# CS213
# Principles of Database Systems(H)

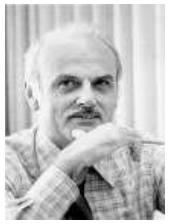
# Chapter 14

Shiqi YU 于仕琪

yusq@sustech.edu.cn

Most contents are from Yuxuan Ma's slides

# History of databases



**Pre-computer technologies:**

Printing press
Dewey decimal system
Punched cards

Magnetic tape
"flat" (sequential) files
Magnetic Disk
IDMS
ADABAS
System R
Oracle V2
Access
Postgres
MySQL
HBase
Dynamo
MongoDB
Redis
VoltDB
Neo4J

1940-50 | 1950-60 | 1960-70 | 1970-80 | 1980-90 | 1990-2000 | 2000-2010

Relational Model defined
IMS
Network Model
Hierarchical model
Indexed-Sequential Access Mechanism (ISAM)
SQL Server
Sybase
Informix
Ingres
DB2
dBase
Aerospike
Hana
Riak
Cassandra
Vertica
Hadoop

From Guy Harrison's slides

# Beyond Storage: Data Analytics

# What is Data (Revisited)

**data** noun, plural in form but singular or plural in construction, often attributive

Save Word

da·ta | \ ˈdā-tə, ˈda- *also* ˈdä- \

**Definition of *data***

**1** : factual information (such as measurements or statistics) used as a basis for reasoning, discussion, or calculation

// the *data* is plentiful and easily available
— H. A. Gleason, Jr.

// comprehensive *data* on economic growth have been published
— N. H. Jacoby

**2** : information in digital form that can be transmitted or processed

**3** : information output by a sensing device or organ that includes both useful and irrelevant or redundant information and must be processed to be meaningful

factual information (such as measurements or statistics) used as a basis for reasoning, discussion, or calculation

https://www.merriam-webster.com/dictionary/data

# Basic Statistical Descriptions

Overall picture of your data

Basis of exploratory data analysis

- Mean $$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} = \frac{x_1 + x_2 + \cdots + x_N}{N}.$$
- Median $$\mathrm{Q}_{\frac{1}{2}}(x) = \begin{cases} x'_{\frac{n+1}{2}}, & \text{if } n \text{ is odd.} \\ \frac{1}{2}(x'_{\frac{n}{2}} + x'_{\frac{n}{2}+1}), & \text{if } n \text{ is even.} \end{cases}$$
- Variance $$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2 = \left(\frac{1}{N}\sum_{i=1}^{N} x_i^2\right) - \bar{x}^2,$$

# Relationship between Data Objects: Data (Dis)Similarity

Measurement of relationships

- Commonly used in many statistical methods and data mining algorithms

Dissimilarity Matrix & Distance Measures

$$\begin{bmatrix} 0 & & & & \\ d(2,1) & 0 & & & \\ d(3,1) & d(3,2) & 0 & & \\ \vdots & \vdots & \vdots & & \\ d(n,1) & d(n,2) & \cdots & \cdots & 0 \end{bmatrix}$$

| | |
|---|---|
| Euclidean | $d(x,y) = \sqrt{\sum (x_i - y_i)^2}$ |
| Squared Euclidean | $d(x,y) = \sum (x_i - y_i)^2$ |
| Manhattan | $d(x,y) = \sum \lvert (x_i - y_i) \rvert$ |
| Canberra | $d(x,y) = \sum \frac{\lvert x_i - y_i \rvert}{\lvert x_i + y_i \rvert}$ |
| Chebychev | $d(x,y) = \max(\lvert x_i - y_i \rvert)$ |
| Bray Curtis | $d(x,y) = \frac{\sum \lvert x_i - y_i \rvert}{\sum x_i + y_i}$ |
| Cosine Correlation | $d(x,y) = \frac{\sum (x_i y_i)}{\sqrt{\sum (x_i)^2 \sum (y_i)^2}}$ |
| Pearson Correlation | $d(x,y) = \frac{\sum (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum (y_i - \overline{y})^2} \sqrt{\sum (y_i - \overline{y})^2}}$ |
| Uncentered Peason Correlation | $d(x,y) = \frac{\sum x_i y_i}{\sqrt{\sum (y_i - \overline{y})^2} \sqrt{\sum (y_i - \overline{y})^2}}$ |
| Euclidean Nullweighted | Same as Euclidean, but only the indexes where both x and y have a value (not NULL) are used, and the result is weighted by the number of values calculated. Nulls must be replaced by the missing value calculator (in dataloader). |

# What is Big Data?

A collection of data sets so large and complex

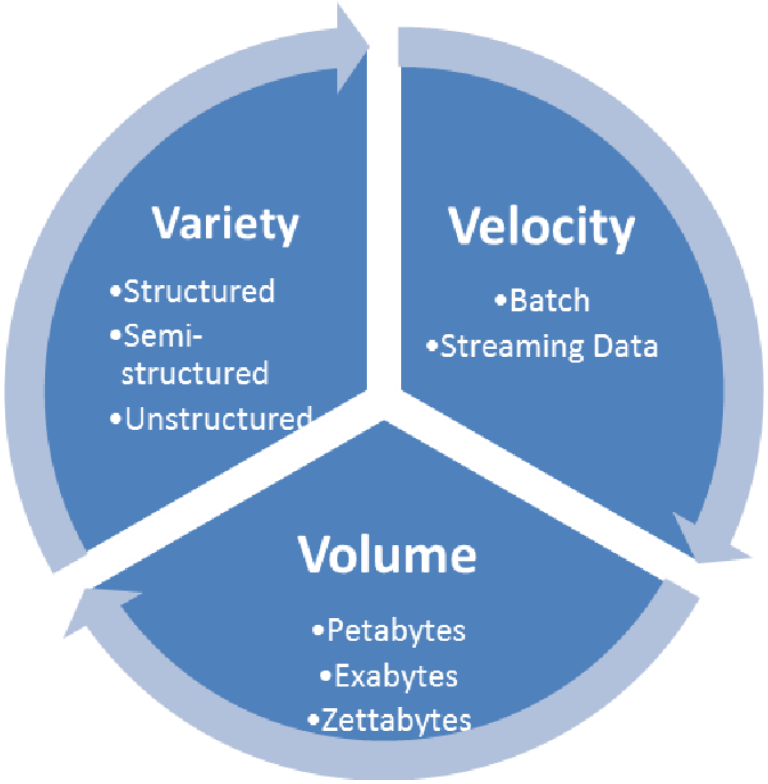
# Three Dimensions of Big Data

## Volume
- From GB to TB, PB, or higher

## Velocity
- Processing speed

## Variety
- Text, sensor data, multimedia, …

Other (new) aspects:
- Veracity: Trustworthiness
- Value: Worth of data



# World is changing faster and faster





George Chernilevsky


2005


2020
GLOBAL CITIZEN
ONE WORLD
TOGETHER AT HOME
GLOBAL CITIZEN
World Health Organization


2013
NBC NEWS
Michael Sohn / AP


2023

# The Emergence of Data Science

2016: “Trump vs. Clinton: How Big Data and scientists helped Trump win the election”

Digital campaigning

## The role of technology in the presidential election

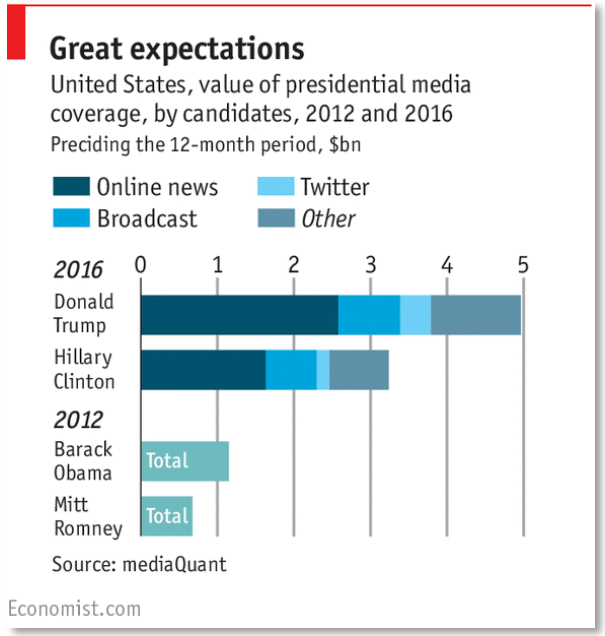
All latest updates

**From fake news to big data, a post mortem is under way**

Nov 20th 2016 | United States

Timekeeper Like 916 Tweet


EARLY in America’s presidential campaign, pundits compared the contest between Hillary Clinton and Donald Trump to a fight between a large tanker and Somali pirates. This turned out to be particularly true of the digital campaigns: a massive data battleship lost to a chaotic flotilla of social-media speedboats. The big question now is what this means for future elections, both in America and abroad.



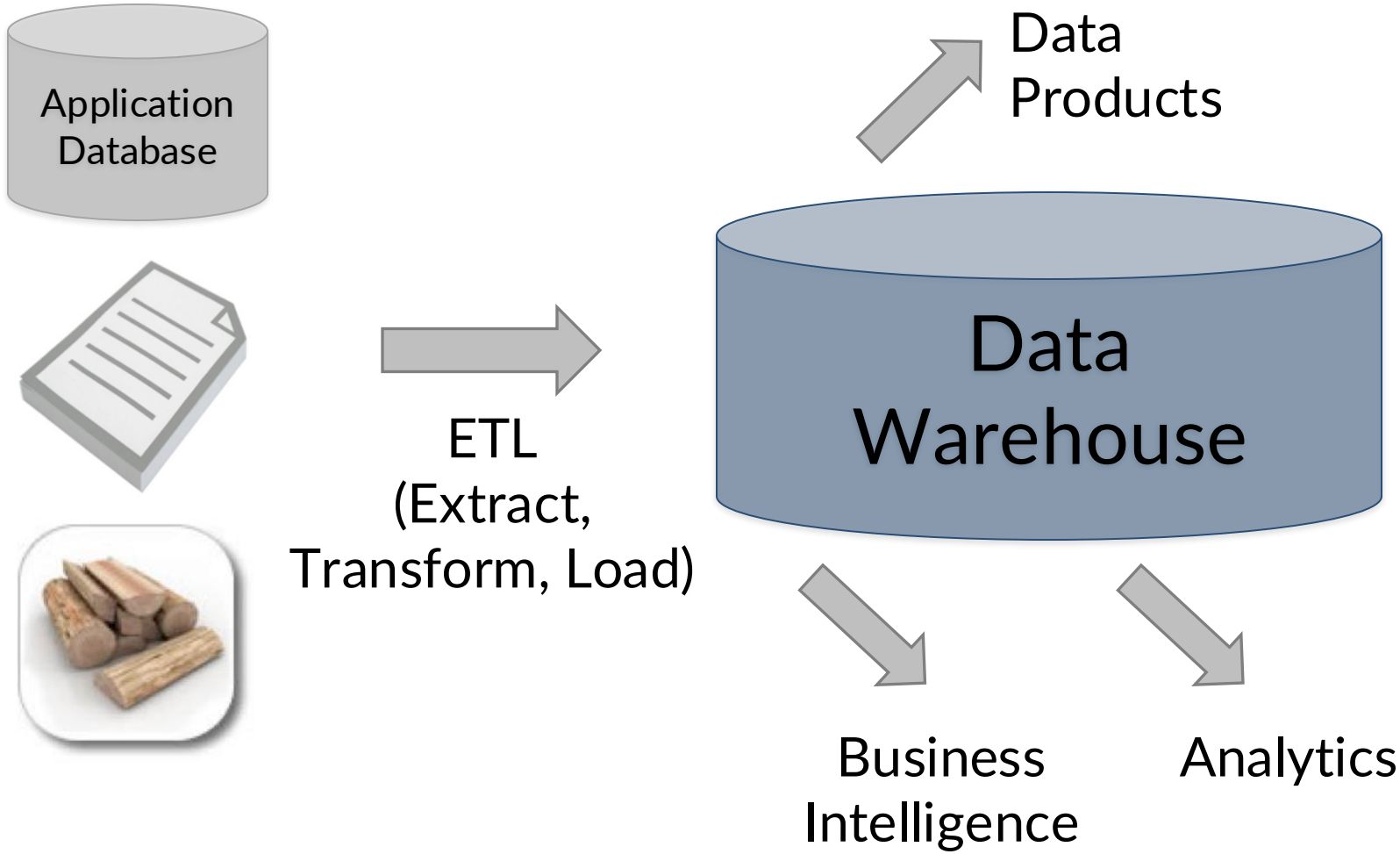
# Data source

Data provided by web sites.

Data generated by users

- Web logs
- Page view data
- Mobile apps, which is clicked, how long, etc.
- Data from sensors (IoT, shared bikes).
- User upload, posts, comments, like/dislike, video streaming, etc.

# Standard Architecture



# Instantiations(1) - Businesspersons

Data Sources
- Web pages
- Excel

Extract-Transform-Load (ETL)
- Copy & paste

Data Warehouse
- Excel

- BI and Analytics
  - Excel functions
  - Excel charts
  - VB scripts?
  - Visualization tools: Power BI, Tableau

# Instantiations(2) - Programmers

Data Sources

- Web scraping, web services API
- CSV files
- Database queries

ETL

- wget, curl, Beautiful Soup, lxml, …

- Data Warehouse
  - Files
- Analytics
  - Numpy, pandas, Matplotlib, R, Octave, …

# Instantiations(3) - Enterprises

Data Sources

- Application databases(Oracle, IBM, …)
- Intranet files
- Application log files

ETL

- Infomatica, IBM DataStage, …

- Data Warehouse
  - Teradata, Oracle, IBM DB2, …
- Business Intelligence & Analytics
  - SAS, SPSS, R, …
  - Power BI, Tableau, Spotfire, …

# Instantiations(4) – Web Companies

Data Sources

- Application databases
- Logs
- Web crawl data

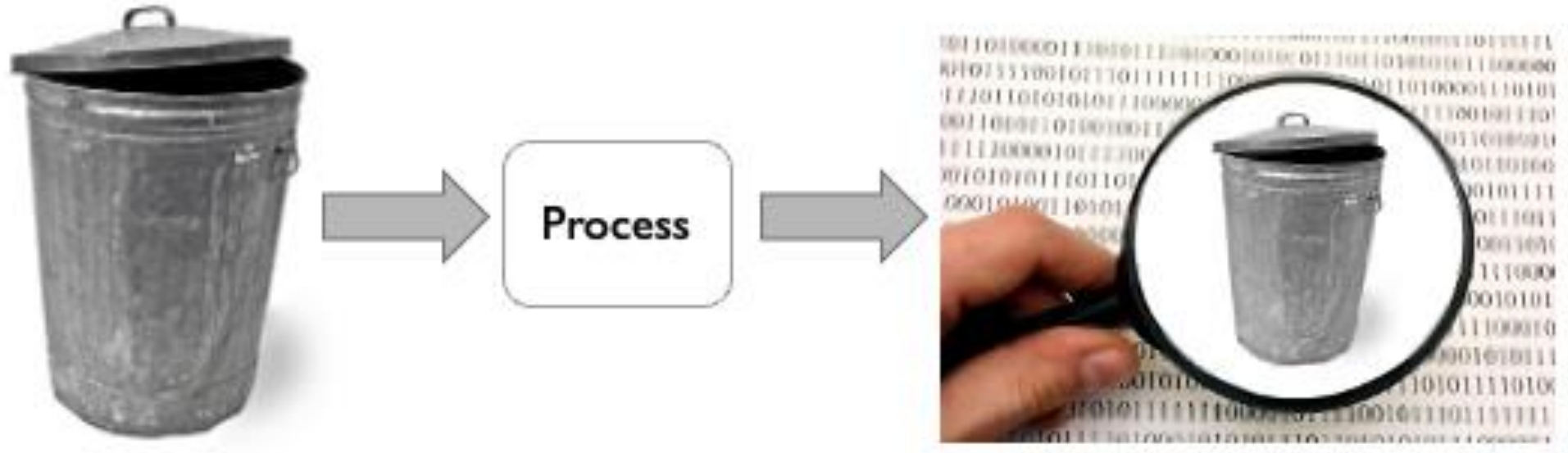
ETL

- Apache Flume, Apache Sqoop, …

- Data Warehouse
  - Hadoop-based: Hive, Hbase
  - Microsoft Azure, Amazon Redshift
- Business Intelligence & Analytics
  - Argus, R, …

# “Garbage in, garbage out.”

Raw data can always be **DIRTY**!



# Data Quality

Data quality: data has quality if it satisfies the requirements of its intended use

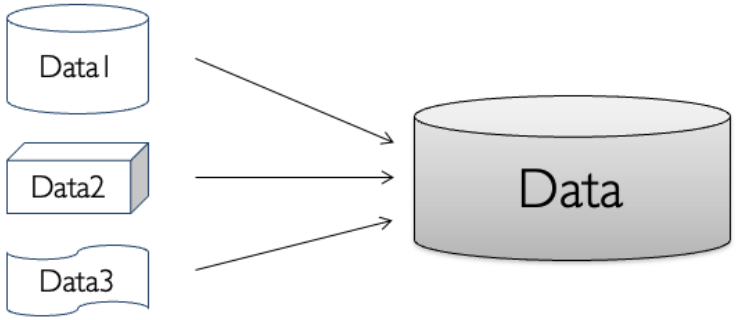
- Accuracy
- Completeness
- Consistency
- Timeliness
- Believability
- Interpretability

# Data Integration

Data integration involves combining data residing in different sources and providing users with a unified view of these data.

- Remember "views" in DBMS?

Management of data from n




***Customer*** (source 1)

| *CID* | *Name* | *Street* | *City* | *Sex* |
|---|---|---|---|---|
| 11 | Kristen Smith | 2 Hurley Pl | South Fork, MN 48503 | 0 |
| 24 | Christian Smith | Hurley St 2 | S Fork MN | 1 |

***Client*** (source 2)

| *Cno* | *LastName* | *FirstName* | *Gender* | *Address* | *Phone/Fax* |
|---|---|---|---|---|---|
| 24 | Smith | Christoph | M | 23 Harley St, Chicago IL, 60633-2394 | 333-222-6542 / 333-222-6599 |
| 493 | Smith | Kris L. | F | 2 Hurley Place, South Fork MN, 48503-5998 | 444-555-6666 |

***Customers*** (integrated target with cleaned data)

| *No* | *LName* | *FName* | *Gender* | *Street* | *City* | *State* | *ZIP* | *Phone* | *Fax* | *CID* | *Cno* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Smith | Kristen L. | F | 2 Hurley Place | South Fork | MN | 48503-5998 | 444-555-6666 | | 11 | 493 |
| 2 | Smith | Christian | M | 2 Hurley Place | South Fork | MN | 48503-5998 | | | 24 | |
| 3 | Smith | Christoph | M | 23 Harley Street | Chicago | IL | 60633-2394 | 333-222-6542 | 333-222-6599 | | 24 |

# Typical Data Cleaning and Integration Workflow

## Data analysis

- Detailed inspection before operations

## Conflicts resolution

- Resolve data confliction between data sources to be integrated

## Definition of transformation workflow and mapping rules

- Workflow methods for schema adaption and transformation

## Verification of  Workflow

- Verify each steps

## Transformation

- start the process

# Load and Store Data

File-based Storage

- Simplest way & easy to manage
- Scalability is low

**Database & DBMS**

- What we have learned for 10+ weeks

Data Warehouse

# Data Warehouse

A data warehouse is a **subject-oriented**, **integrated**, **time-varient**, and **nonvolatile** collection of data in support of management's decision making process.

*-- W. H. Inmon, "Building the Data Warehouse". 1996.*

Loosely Speaking, a data warehouse refers to a data repository that is **maintained separately** from an organization's operational databases.

*-- J. Han and M. Kamber, "Data Mining: Concepts and Techniques", 3rd ed., 2011.*

# Differences between Databases and Data Warehouses

| | DB | DW |
|---|---|---|
| *Characteristics* | operational processing | informational processing |
| *Orientation* | transaction | analysis |
| *User* | terminal users: clerk, database administrator(DBA) | knowledge workers: manager, analyst, executive |
| *Function* | everyday operations | long-term informational requirements decision support |
| *Data* | current, up-to-date | historic, accuracy maintained over time |
| *Access* | read/write | mostly read |
| *Focus* | data in | information/knowledge out |
| *Size* | GB to high-order GB | >=TB |

# Data Analysis

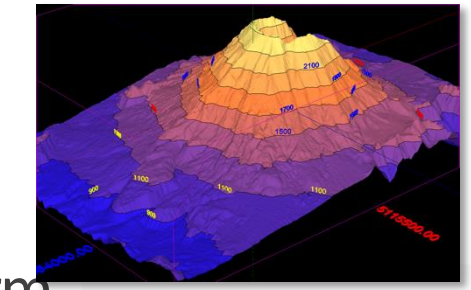
Exploratory Data Analysis

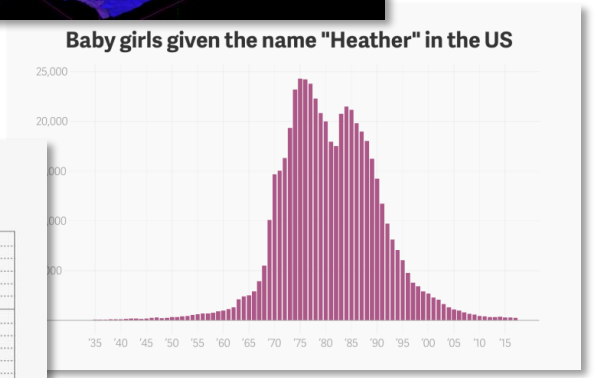
Data Mining

# Exploratory Data Analysis (EDA)

Based on statistics

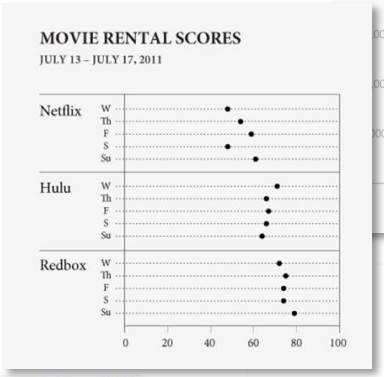
- Data visualization-driven method
- Summary of main characteristics in easy-to-understand form

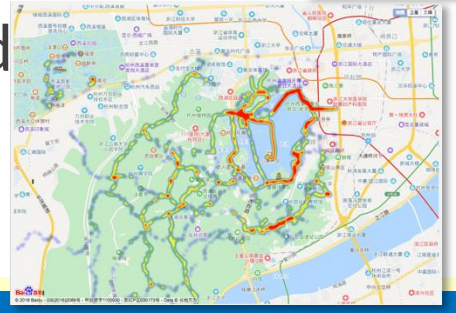


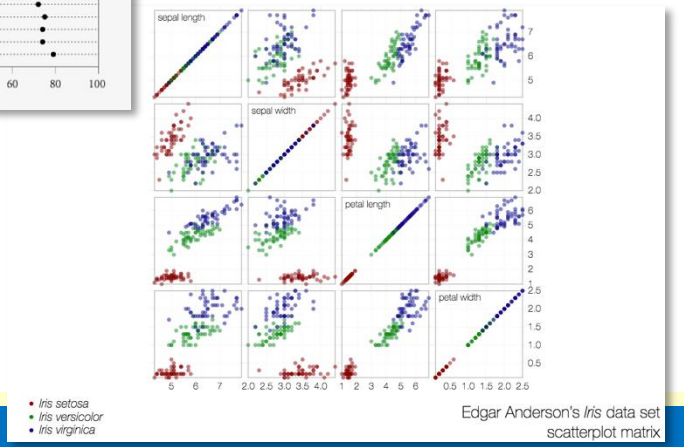



Types of data visualization methods in EDA:

- Plotting of raw data
- Plotting of statistical values
- Multiple coordinated views (Dashboard



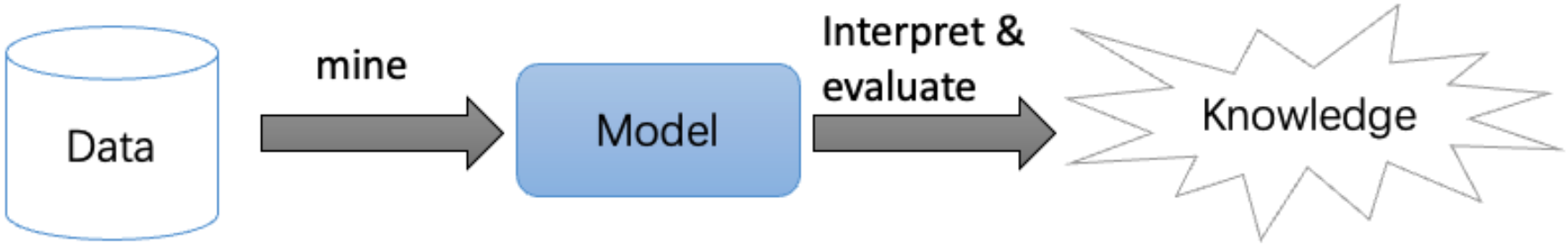





# Data Mining

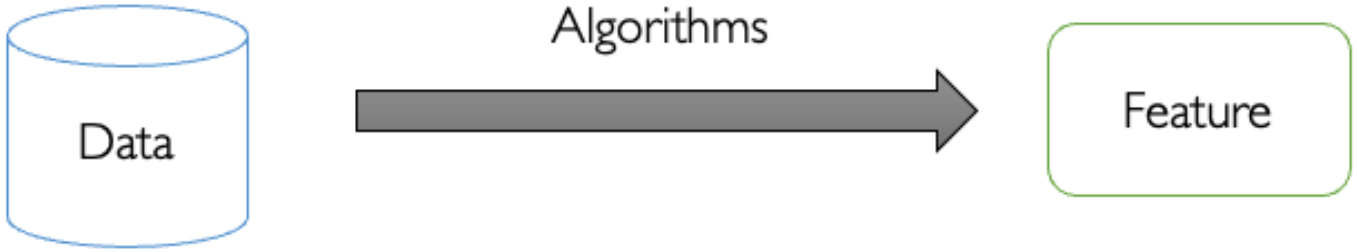
"Data Mining, also popularly referred to as knowledge discovery from data (KDD), is the automated or convenient extraction of patterns representing knowledge implicitly stored or captured in large databases, data warehouses, the Web, other massive repositories, or data streams."

*-- H. Jiawei and M. Kamber, "Data Mining: Concepts and Techniques", 3rd ed., 2011.*

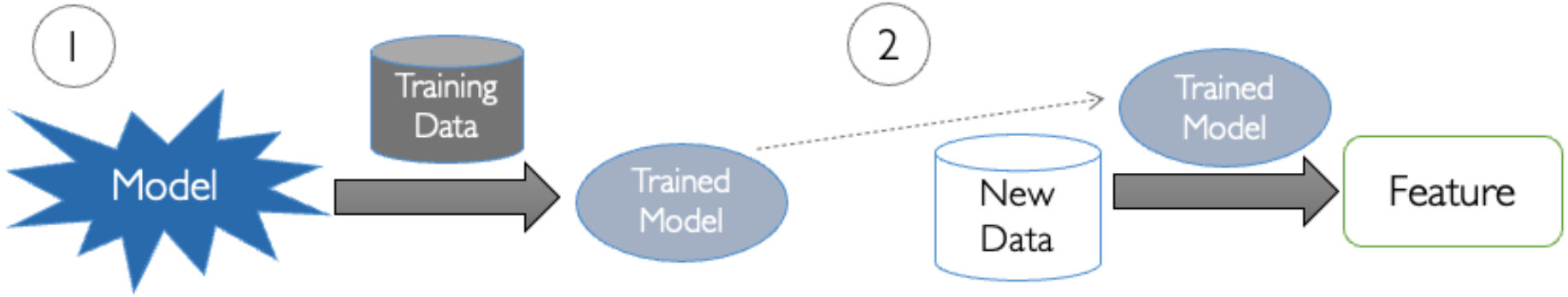


# Tasks in Data Mining

## Descriptive Tasks




## Predictive T



# Descriptive Tasks

## Concept Description

- Describe features of data directly

## Association Analysis

- Analyze “feature-value” pairs that occur frequently in data

## Clustering

- Group data on the principle of maximizing the intra-class similarity and minimizing the inter-class similarity

## Outlier Detection

- Analyze objects that do not comply with the general behavior or model of the data

# Predictive Tasks

## Regression

- Model the relationship between a scalar response and a number of variables

## Classification

- Find a model/function that describes and distinguish data classes or concepts based on analysis of a set of training data

## Evolution Analysis

- Analyze temporal and spatial patterns in dataset, model these patterns and predict data in unknown spatio-temporal positions

# Data Visualization

- Visualization is the creation and study of the visual representation of data

**Input**: data

**Output**: visual form

**Goal**: insight

# Why Do We Need Visualization?

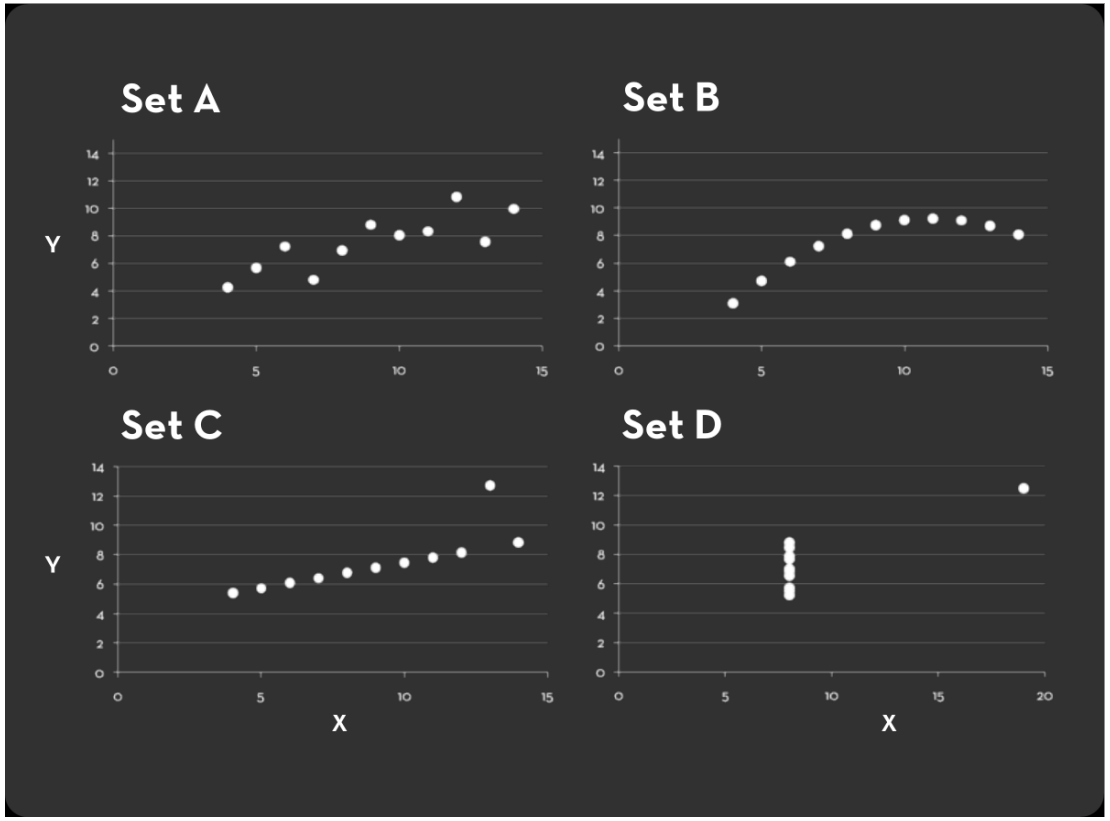
Sometimes, statistics may not work

| Set A | | Set B | | Set C | | Set D | |
|---|---|---|---|---|---|---|---|
| X | Y | X | Y | X | Y | X | Y |
| 10 | 8.04 | 10 | 9.14 | 10 | 7.46 | 8 | 6.58 |
| 8 | 6.95 | 8 | 8.14 | 8 | 6.77 | 8 | 5.76 |
| 13 | 7.58 | 13 | 8.74 | 13 | 12.74 | 8 | 7.71 |
| 9 | 8.81 | 9 | 8.77 | 9 | 7.11 | 8 | 8.84 |
| 11 | 8.33 | 11 | 9.26 | 11 | 7.81 | 8 | 8.47 |
| 14 | 9.96 | 14 | 8.1 | 14 | 8.84 | 8 | 7.04 |
| 6 | 7.24 | 6 | 6.13 | 6 | 6.08 | 8 | 5.25 |
| 4 | 4.26 | 4 | 3.1 | 4 | 5.39 | 19 | 12.5 |
| 12 | 10.84 | 12 | 9.11 | 12 | 8.15 | 8 | 5.56 |
| 7 | 4.82 | 7 | 7.26 | 7 | 6.42 | 8 | 7.91 |
| 5 | 5.68 | 5 | 4.74 | 5 | 5.73 | 8 | 6.89 |

**Summary Statistics**
$u_X = 9.0$ $\sigma_X = 3.317$
$u_Y = 7.5$ $\sigma_Y = 2.03$

**Linear Regression**
$Y = 3 + 0.5\ X$
$R^2 = 0.67$

[Anscombe 73]



# A Guide to NoSQL Databases

Traversy Media@YouTube

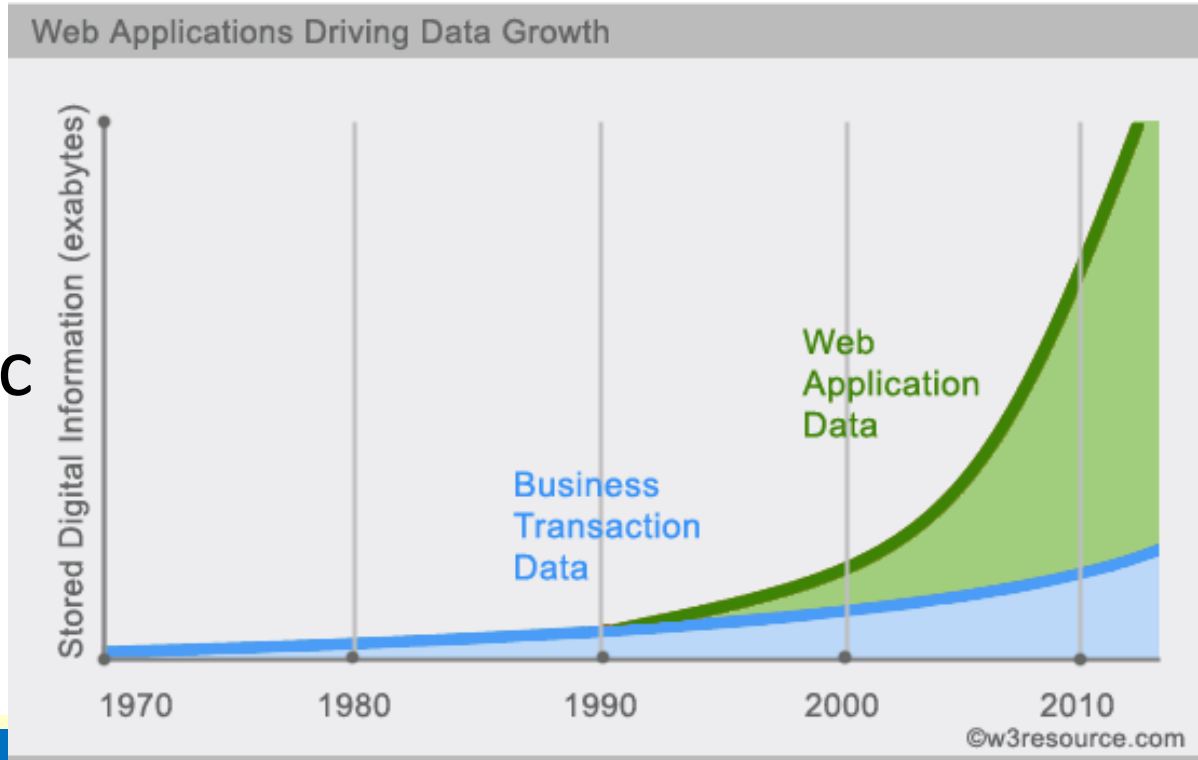
https://www.youtube.com/watch?v=uD3p_rZPBUQ

# What is NoSQL?

- Stands for “NOT ONLY SQL”
- A **Non-Relational** database (No Tables)
- A flexible database used for **big data** & **real-time** web apps
- Multiple types of NoSQL databases

# What is Big Data?

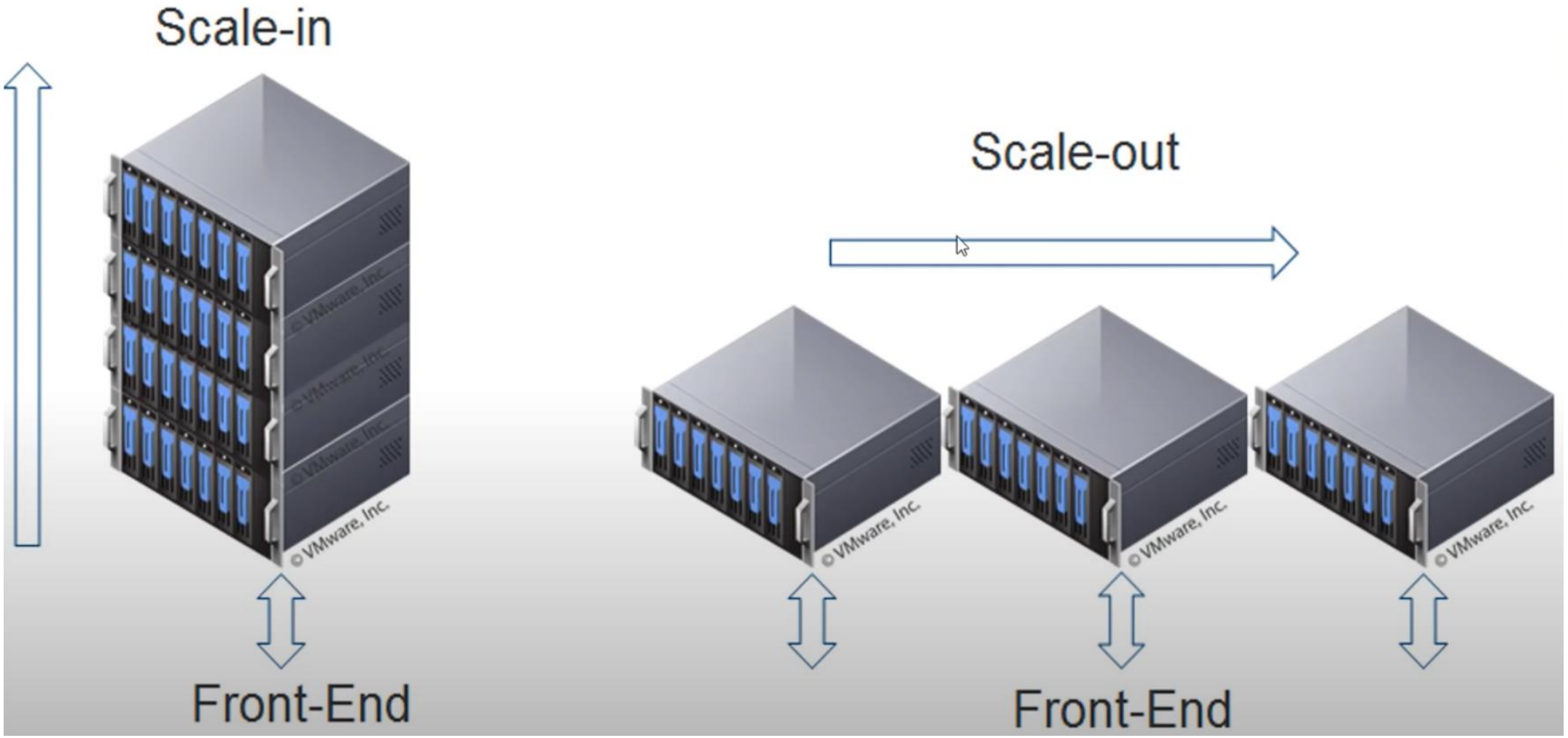
- A term for data sets that are so large that traditional methods of storage & processing are inadequate.
- Massive increase in data volume within the last decade or so
- Social networks, search engines, etc
- Challenges in storage, capture, analysis, transfer, etc



# Advantages of NoSQL over RDBMS

- Handles Big Data
- Data Models – No predefined schema
- Data Structure – NoSQL handles unstructured data
- Cheaper to manage
- Scaling – Scale out / horizontal scaling

# Scale Out vs Scale UP



# Advantages of RDBMS over NoSQL

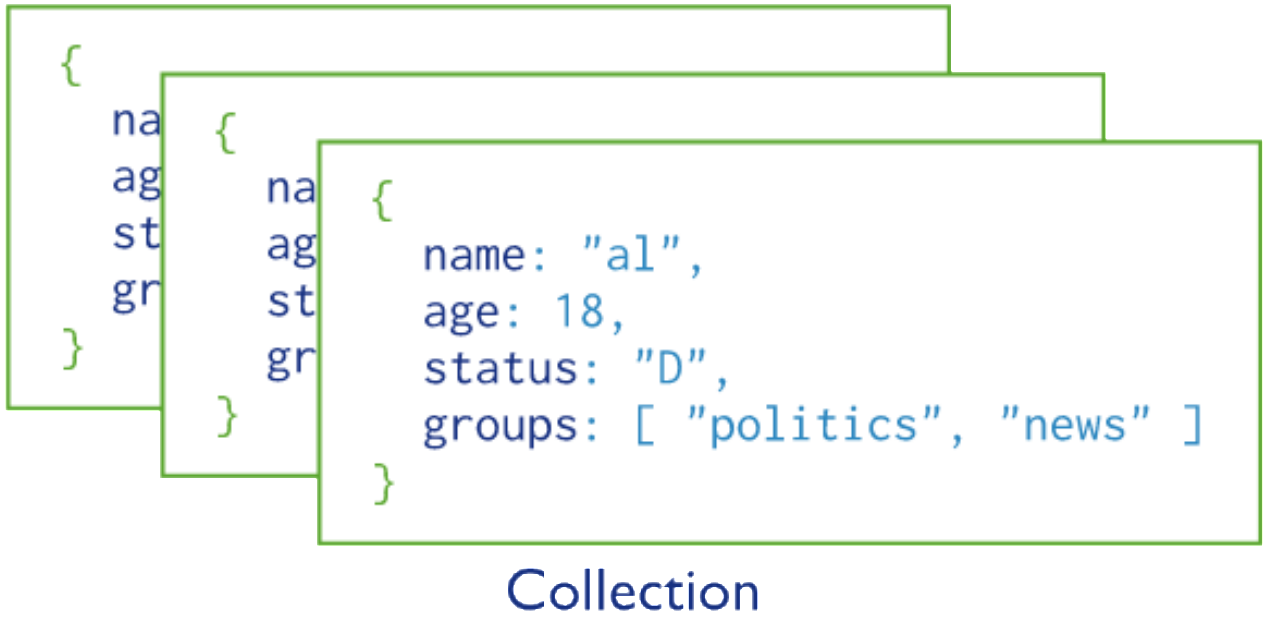
- Better for relational data
- Normalization
- Well known language (SQL)
- Data Integrity
- ACID Compliance (atomicity, consistency, isolation, durability)

# Types of NoSQL Databases

- Document Databases [MongoDB, CouchDB]
- Column Databases [Apache Cassandra]
- Key-Value Stores [Redis, Couchbase Server]
- Cache Systems [Redis, Memcache]
- Graph Databases [Neo4]

# MongoDB examples

- MongoDB stores documents in collections. Collections are analogous to tables in relational databases.
- Data is stored in json files.




https://docs.mongodb.com/manual/core/databases-and-collections/

# Beyond Tables: More Data Types

# Semi-Structured Data

Many applications require storage of complex data, whose schema changes often

The relational model's requirement of atomic data types may be **an overkill**

- E.g., storing set of interests as a set-valued attribute of a user profile may be simpler than normalizing it

Data exchange can benefit greatly from semi-structured data

- Exchange can be between applications, or between back-end and front-end of an application
- Web-services are widely used today, with complex data fetched to the front-end and displayed using a mobile app or JavaScript

**JSON** and **XML** are widely used semi-structured data models

# Features of Semi-Structured Data Models

Flexible schema

- Wide column representation: allow each tuple to have a different set of attributes, can add new attributes at any time
- Sparse column representation: schema has a fixed but large set of attributes, by each tuple may store only a subset

# Features of Semi-Structured Data Models

Multivalued data types

- Sets, multisets
  - E.g.,: set of interests: `{"basketball", "cooking", "anime", "jazz"}`
- Key-value map (or just map for short)
  - Store a set of key-value pairs
  - E.g.,
    - `{(brand, Apple), (ID, MacBook Air), (size, 13), (color, silver)}`
  - Operations on maps
    - `put(key, value)`
    - `get(key)`
    - `delete(key)`

# Features of Semi-Structured Data Models

Arrays

- Widely used for scientific and monitoring applications
- E.g., readings taken at regular intervals can be represented as array of values instead of (time, value) pairs
  - [5, 8, 9, 11] instead of {(1,5), (2, 8), (3, 9), (4, 11)}

Array database: a database that provides specialized support for arrays

- E.g., compressed storage, query language extensions, etc.
- Oracle GeoRaster, PostGIS, SciDB, etc

# Nested Data Types

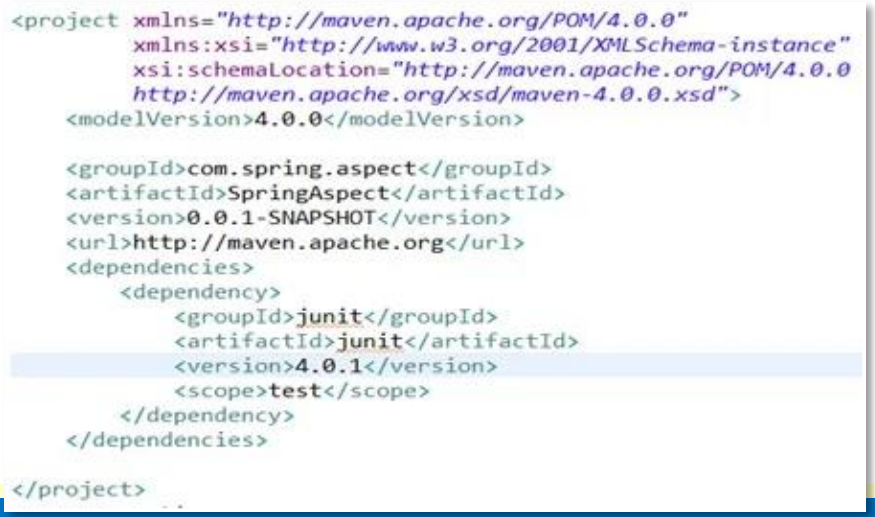
Hierarchical data is common in many applications

**JSON** (JavaScript Object Notation)

- Widely used today

**XML** (eXtensible Markup Language)

- Earlier generation notation, still used extensively

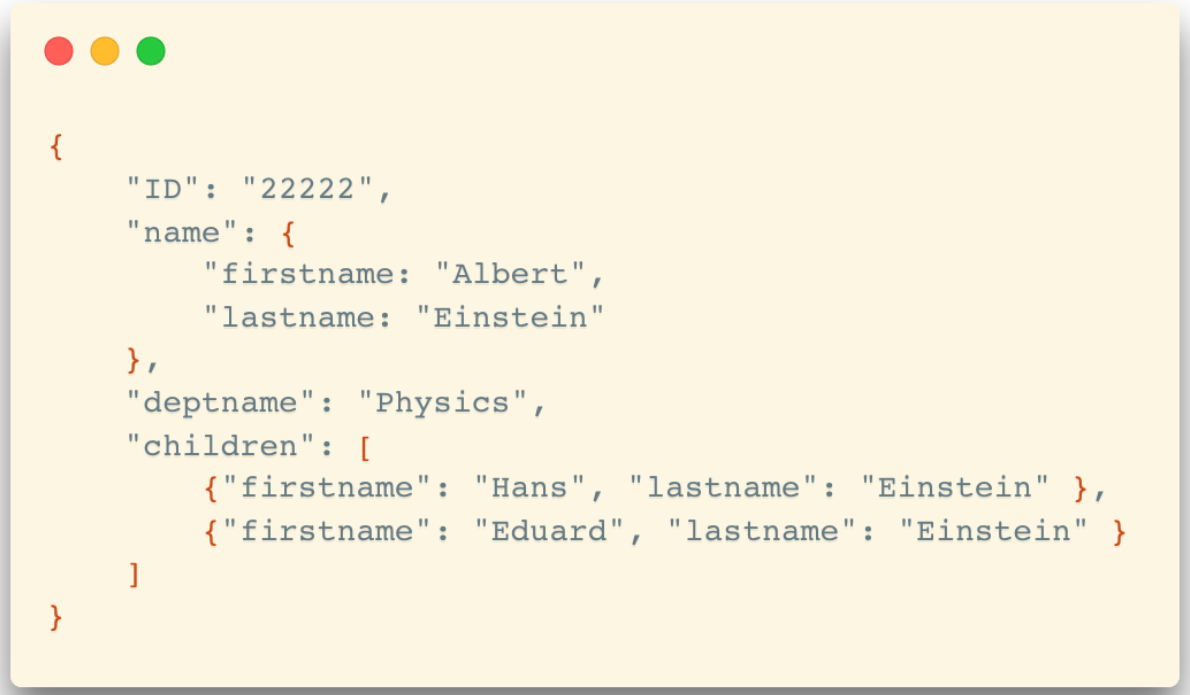



# JSON

Textual representation widely used for data exchange

Types: integer, real, string, and

- Objects: key-value maps, i.e. sets of (attribute name, value) pairs
- Arrays: also key-value maps (from offset to value)



# JSON

JSON is ubiquitous in data exchange today

- Widely used for web services
  - Most modern applications are architected around on web services

PostgreSQL supports JSON format columns

```
create table json_test (
    id serial not null primary key,
    student json not null
);

insert into json_test (student) values ('{"name": "aaa", "age": 20, "major": {"primary": "cs", "minor":
"math"}}');
insert into json_test (student) values ('{"name": "bbb", "major": {"primary": "math", "minor": "physics"}}');
insert into json_test (student) values ('{"name": "ccc", "age": 19, "major": {"primary": "biology"}}');
```

# JSON

JSON is ubiquitous in data exchange today

- Widely used for web services
  - Most modern applications are architected around on web services

PostgreSQL supports JSON format columns

```
-- select all content from the column
select * from json_test;

-- select a value of a key with "->"
select student -> 'major' -> 'minor' from json_test;
```

| | id | student |
|---|---|---|
| 1 | 1 | {"name": "aaa", "age": 20, "major": {"primary": "cs", "minor": "math"}} |
| 2 | 2 | {"name": "bbb", "major": {"primary": "math", "minor": "physics"}} |
| 3 | 3 | {"name": "ccc", "age": 19, "major": {"primary": "biology"}} |

| | ?column? |
|---|---|
| 1 | "math" |
| 2 | "physics" |
| 3 | <null> |

# XML

XML uses tags to mark up text

- Tags make the data self-documenting
- Tags can be hierarchical

```
<course>
    <course id>CS-101</course id>
    <title>Intro. to Computer Science</title>
    <dept name>Comp. Sci.</dept name>
    <credits>4</credits>
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# Textual Data

Information retrieval: querying of unstructured data

- Simple model of keyword-based queries
  - Given query keywords, retrieve documents containing all the keywords
- More advanced models rank relevance of documents
- Today, keyword queries return many types of information as answers
  - E.g., a query “cricket” typically returns information about ongoing cricket matches

Relevance ranking

- Essential since there are usually many documents matching keywords

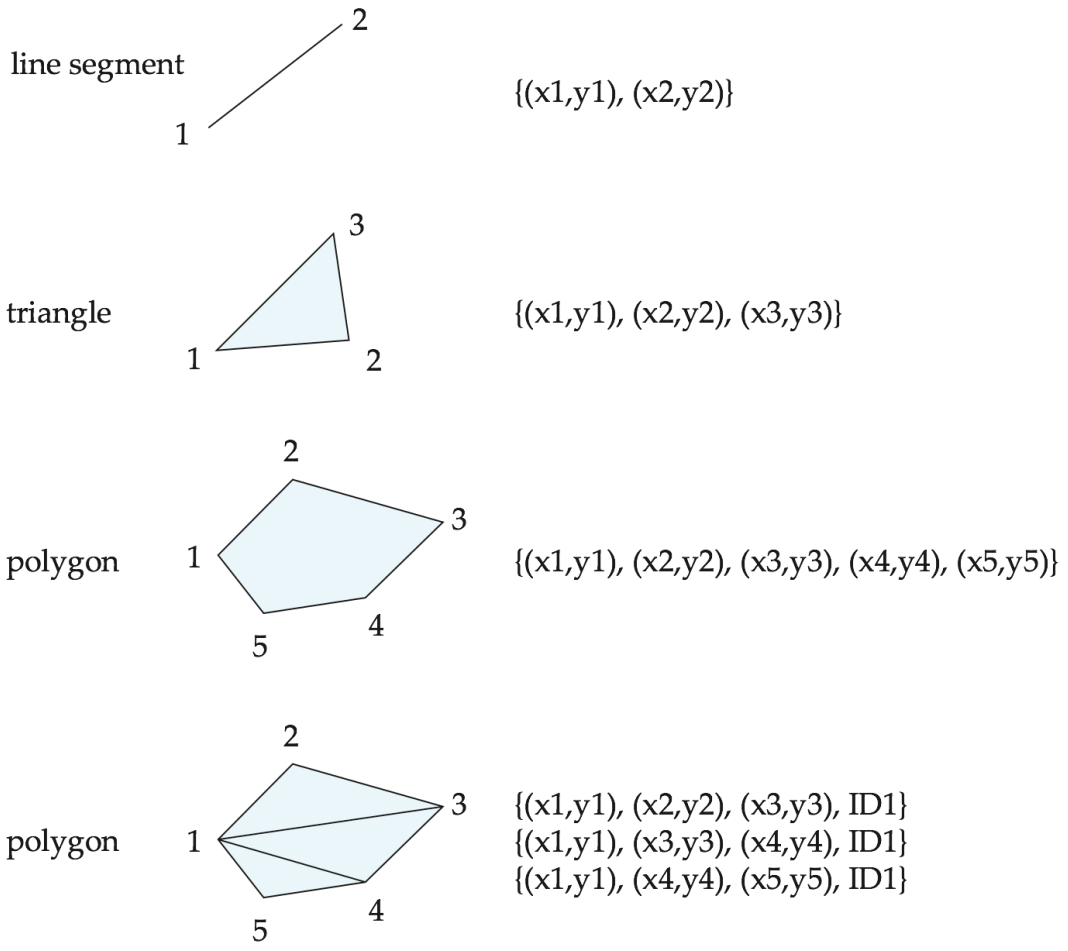
# Spatial Data

**Spatial databases** store information related to spatial locations, and support efficient storage, indexing and querying of spatial data.

- **Geographic data**: road maps, land-usage maps, topographic elevation maps, political maps showing boundaries, land-ownership maps, and so on.
  - Geographic information systems (GIS) are special-purpose databases tailored for storing geographic data.
  - Round-earth coordinate system may be used
    - (Latitude, longitude, elevation)
- **Geometric data**: design information about how objects are constructed
  - E.g., designs of buildings, aircraft, layouts of integrated-circuits.
  - 2 or 3 dimensional Euclidean space with (X, Y, Z) coordinates

# Representation of Geometric Information

Various geometric constructs can be represented in a database in a normalized fashion



# NoSQL Database

"Not Only SQL"

- Useful when working with a huge quantity of data when nature of data does not require a relational model
- Usually not built on tables and queried by SQL

Examples

- Document store – MongoDB
- Graph structure – Neo4j
- Key-value storage – Redis, LevelDB
- Tabular – Apache Hbase (Hadoop-based)

# Beyond PostgreSQL: More DBMS

# Commercial & Open-Source Solutions

Commercial Relational DBMS:

Oracle Database

Microsoft SQL Server

IBM DB2

…

Open-Source Counterparts:

- MySQL (MariaDB)
- PostgreSQL
- …

# Commercial & Open-Source Solutions

Factors to consider open-source databases

- Cost
  - Open-source databases are generally free
- Customizability
  - Add your own features in the source code
- Community support
  - Documentations, bug fixes, discussions

# Commercial & Open-Source Solutions

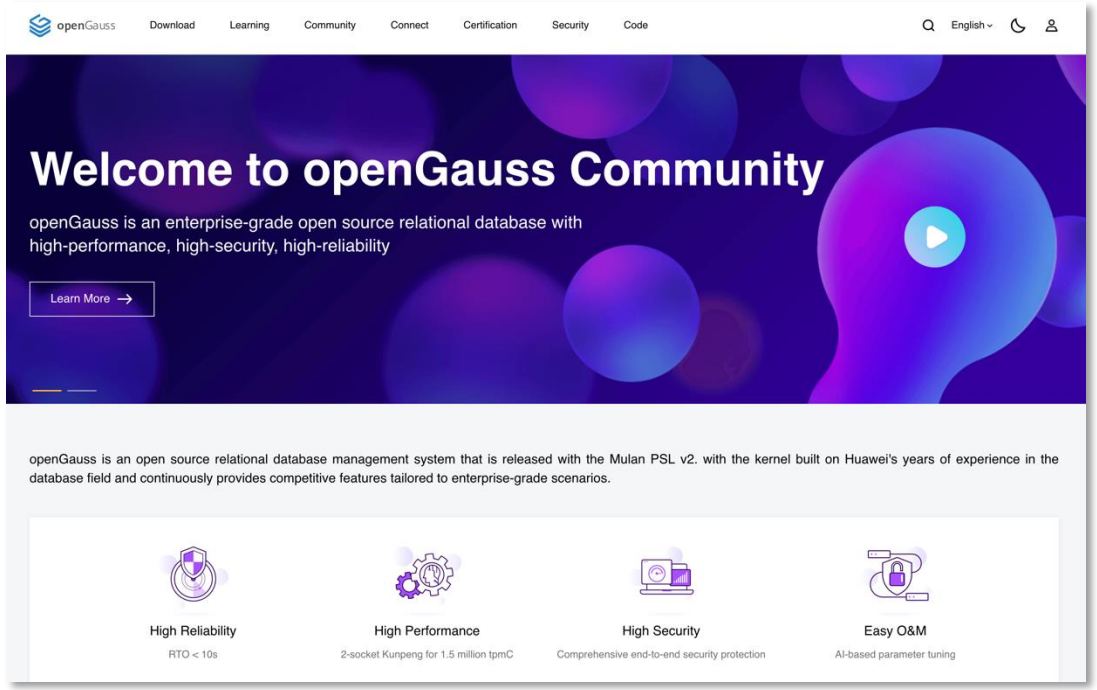
Factors to consider commercial databases

- Technical support
  - Guaranteed professional services
- Usability
  - Generally easier to deploy and use
  - Can be seamlessly integrated into other commercial products
- Feature support
  - Enterprise-level feature extension (More functions, useful SQL syntax, etc.)

# openGauss

Relational DBMS from Huawei

- Enterprise-grade open-source relational database
- Client-server architecture
- High-performance, high-reliability, high-security
- Community support
- * Compatible to PostgreSQL clients




https://www.opengauss.org/en/

# Key Differences between openGauss and PostgreSQL

originated from PostgreSQL-XC (eXtensible Cluster)

Fundamental differences in the architecture and key technologies, especially in the storage engine and query optimizer

| 关键差异化因素 | | openGauss | PostgreSQL |
|---|---|---|---|
| 运行时模型 | 执行模型 | 线程池模型，高并发连接切换代价小、内存损耗小，执行效率高，一万并发连接比最优性能损耗<5%。 | 进程模型，数据库进通过共享内存实现通讯和数据共享。每个进程对应一个并发连接，存在切换性能损耗，导致多核扩展性问题。 |
| 事务处理 | 并发控制 | 64位事务ID，使用CSN解决动态快照膨胀问题;<br>NUMA-Aware引擎优化改造解决“五把大锁。 | 事务ID回卷，长期运行性能因为ID回收周期大幅波动；存在“五把大锁”的问题，导致事务执行效率和多处理器多核扩展性存在瓶颈。 |
| | 日志和检查点 | 增量Checkpoint机制，实现性能波动<5%。 | 全量checkpoint，性能短期波动>15%。 |
| | 鲲鹏NUMA | NUMA改造、cache-line padding、原生spin-lock。 | NUMA多核能力弱，单机两路性能TPMC <60w。 |
| 数据组织 | 多引擎 | 行存、列存、内存引擎，在研DFV存储和原位更新。 | 仅支持行存。 |
| SQL引擎 | 优化器 | 支持SQL Bypass, CBO吸收工行等企业场景优化能力。 | 支持CBO，复杂场景优化能力一般。 |
| | SQL解析 | ANSI/ISO标准SQL92、SQL99和SQL2003<br>和企业扩展包。 | ANSI/ISO标准SQL92、SQL99和SQL2003。 |

# Key Differences between openGauss and PostgreSQL

originated from PostgreSQL-XC (eXtensible Cluster)

Fundamental differences in the architecture and key technologies, especially in the storage engine and query optimizer

| | **openGauss** | **PostgreSQL** |
|---|---|---|
| *Execution Model* | Thread pool-based (higher concurrency performance) | Process-based |
| *Data Organization* | Multiple engines: Row-oriented, column-oriented, in-memory storage | Only row-oriented |
| *SQL Optimization* | More complex enterprise-level optimization | Cost-based optimization |
| *SQL Parsing* | ANSI/ISO SQL92, SQL99, SQL2003 w/ enterprise-level extensions | ANSI/ISO SQL92, SQL99, SQL2003 |

Intricity101@YouTube

1. What is Hodoop
2. What is Hadoop: SQL Comparison
3. What is Hadoop: Why it scales
4. What is a Data Lake
5. What is NoSQL
6. Why Hadoop is Dying
7. Why born in the cloud matters

What will be the next?