (SQL-99 is the official name)

Tuple types

```
create row type PersType(
  Name varchar(30) not null,
  Residence varchar(30),
  TaxCode char(16) primary key)

create table Person of type PersType
create table Industrial of type PersType

create table Manufacturer of type ManufacturerType
values for ManufID are system generated
scope for President is Person
```

- Tuples correspond to the objects
- Relations correspond to the classes
- It is possible to use references and to include objects

Queries

- Select the Name of the President of the Maker of Automobiles using the Motor “XV154”

```
select Maker -> President -> Name
from Automobile
where MechanicalParts -> Motor = ‘XV154’
```

- Extract for each city the set of its Manufacturers

```
select City, set(name)
from Manufacturer
group by City
```

Adoption of ODBMS in practice

- ODBMS originally thought of to replace RDBMS because of their better fit with object-oriented programming languages
- But:
  - high switching cost
  - introduction of ORDBMS
  - emergence of object-relational mappers (ORMs)

  have made RDBMS successfully defend their dominance in the data center for server-side persistence

- Object databases are now established as a complement
  - as embeddable persistence solutions in devices, on clients, in packaged software, in real-time control systems, and to power websites.

DB EVOLUTION

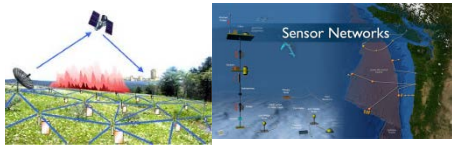
2000-NOW

Big Data EveryWhere!

Social media and networks
(all of us are generating data)

Scientific instruments
(collecting all sorts of data)

Mobile devices
(tracking all objects all the time)



Sensor technology and networks
(measuring all kinds of data)

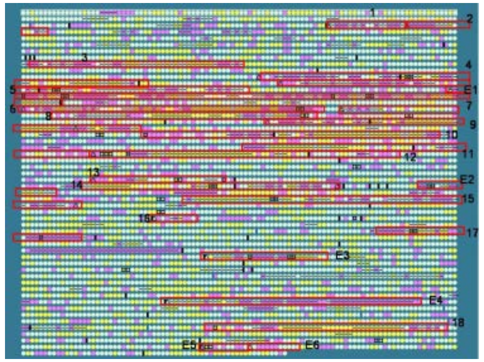
Needs for ability <u>to manage, analyze, summarize, visualize, and discover knowledge</u> from the collected data in a <u>timely</u> manner and in a <u>scalable</u> fashion

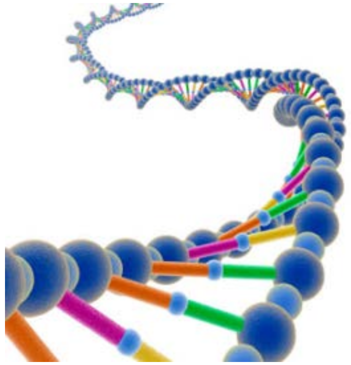
Characteristics of Big Data: 1-Scale (Volume)

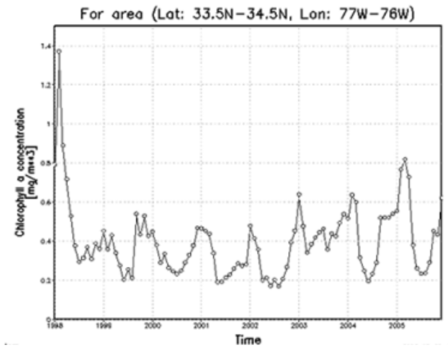
- **Data Volume**
  - 44x increase from 2009 to 2020
  - From 0.8 zettabytes to 35zb
- Data volume is increasing exponentially

Characteristics of Big Data: 2-Complexity (Variety)

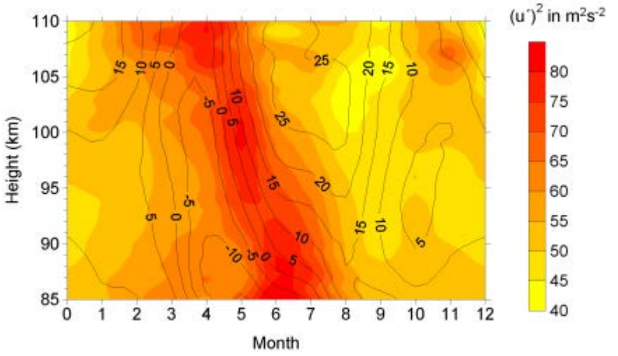
- Various formats, types, and structures
- Text, numerical, images, audio, video, sequences, time series, social media data, multi-dim arrays, etc…
- Static data vs. streaming data
- A single application can be generating/collecting many types of data







To extract knowledge
➔ all these types of data need to be linked together



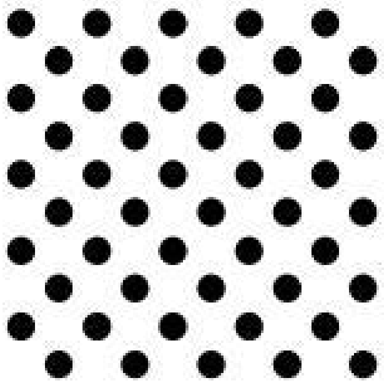
Characteristics of Big Data: 3-Speed (Velocity)

- Data is begin generated fast and need to be processed fast
- Online Data Analytics
- Late decisions ➔ missing opportunities

- **Examples**
  - **E-Promotions:** Based on your current location, your purchase history, what you like ➔ send promotions right now for store next to you
  - **Healthcare monitoring:** sensors monitoring your activities and body ➔ any abnormal measurements require immediate reaction

Some Make it 4V's

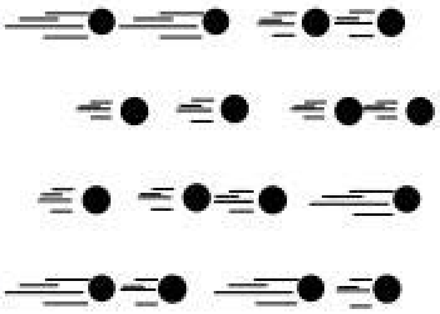
Volume



Data at Rest

Terabytes to exabytes of existing data to process

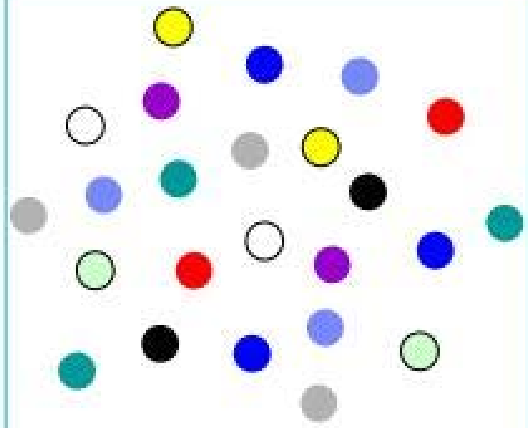
Velocity



Data in Motion

Streaming data, milliseconds to seconds to respond

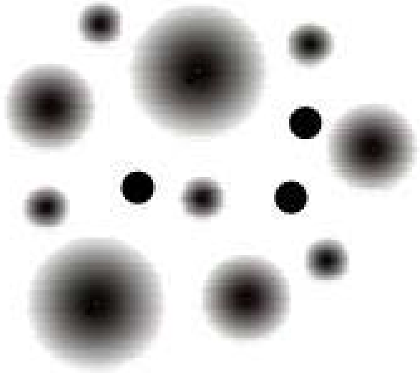
Variety



Data in Many Forms

Structured, unstructured, text, multimedia

Veracity*



Data in Doubt

Uncertainty due to data inconsistency & incompleteness, ambiguities, latency, deception, model approximations

NoSQL

- "NoSQL" = "Not Only SQL"
  - Not every data management/analysis problem is best solved exclusively using a traditional DBMS

- Definition (from http://nosql-database.org/ NoSQL)

Next Generation Databases mostly addressing some of the points: being **non-relational, distributed, open-source** and **horizontally scalable**.

The movement began early 2009 and is growing rapidly. Often more characteristics apply such as: **schema-free, easy replication support, simple API, eventually consistent** / **BASE** (not ACID), a **huge amount of data** and more.

NoSQL taxonomy

What do they miss compared to RDBMs?

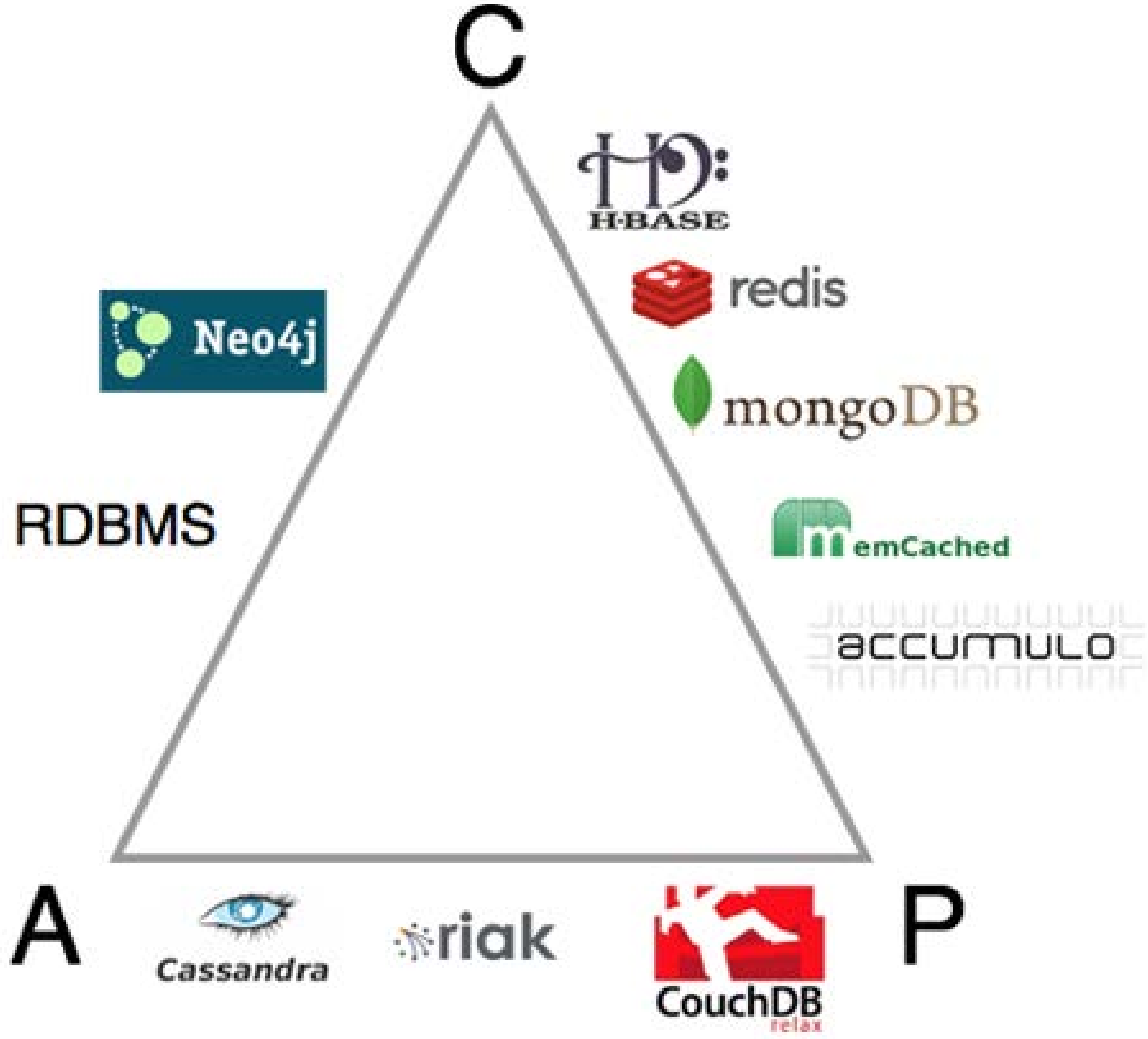
In general, the do not (fully) support:

- Joins
- Group by
- Order by
- ACID transactions

Brewer's CAP Theorem

- *Consistency*: Every read receives the most recent write or an error
- *Availability*: Every request receives a (non-error) response – without the guarantee that it contains the most recent write
- *Partition tolerance*: The system continues to operate despite an arbitrary number of messages being dropped (or delayed) by the network between nodes

Theorem: for any system sharing data it is impossible to guarantee simultaneously all of these three properties



Eventual Consistency

- BASE (**B**asically **A**vailable, **S**oft state, **E**ventual consistency) properties, as opposed to ACID
  - **S**oft state: copies of a data item may be inconsistent
  - **E**ventually Consistent – copies becomes consistent at some later time if there are no more updates to that data item
  - **B**asically **A**vailable – possibilities of faults but not a fault of the whole system

ACID	BASE
Strong consistency	Weak consistency – stale data OK
Isolation	Availability first
Focus on "commit"	Best effort
Nested transactions	Approximate answers OK
Availability?	Aggressive (optimistic)
Conservative (pessimistic)	Simpler!
Difficult evolution (e.g. schema)	Faster
	Easier evolution

New RDBMs

- To increase **scalability**:
  - Oracle RAC
  - MySQL Cluster

  Provide partitioning of load over multiple nodes

  Other options: ScaleDB, VoltDB, NimbusDB, Clustrix

  → also called **NewSQL**

  They support the relational data model and SQL, and guarantee ACID properties.

Then, which solutions should we choose?

- RDBMs if performances can be achieved with a **single server** or possibly with indexed caching front-end (there are tools available with the different RDBMS solutions)
- If you already use SQL and need some **scalability**: new RDBMs for scalability
- Key-value stores if you need to **partition** data across different RAMs in a LAN
- If you need to **scale to 100X** the single server → document or column stores

NoSQL Databases

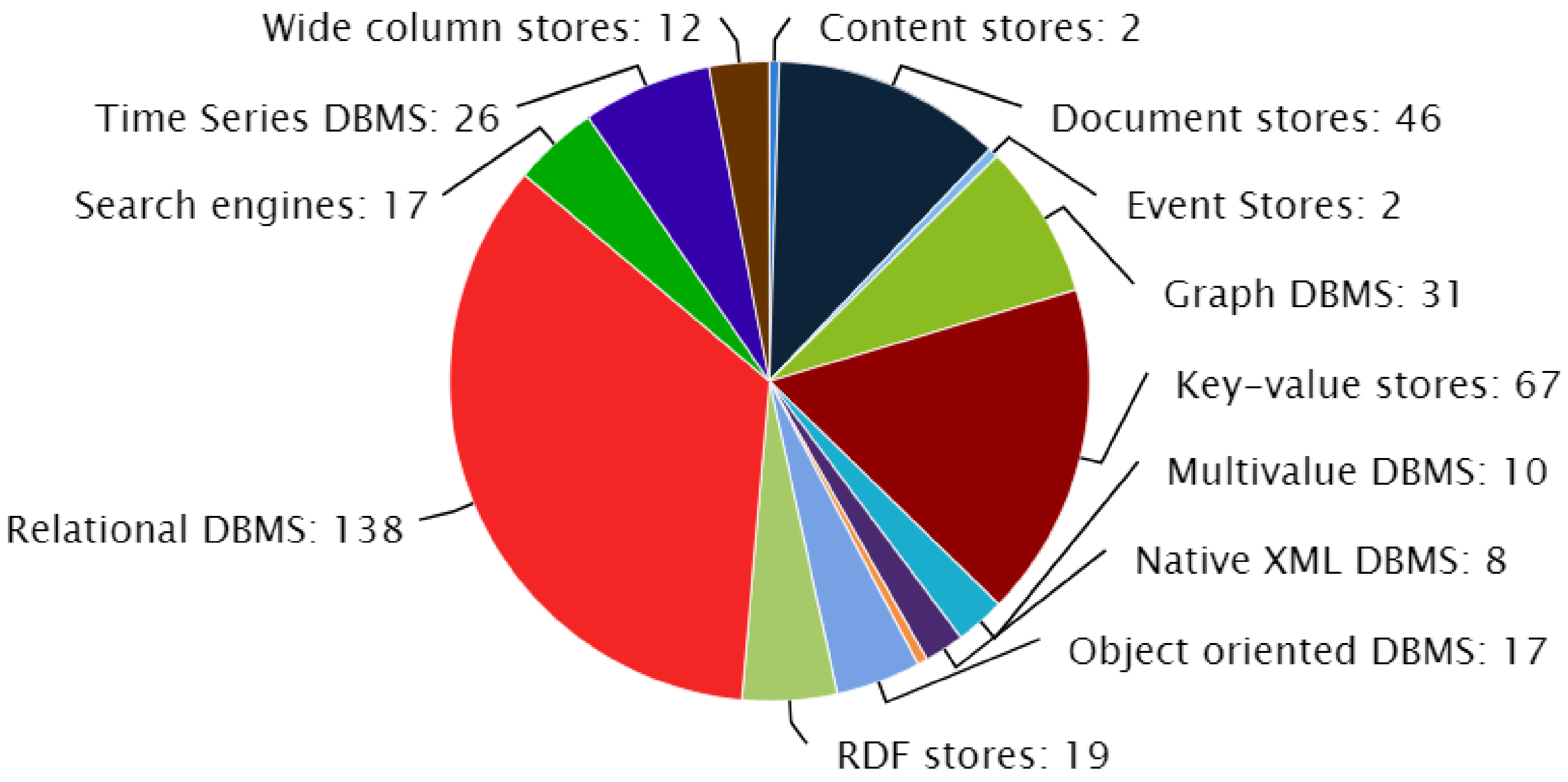
Ranking from http://db-engines.com/en/ranking

343 systems in ranking, August 2018

Rank Aug 2018	Rank Jul 2018	Rank Aug 2017	DBMS	Database Model	Score Aug 2018	Score Jul 2018	Score Aug 2017
1.	1.	1.	Oracle	Relational DBMS	1312.02	+34.24	-55.85
2.	2.	2.	MySQL	Relational DBMS	1206.81	+10.74	-133.49
3.	3.	3.	Microsoft SQL Server	Relational DBMS	1072.65	+19.24	-152.82
4.	4.	4.	PostgreSQL	Relational DBMS	417.50	+11.69	+47.74
5.	5.	5.	MongoDB	Document store	350.98	+0.65	+20.48
6.	6.	6.	DB2	Relational DBMS	181.84	-4.36	-15.62
7.	7.	↑ 9.	Redis	Key-value store	138.58	-1.34	+16.68
8.	8.	↑ 10.	Elasticsearch	Search engine	138.12	+1.90	+20.47
9.	9.	↓ 7.	Microsoft Access	Relational DBMS	129.10	-3.48	+2.07
10.	10.	↓ 8.	Cassandra	Wide column store	119.58	-1.48	-7.14
11.	11.	11.	SQLite	Relational DBMS	113.73	-1.55	+2.88
12.	12.	12.	Teradata	Relational DBMS	77.41	-0.82	-1.83

NoSQL Databases

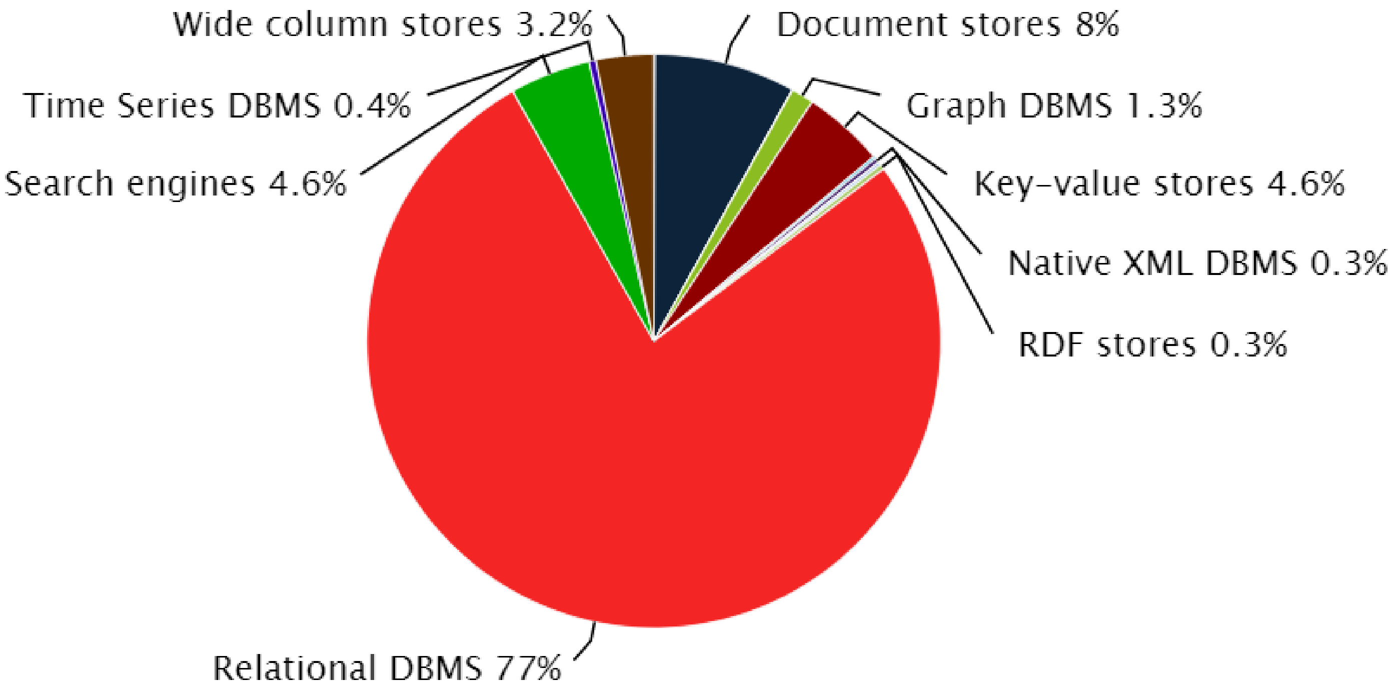
Number of systems per category, August 2018



Popularity of the models

http://db-engines.com/en/ranking

Ranking scores per category in percent, August 2018



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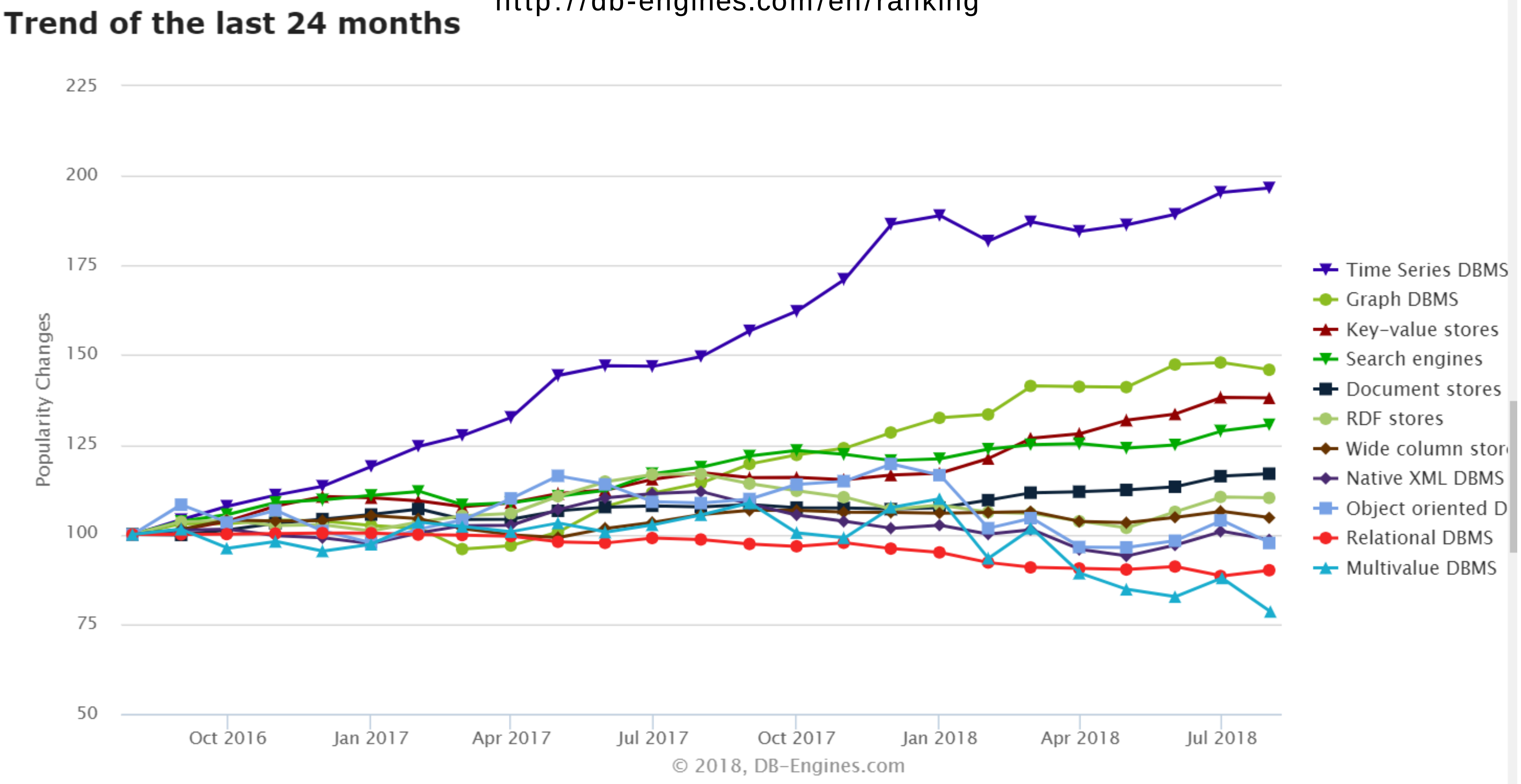
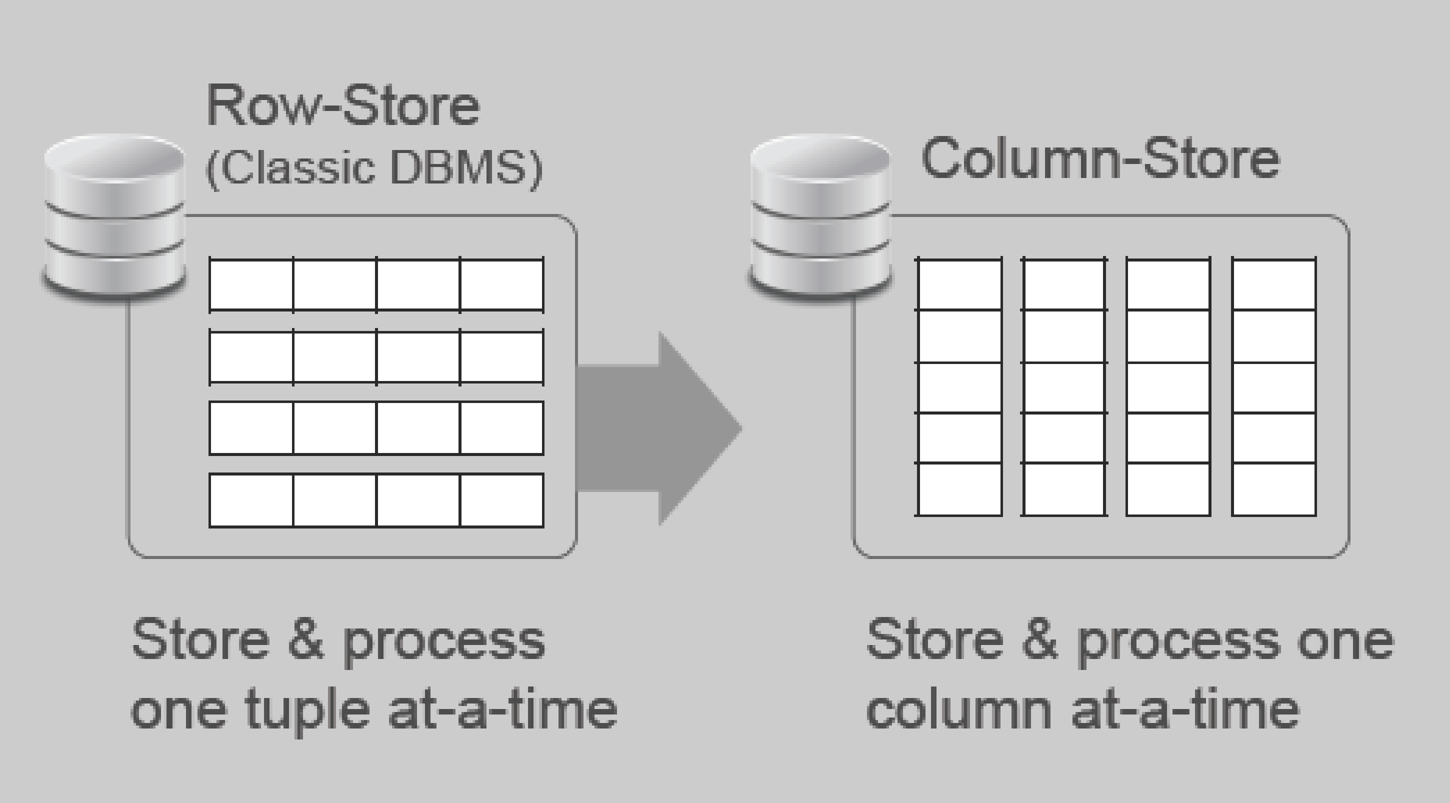


COLUMN-STORES

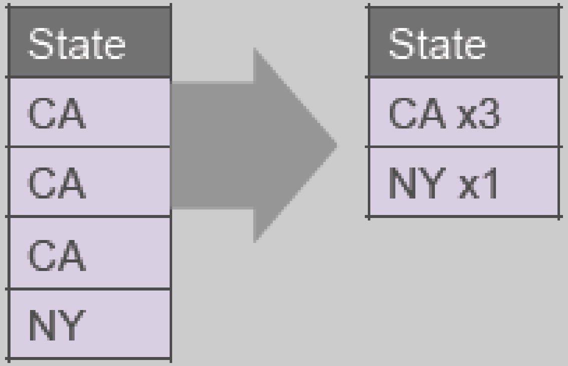
Column-store: an overview



	Row-Store	Column-Store
Tuple Insertion:	⊕ Fast	⊖ Requires multiple seeks
Queries:	⊖ May access more data than needed	⊕ Read only relevant data
		Perfect for analytics!

Compression

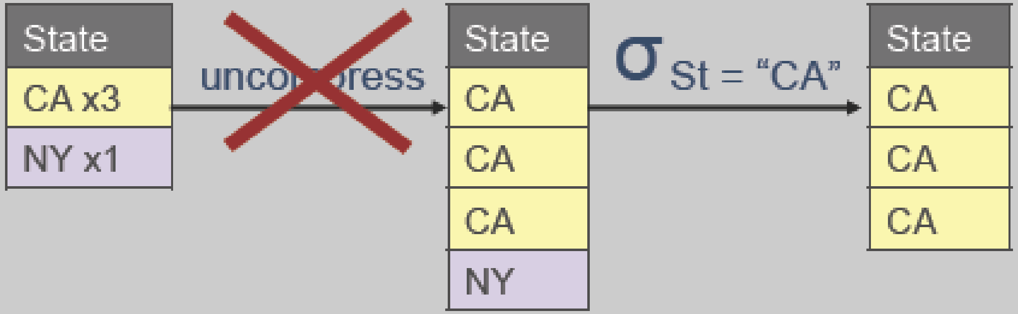
- Run-length encoding
  Replace list of identical values by pair (value, count)

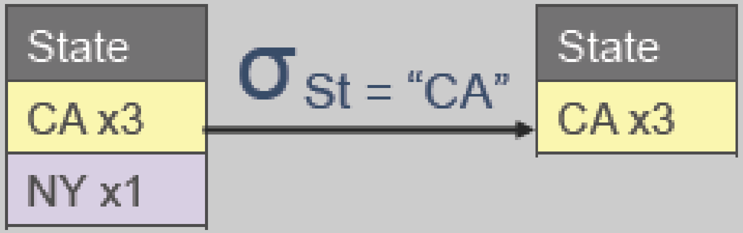


⊕ Enables query processing on compressed data directly

⊕ Good for sorted columns

e.g., Select persons in CA





Late tuple materialization

e.g., SELECT Name FROM Person WHERE City="SD" AND State="CA"

π_{Name}

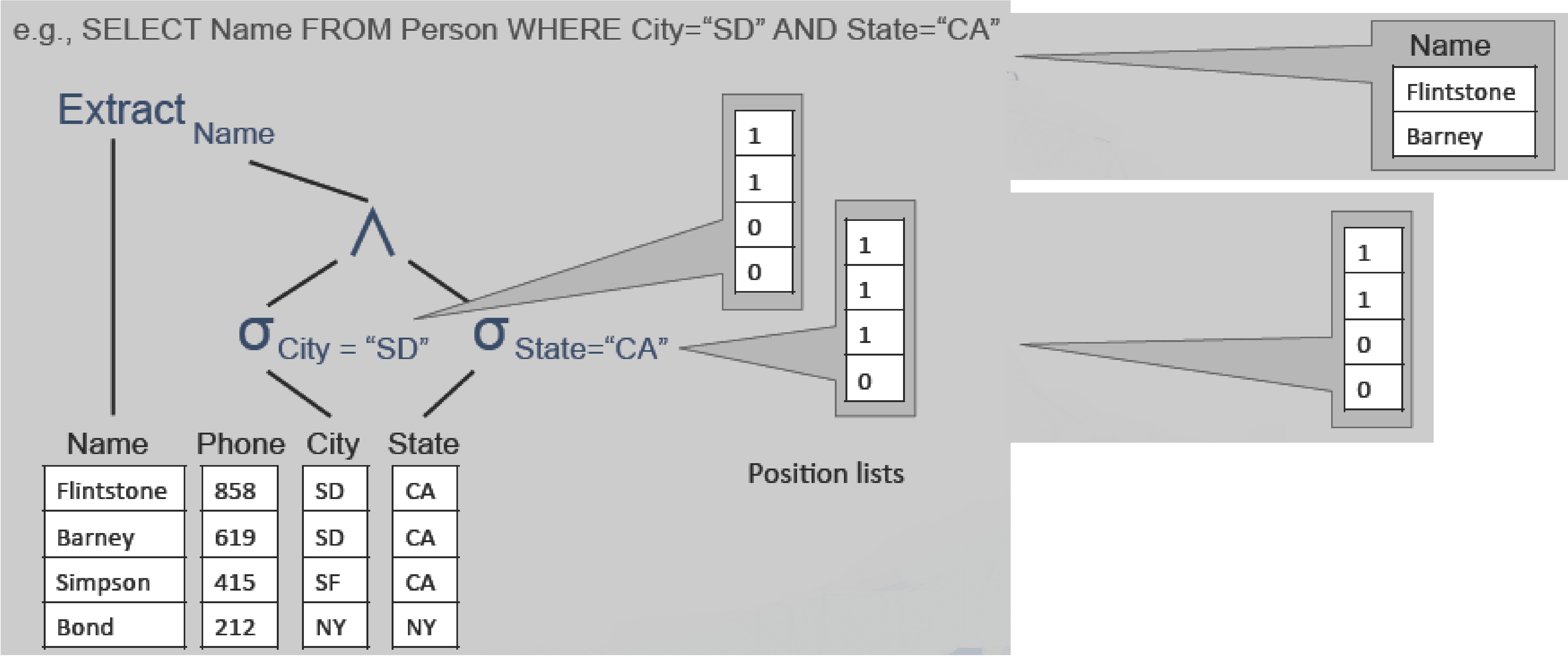
$\sigma_{\text{City = "SD"} \land \text{State="CA"}}$

Create tuples

Name	~~Phone~~	City	State
Flintstone	~~858~~	SD	CA
Barney	~~619~~	SD	CA
Simpson	~~415~~	SF	CA
Bond	~~212~~	NY	NY

⊕ Reads relevant columns only

Late tuple materialization



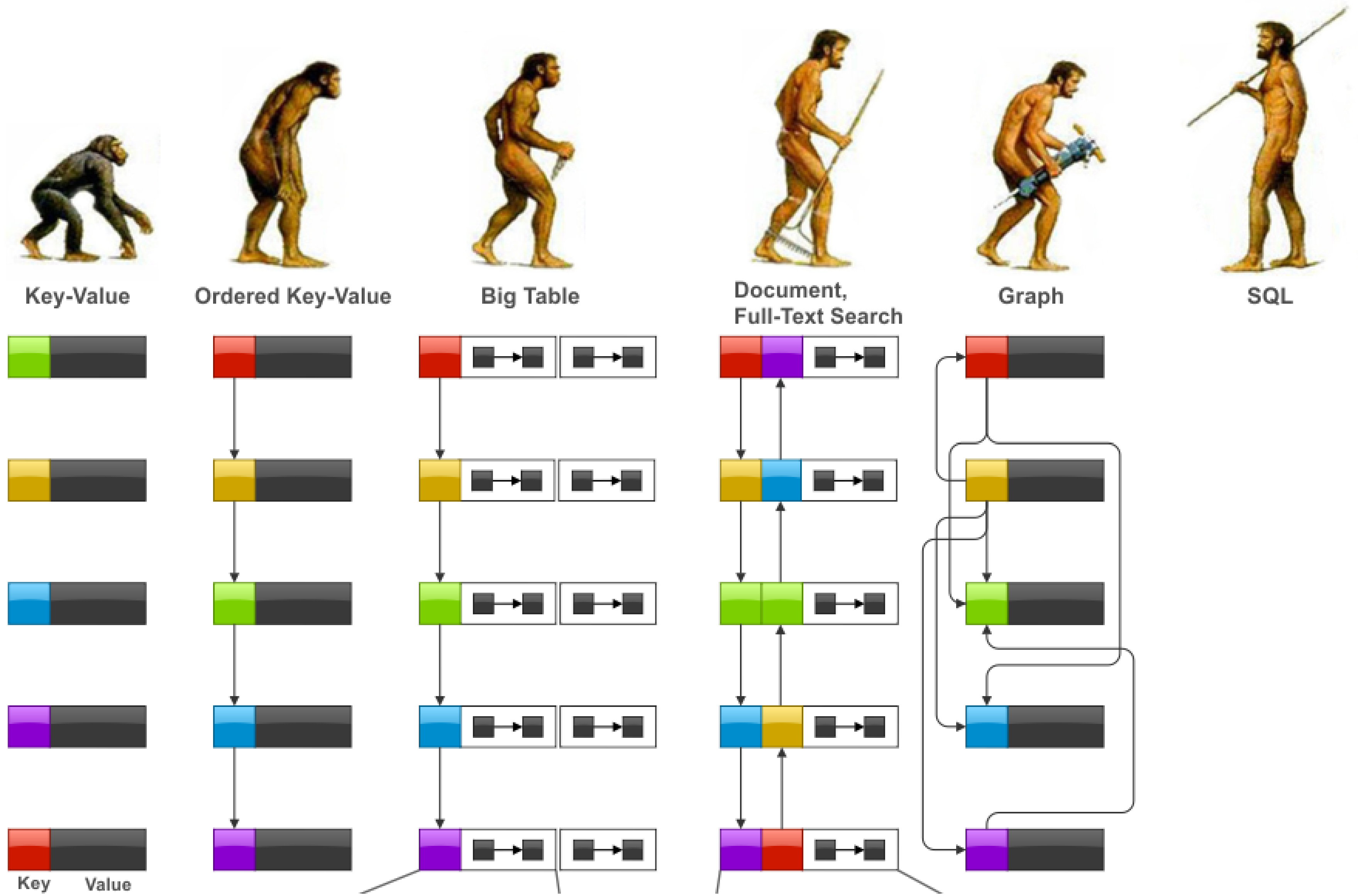
KEY-VALUE STORES

Key-Value Stores

- Extremely simple interface
  - Data model: (key, value) pairs
  - Operations: Insert(key,value), Fetch(key), Update(key), Delete(key)

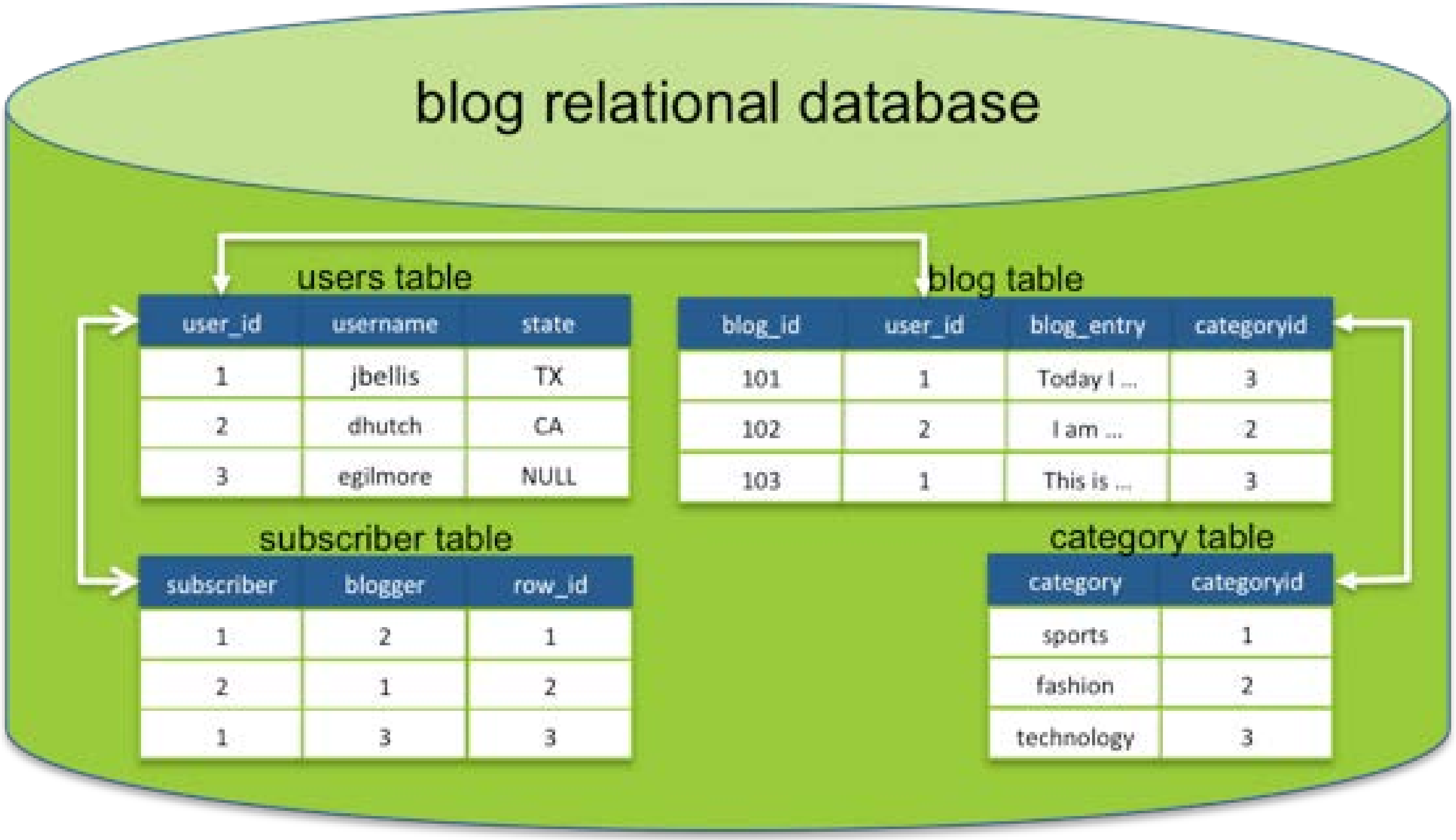
Key-Value Stores

- Primary version of a DB!
- Like associative arrays
- Only for performance reasons

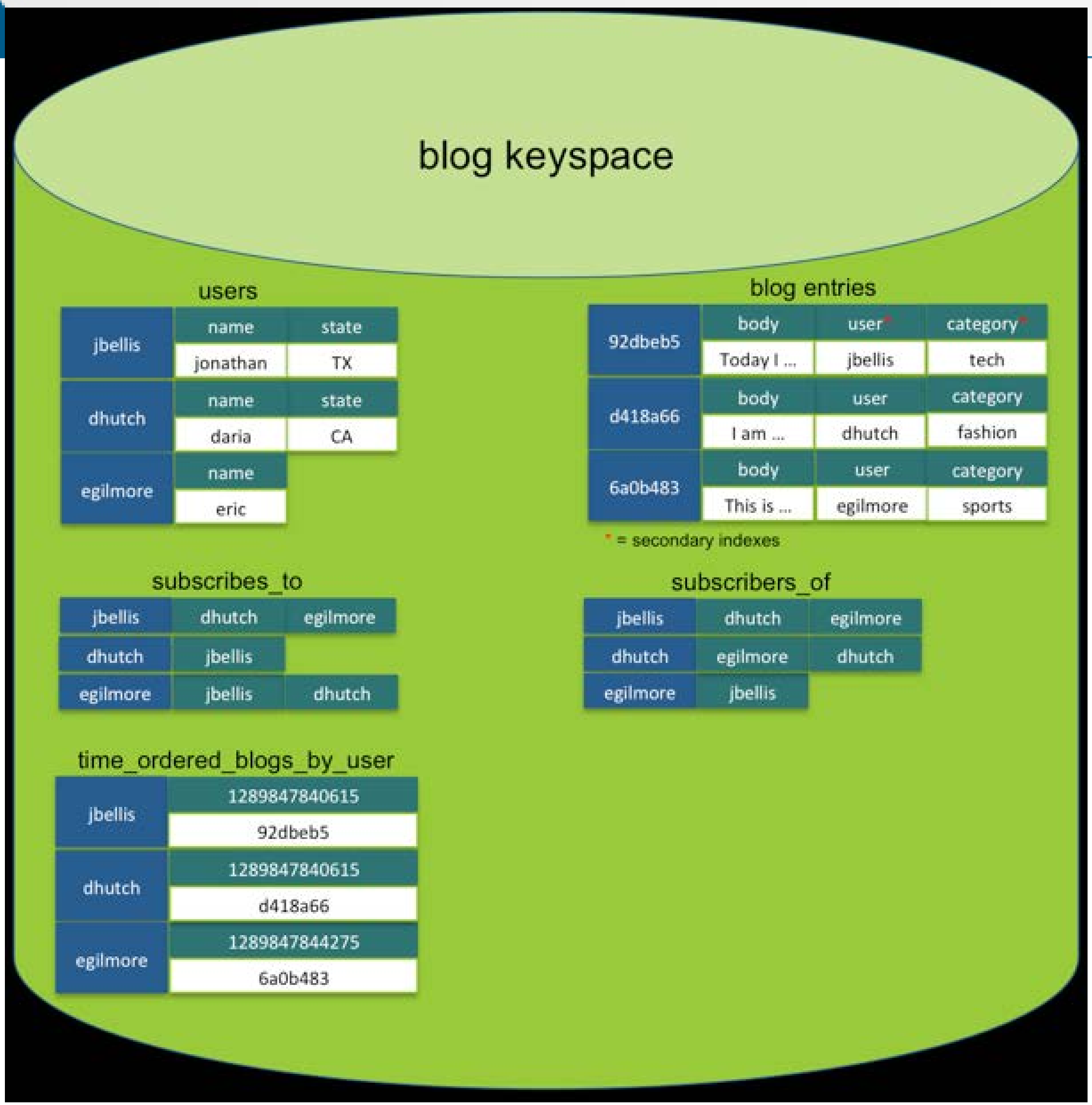


Example (Cassandra data model)

- Consider the relational DB



NoSQL Databases



- One or more *column family* objects, analogous to tables
- Identified by an application-supplied row *key*
- Each row in a column family is *not* required to have the same set of columns
- There are no formal foreign keys and joining column families at query time is not supported

Cassandra Query Language

Examples:

- INSERT INTO users (KEY, name, state) VALUES (‘jbellis’, ‘jonathan', ‘TX');
- Select * from users where KEY='jbellis';

DOCUMENT STORES

Document Stores

- Like Key-Value Stores except that “value” is a document
  - Data model: (key, document) pairs
  - Document: JSON, XML, other semistructured formats
  - Basic operations: Insert(key,document), Fetch(key), Update(key), Delete(key)
  - Also Fetch based on document contents

MongoDB example

A document representing a wiki article may look like the following in JSON notation:

```
{ title : " MongoDB " ,
  last_editor : "172.5.123.91" ,
  last_modified : new Date ("9/23/2010") ,
  body : " MongoDB is a ..." ,
  categories : [" Database " , " NoSQL " , " Document Database "] ,
  reviewed : false }
```

Insertion into a MongoDB collection:

```
db . < collection >. insert ( { title : " MongoDB " , last_editor : ... } ) ;
```

Retrieval examples:

```
db . < collection >. find ( { title : " MongoDB " ) ;
db . < collection >. find ({ categories : { $in : [" NoSQL " , " Document Databases "]} }) ;
db . < collection >. find ({ categories : { $all : [" NoSQL " , " Document Databases "]} }) ;
```

GRAPH DATABASES

Graph Database Systems

- Data model: nodes and edges
- Nodes may have properties (including ID)
- Edges may have labels or roles
- Interfaces and query languages vary

- Example systems
  - Neo4j, FlockDB, Pregel, ...

- Aim to manage:
  - Multi-valued and/or complex attributes (Violations of the 1NF)
  - Dynamic data → accommodate changes
  - Data and query in a uniform way (to facilitate learning and reasoning)

Database Representation

- Sailors(sid:integer, sname:char(10), rating: integer, age:real)
- Boats(bid:integer, bname:char(10), color:char(10))
- Reserve(sid:integer, bid:integer, day:date)

Sailors

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

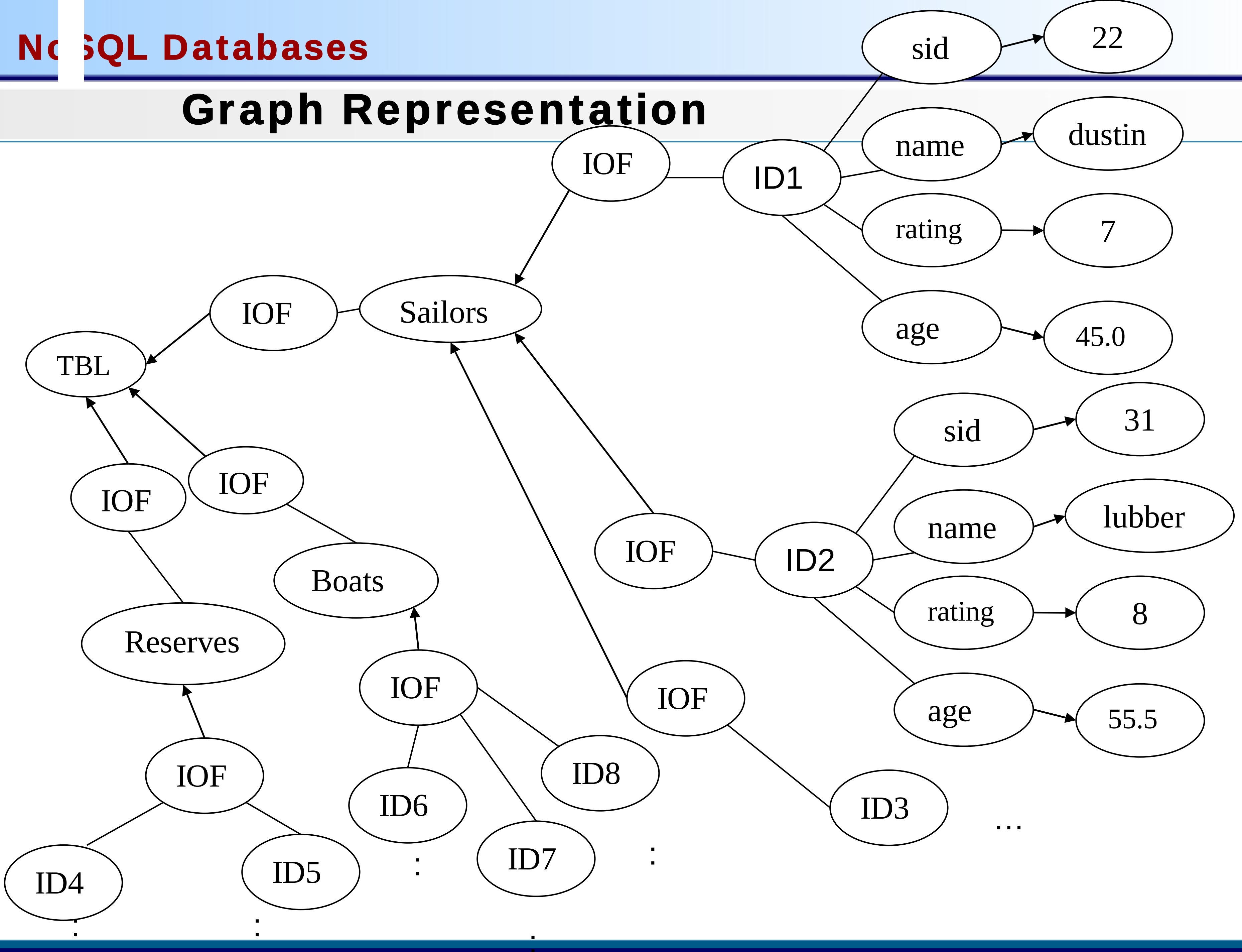
Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

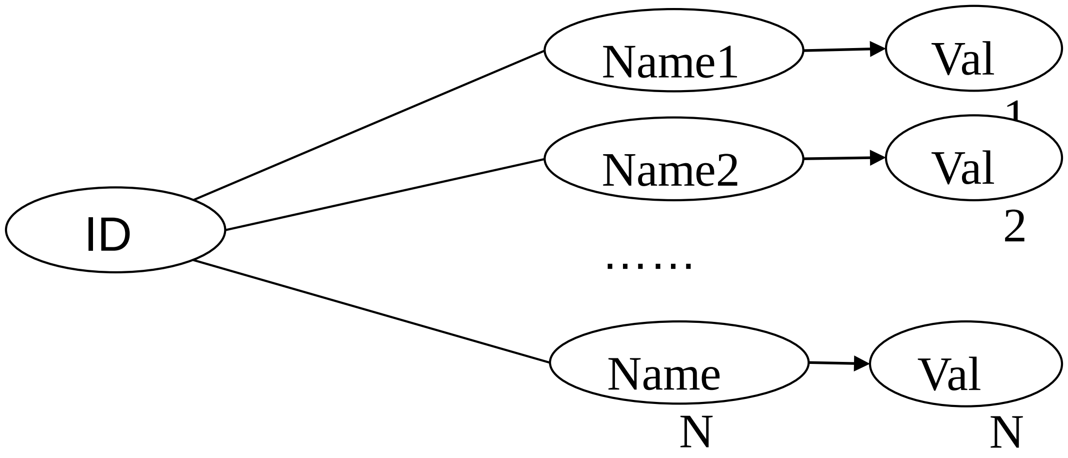
Boats

bid	bname	color
101	Interlake	red
102	Clipper	green
103	Marine	red

Graph Representation



Data Representation in the GDB DDL



- ID:(Name1=Val1,…,NameN=ValN)

Examples:

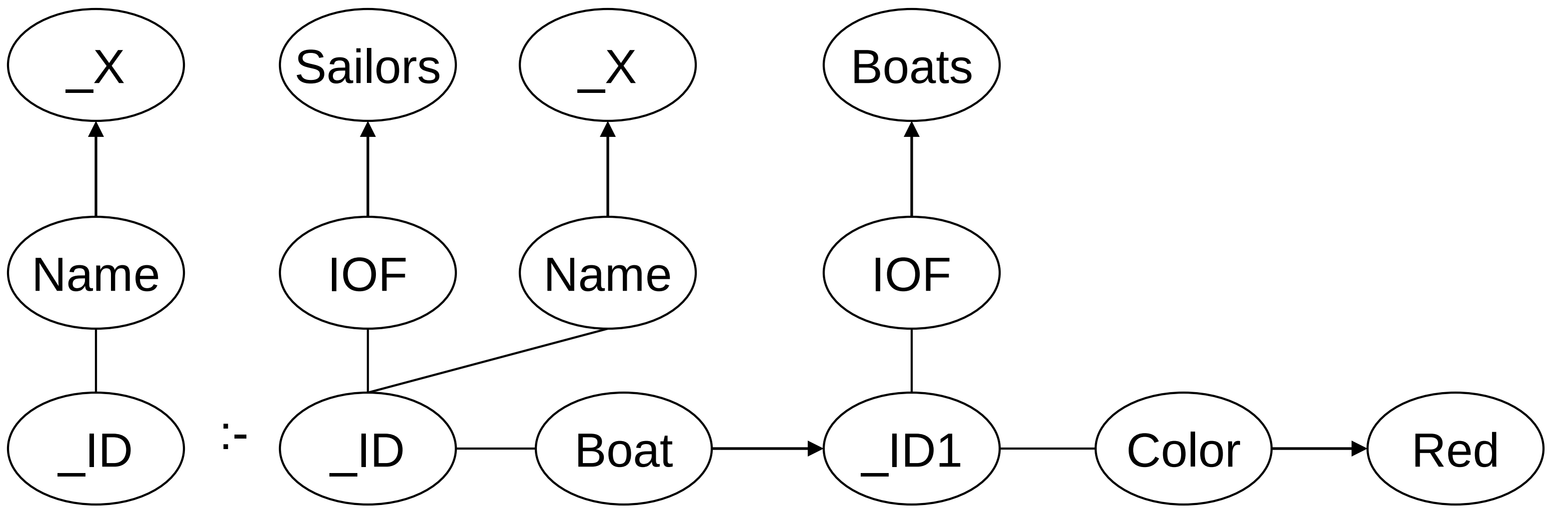
ID1:(sid=22, name=“Dustin”, rating=7, age=45.0)

ID4:(sailor=ID1, day=“10/10/96”, boat=ID6)

ID6:(bid=101, bname=“Interlake”, color=“red”)

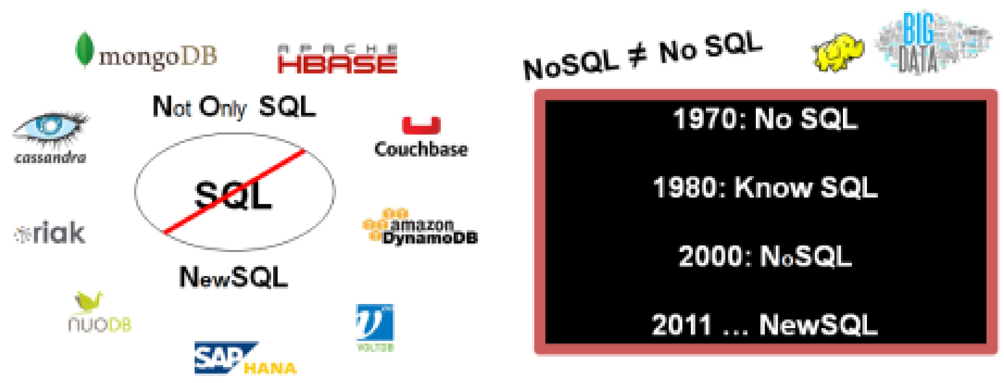
[DML-QL] Writing simple queries:

- The names of all sailors who have reserved a red boat



_ID:(Name = _X) :-
    _ID:(IOF = Sailors, Boat = _ID1, Name = _X),
    _ID1:(IOF = Boats, Color = Red).

The query is matched against the data graph



The evolving database landscape