Principles of Database Systems (CS307)

Lecture 15: Advanced Topics

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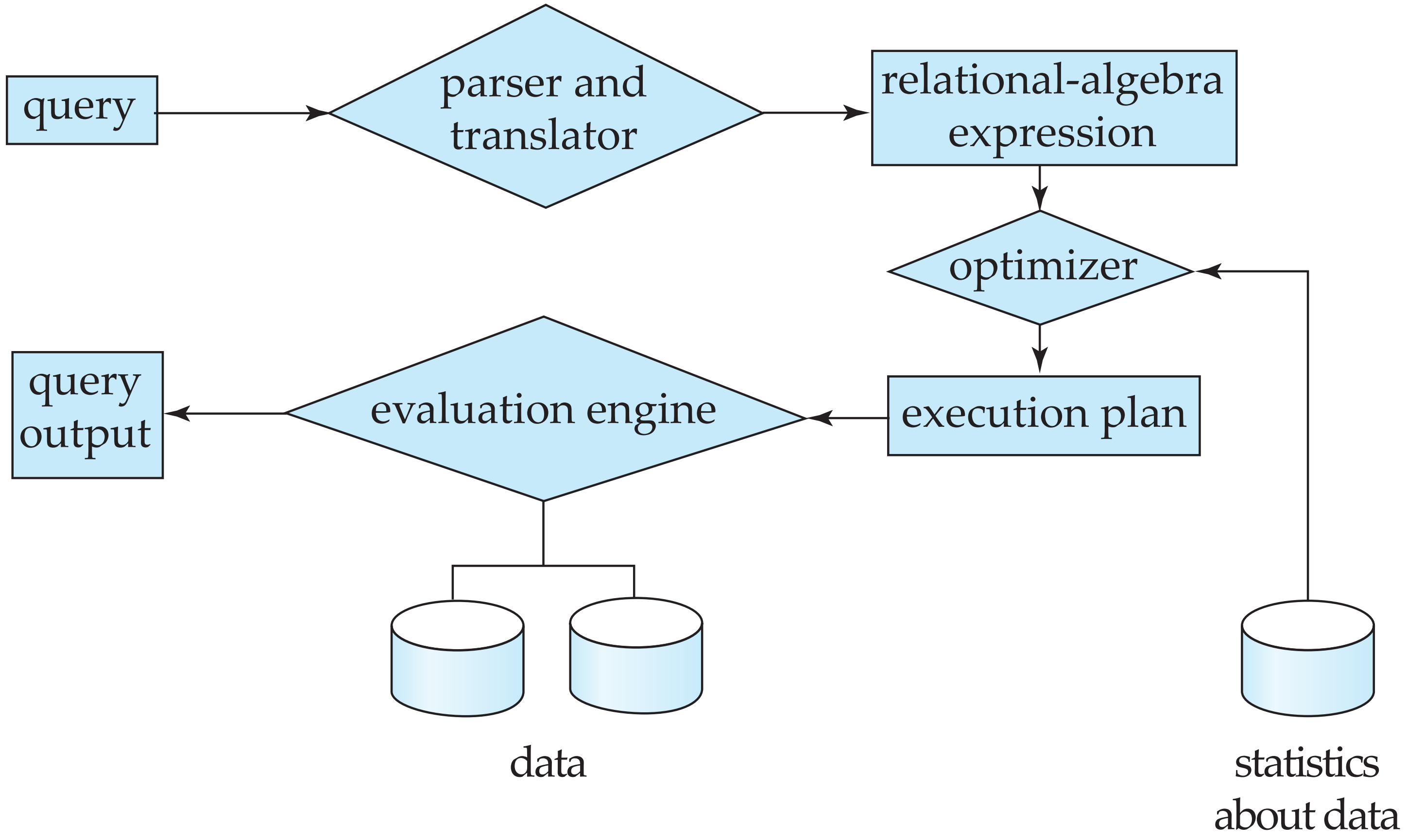
- Most contents are from slides made by Stéphane Faroult and the authors of Database System Concepts (7th Edition).
- Their original slides have been modified to adapt to the schedule of CS307 at SUSTech.

Query Planning and Optimization

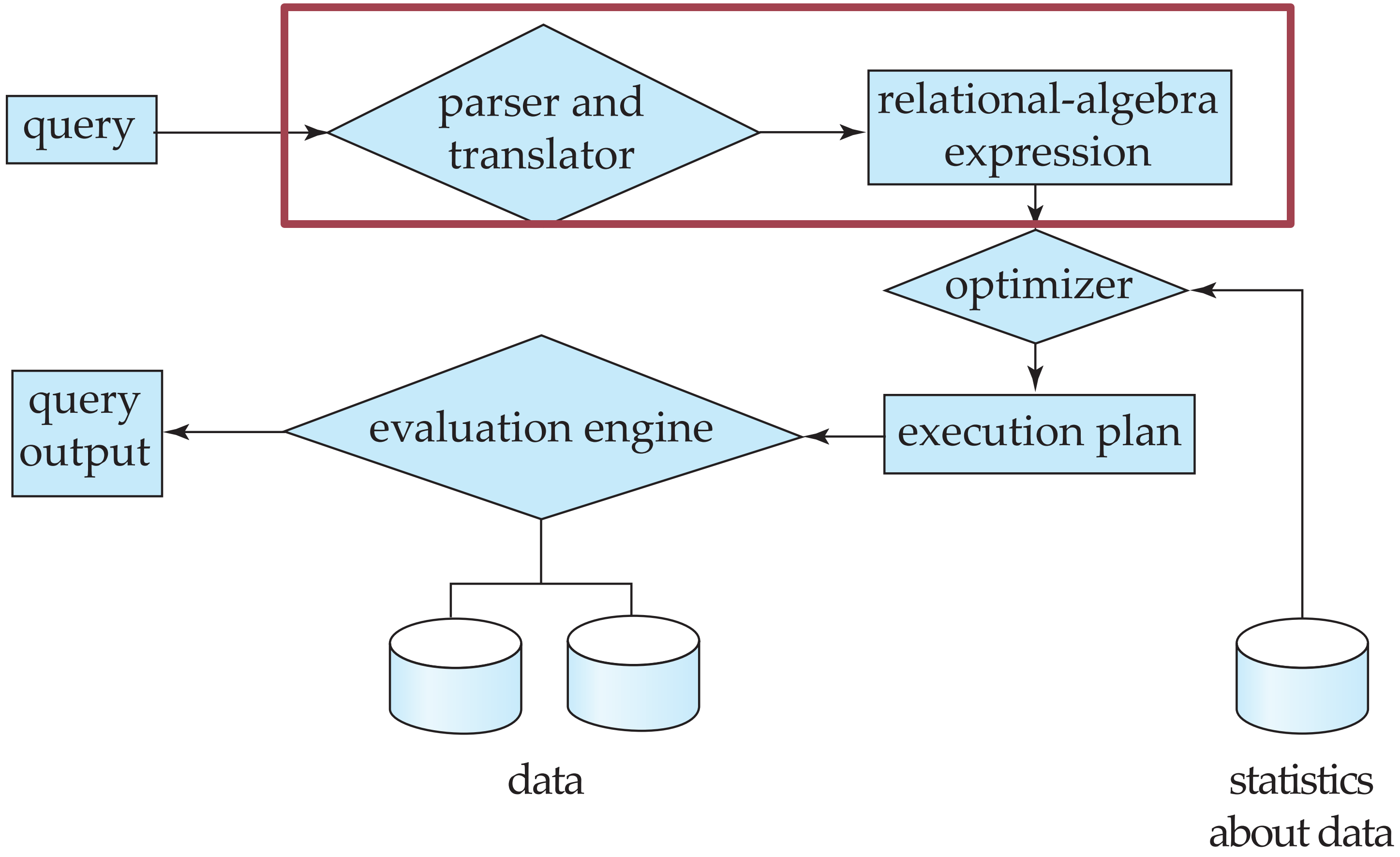
Basic Steps in Query Processing

- Parsing and Translation
- Optimization
- Evaluation



Basic Steps in Query Processing

- Parsing and Translation
  - Translate the query into its internal form
    - The internal form is then translated into relational algebra
  - Parser checks syntax and verifies relations



Basic Steps in Query Processing

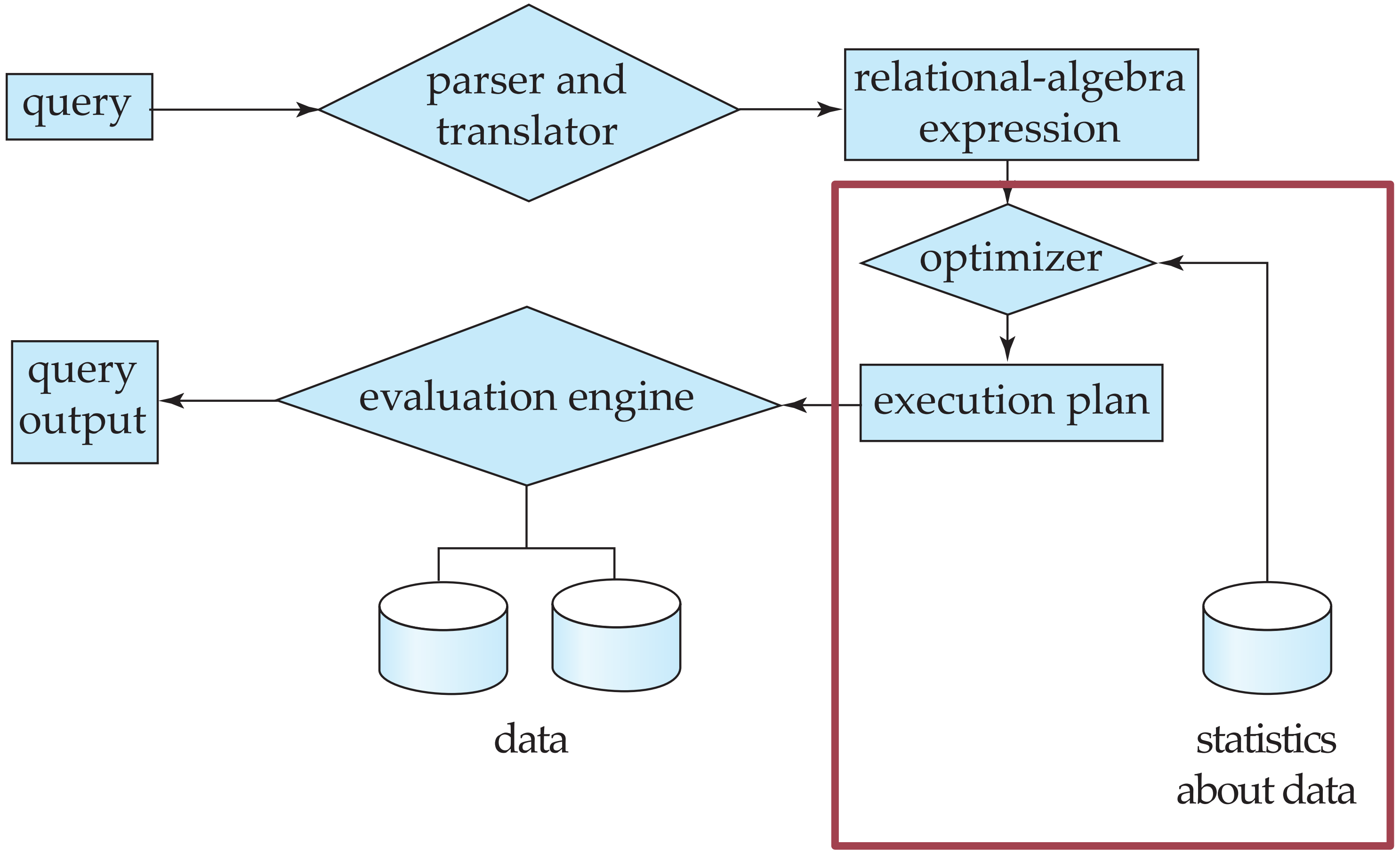
- Optimization
  - A relational algebra expression may have many equivalent expressions
  - E.g.,

$$\sigma_{salary<75000}(\Pi_{salary}(\text{instructor}))$$

is equivalent to

$$\Pi_{\text{salary}}(\sigma_{\text{salary}<75000}(\text{instructor}))$$

Really equaivalent?



But the number of rows involved in the projection operation may be (significantly) smaller in the second expression

Basic Steps in Query Processing

- Optimization
  - A relational algebra expression may have many equivalent expressions
    - … and each relational algebra operation can be evaluated using one of several different algorithms
  - *Correspondingly, a relational-algebra expression can be evaluated in many ways*

Basic Steps in Query Processing

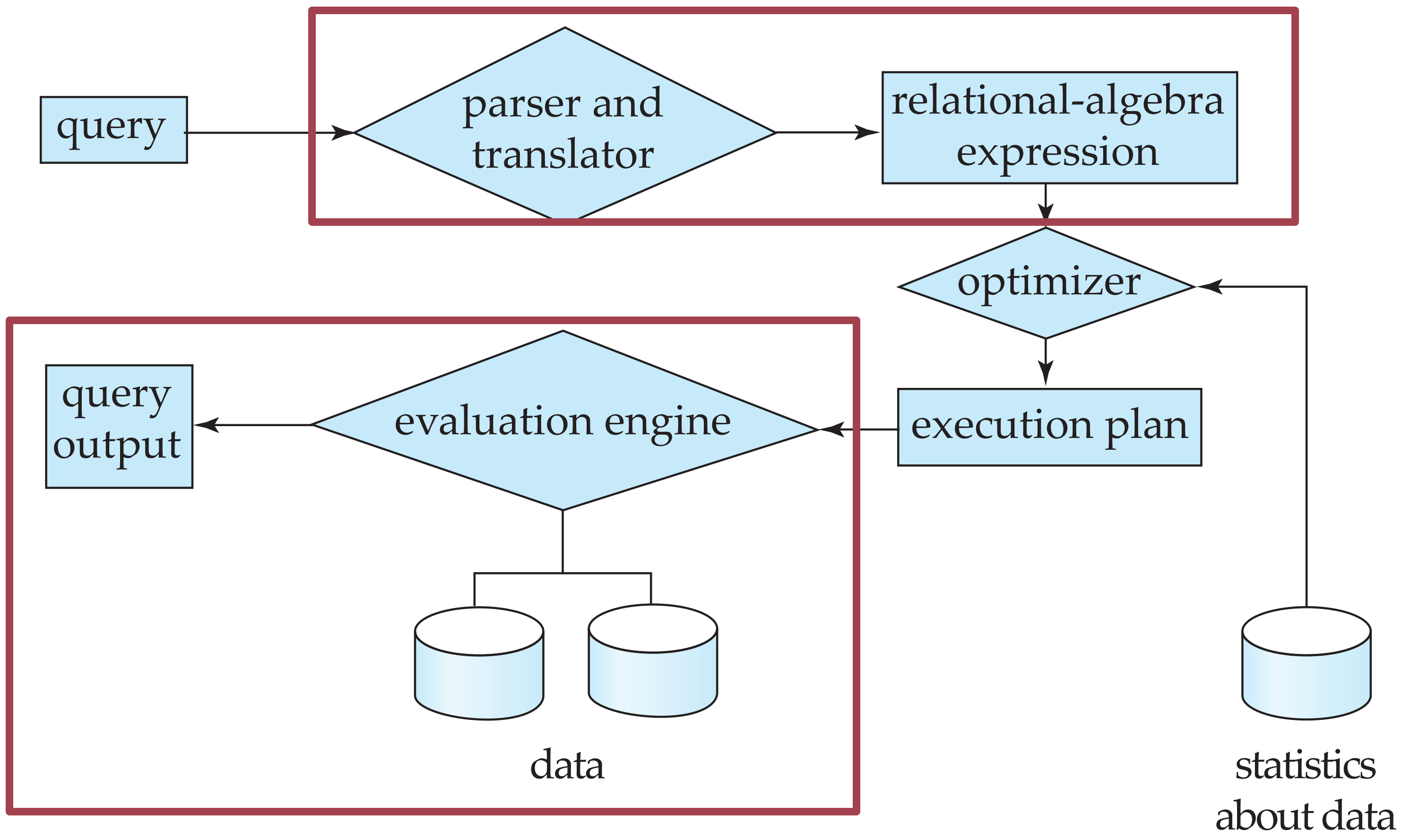
- Optimization
  - **Evaluation Plan**: Annotated expression specifying detailed evaluation strategy
  - E.g.,:
    - Use an index on `salary` to find instructors with `salary<75000`
    - Or perform complete relation scan and discard instructors with `salary<75000`

Query Optimization: Choose the one with the lowest cost among all equivalent evaluation plans

- Cost can be estimated using statistical information from the database catalog
  - E.g., Number of tuples in each relation, size of tuples, etc.

Basic Steps in Query Processing

- Evaluation
  - The query-execution engine takes a query-evaluation plan, executes that plan, and returns the answers to the query



Further Reading

- Database System Concepts , 7th Edition
  - Part Six
    - Chapter 15 “Query Processing”
    - Chapter 16 “Query Optimization”

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

UserID	Name	Email	Interests	LastLoginTime
1	Alice	alice@example.com	["Music", "Reading"]	2021-07-10T14:20
2	Bob	bob@example.com	["Sports", "Technology", "Art"]	2021-07-11T17:45
3	Charlie	charlie@example.com		2021-07-12T08:00

UserID	Name	Email	BirthYear	FavoriteColor	PreferredLanguage
1	Alice	alice@example.com	1984	Blue	
2	Bob	bob@example.com			English
3	Charlie	charlie@example.com	1992		Spanish

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
{
    "contentLink": {
        "id": 6,
        "workId": 0,
        "guidValue": "ca287bcd-6790-4ac1-9132-ccc
        "providerName": null,
        "url": "/en/alloy-plan/",
        "expanded": null
    },
    "name": "Alloy Plan",
    "language": {
        "link": "/en/alloy-plan/",
        "displayName": "English",
        "name": "en"
    },
    "existingLanguages": [
        {
            "link": "/en/alloy-plan/",
            "displayName": "English",
            "name": "en"
        }
    ]
}
```



```xml
<project xmlns="http://maven.apache.org/POM/4.0.0"
         xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
         xsi:schemaLocation="http://maven.apache.org/POM/4.0.0
         http://maven.apache.org/xsd/maven-4.0.0.xsd">
    <modelVersion>4.0.0</modelVersion>

    <groupId>com.spring.aspect</groupId>
    <artifactId>SpringAspect</artifactId>
    <version>0.0.1-SNAPSHOT</version>
    <url>http://maven.apache.org</url>
    <dependencies>
        <dependency>
            <groupId>junit</groupId>
            <artifactId>junit</artifactId>
            <version>4.0.1</version>
            <scope>test</scope>
        </dependency>
    </dependencies>

</project>
```

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)

```
{
    "ID": "22222",
    "name": {
        "firstname: "Albert",
        "lastname: "Einstein"
    },
    "deptname": "Physics",
    "children": [
        {"firstname": "Hans", "lastname": "Einstein" },
        {"firstname": "Eduard", "lastname": "Einstein" }
    ]
}
```

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

```sql
-- 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

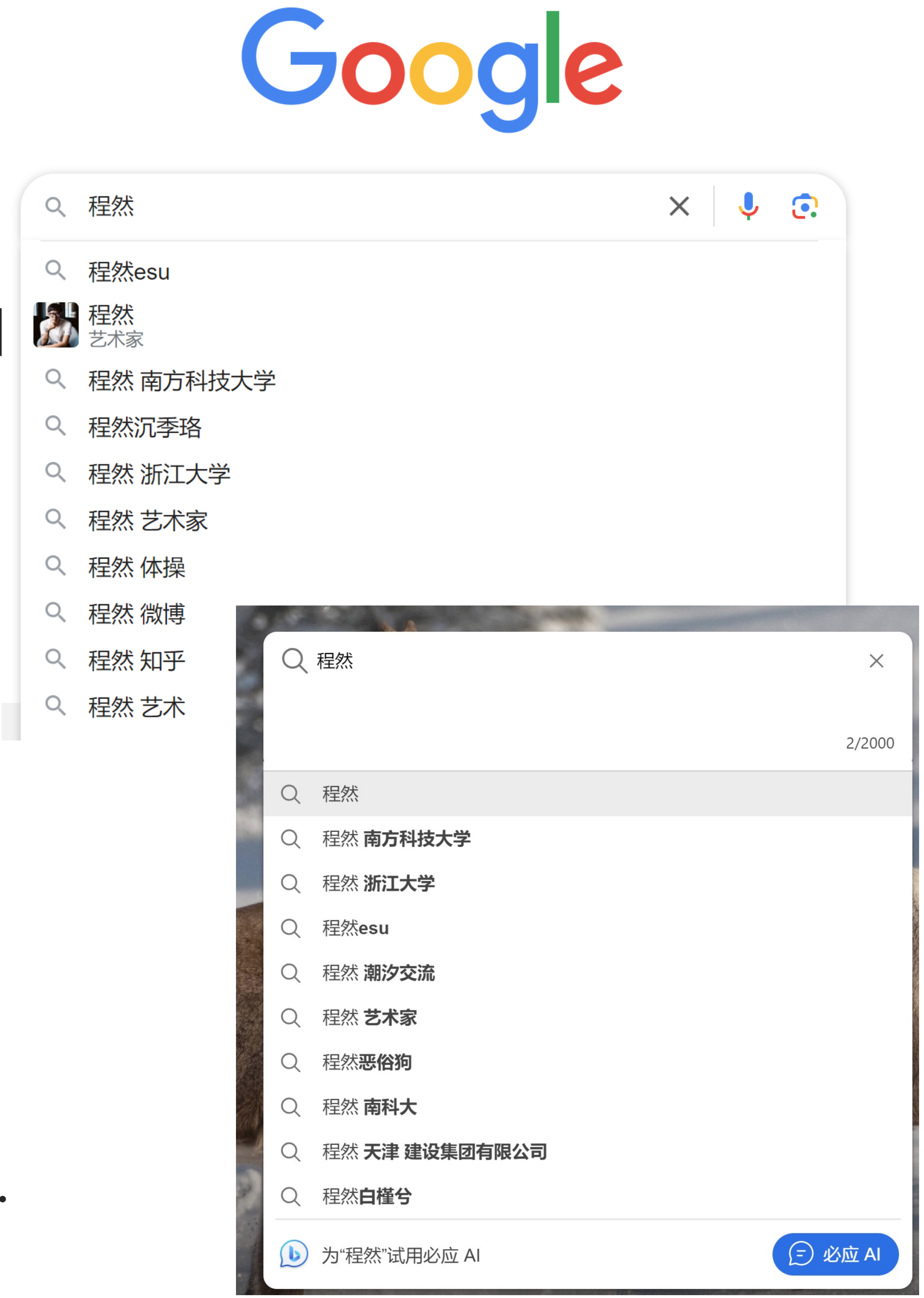
- XML uses tags to mark up text
  - Tags make the data self-documenting
  - Tags can be hierarchical

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

```
<info>
    <name>aaa</name>
    <age>20</age>
    <major>
        <primary>cs</primary>
        <minor>math</minor>
    </major>
</course>
```

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
- Relevance ranking (e.g. 搜索引擎)
  - Apart from keywords, we need to consider:
    - Frequency of keywords within the documents.
    - Recency of the documents.
    - User interaction metrics (e.g., click-through rate).
    - …

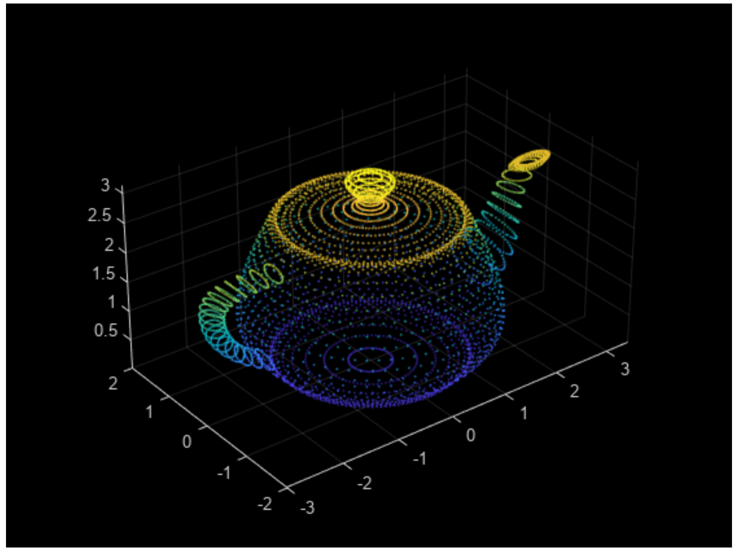


Spatial Data

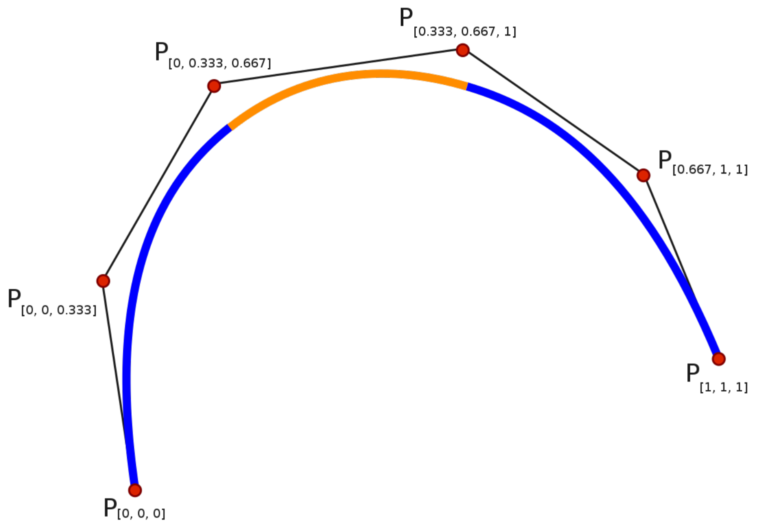
- **Spatial databases** store information related to spatial locations, and support efficient storage, indexing and querying of spatial data.
  - **Geographic data**: road maps, land-usage maps, topographic elevation maps, political maps showing boundaries, land-ownership maps, and so on.
    - Geographic information systems (GIS) are special-purpose databases tailored for storing geographic data.
    - Round-earth coordinate system may be used
      - (latitude 纬度, longitude 经度, elevation 海拔)
  - **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

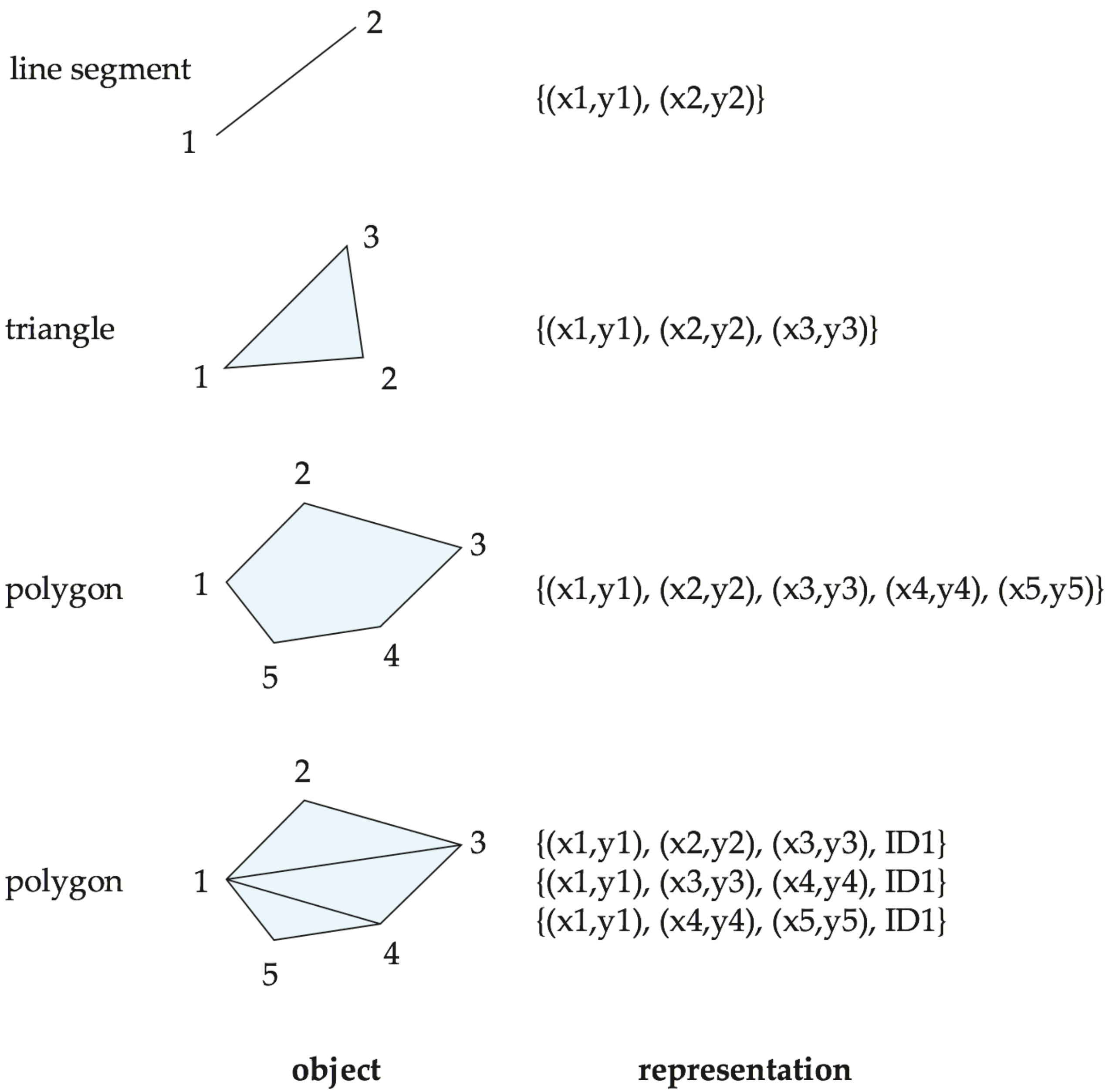
- Various geometric constructs can be represented in a database in a normalized fashion



Point cloud



B splines



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

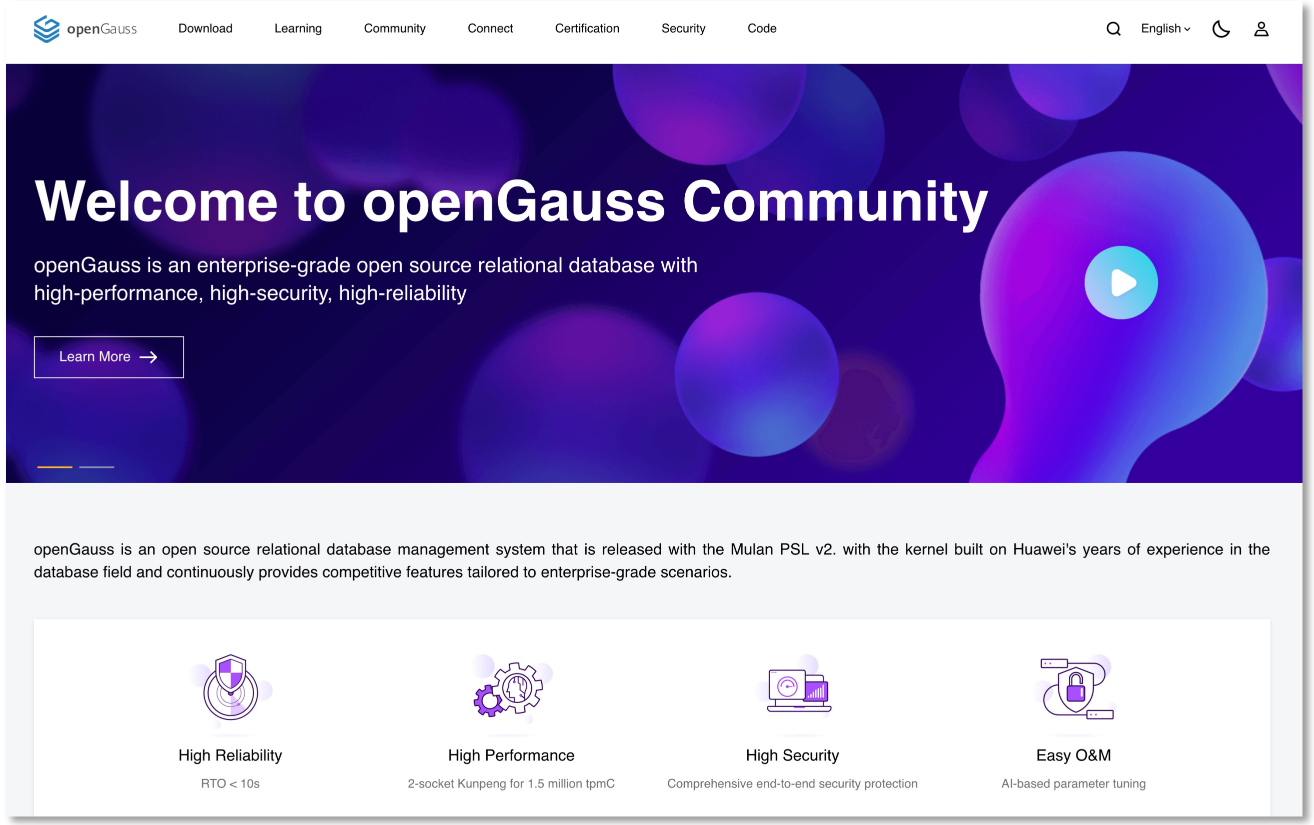
- Factors to consider open-source databases
  - Cost
    - Open-source databases are generally free
  - Customizability
    - Add your own features in the source code
  - Community support
    - Documentations, bug fixes, discussions

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；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

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

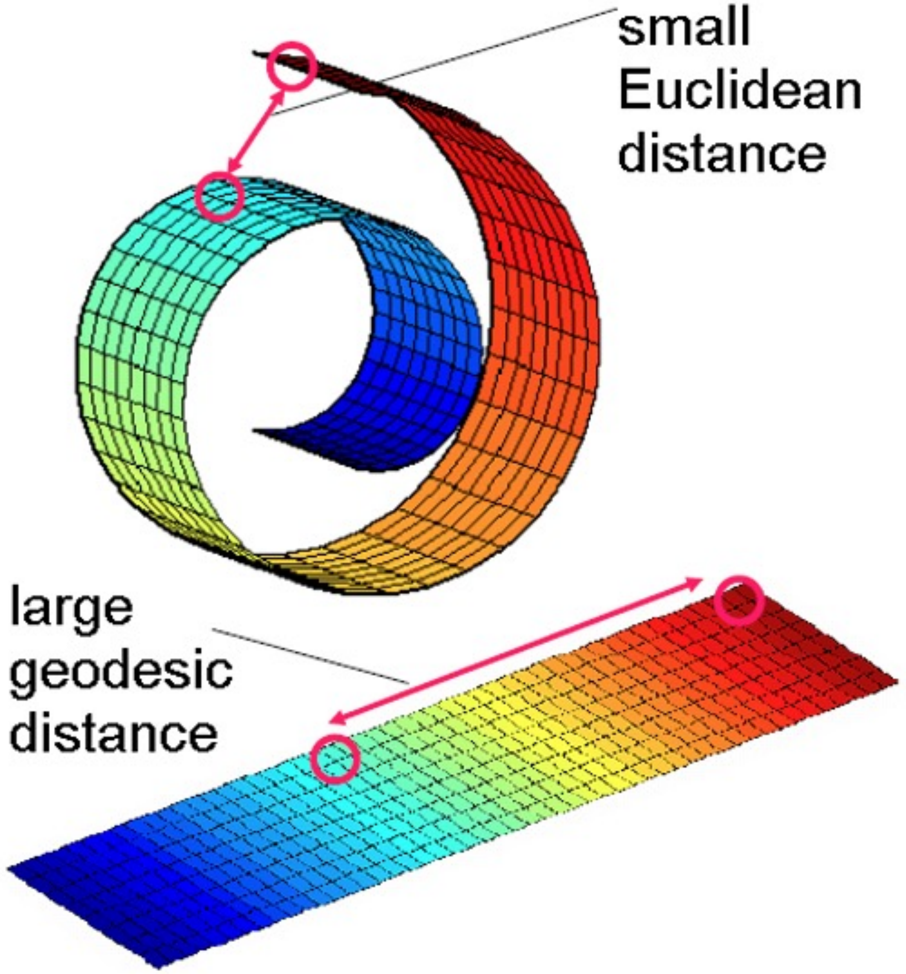
2 : information in digital form that can be transmitted or processed

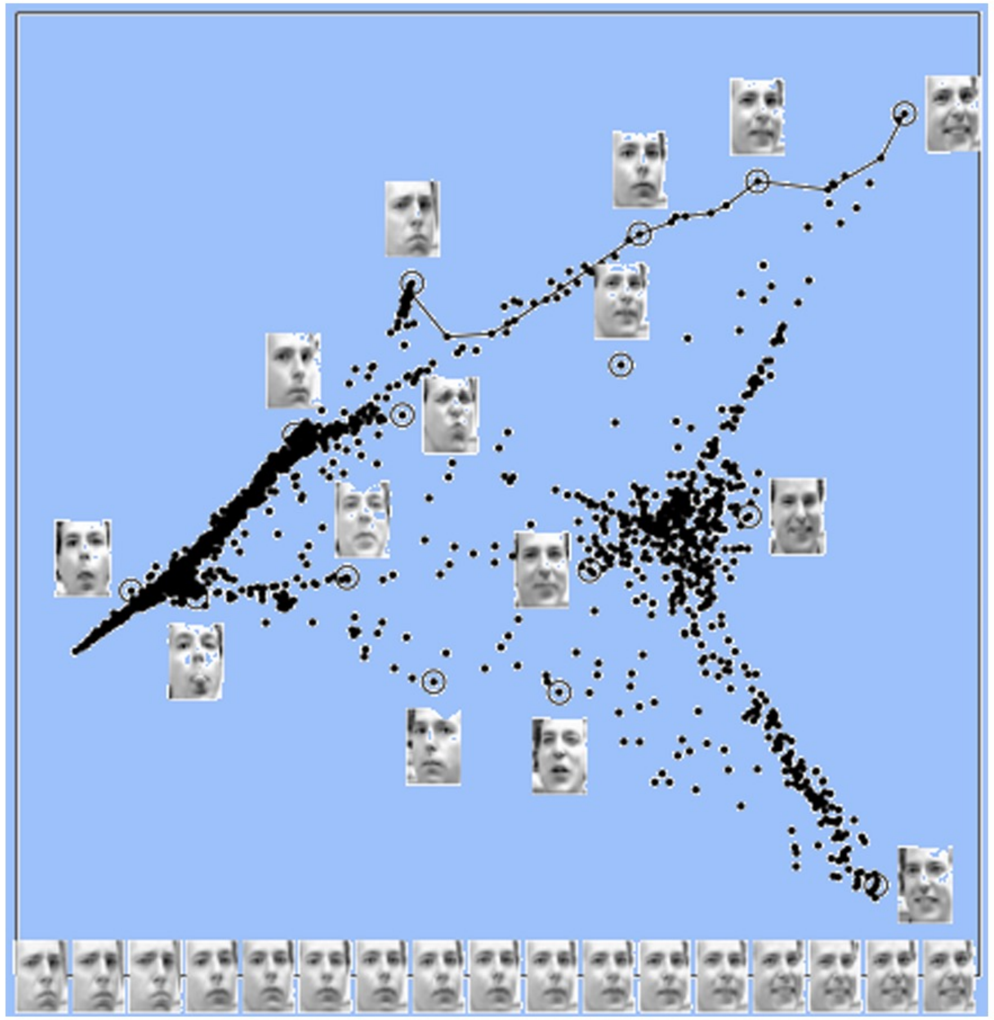
3 : information output by a sensing device or organ that includes both useful and irrelevant or redundant information and must be processed to be meaningful

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

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

What you see is what you get?





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

$$Q_{\frac{1}{2}}(x) = \begin{cases} x'_{\frac{n+1}{2}}, & \text{if } n \text{ is odd.} \\ \frac{1}{2}(x'_{\frac{n}{2}} + x'_{\frac{n}{2}+1}), & \text{if } n \text{ is even.} \end{cases}$$

- 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).

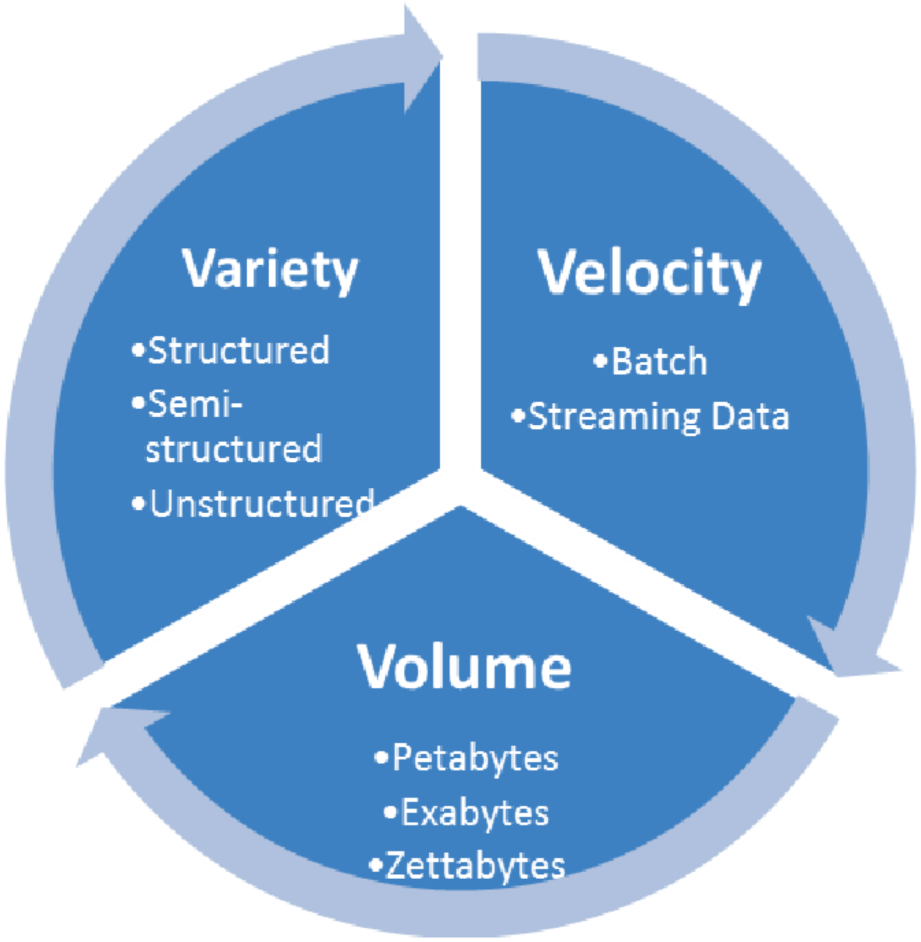
What is Big Data?

- 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



The Emergence of Data Science

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

Digital campaigning

All latest updates

The role of technology in the presidential election

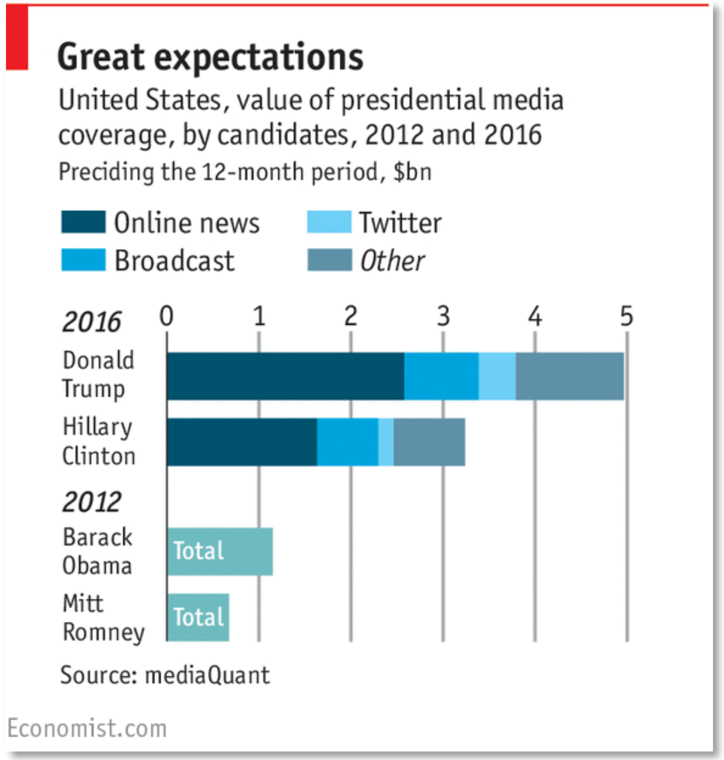
From fake news to big data, a post mortem is under way

Nov 20th 2016 | United States

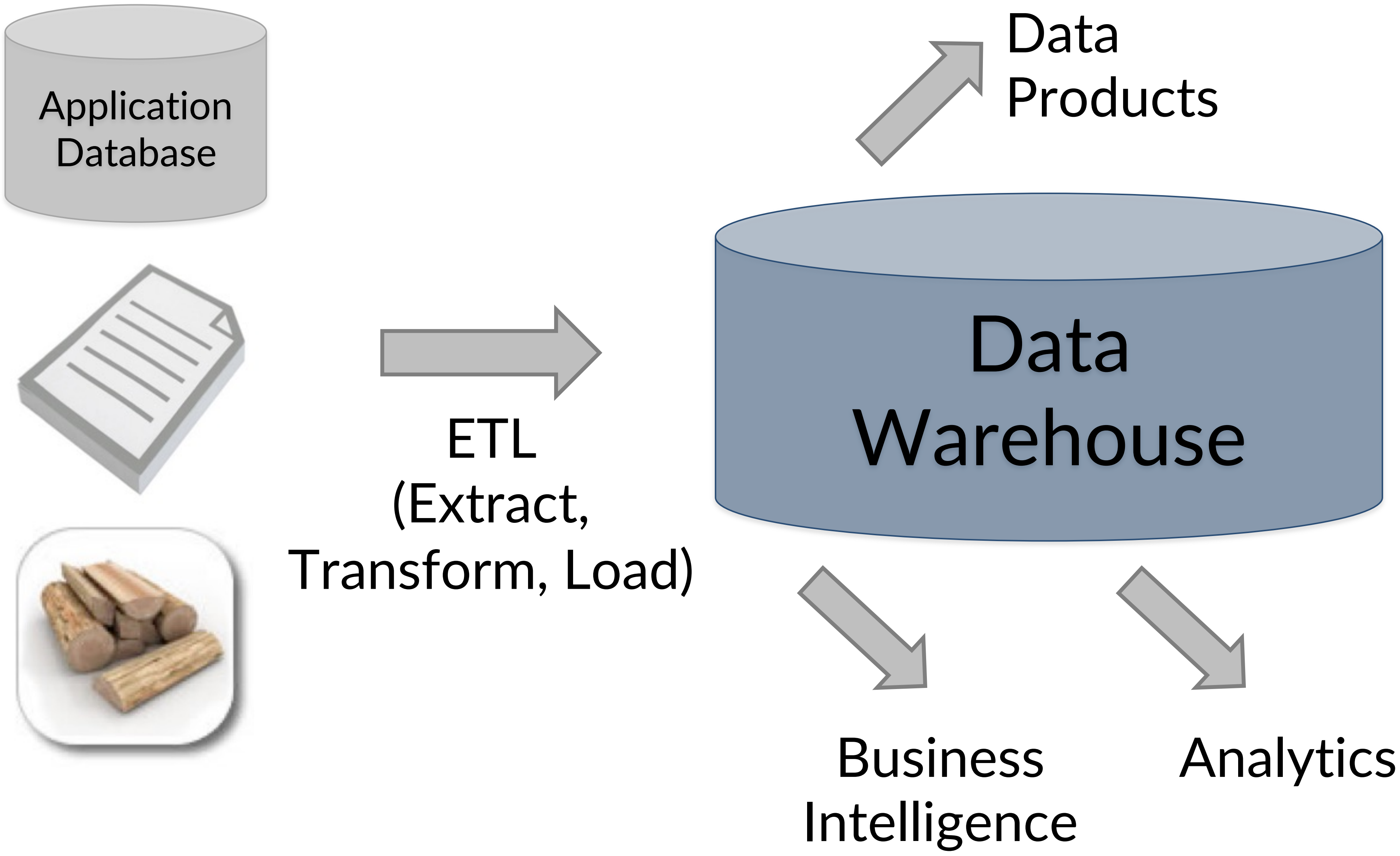
Timekeeper Like 916 Tweet

Reuters

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.



Standard Architecture



Instantiations(1) - Businessmen

- Data Sources
  - Web pages
  - Excel
- Data Warehouse
  - Excel
- Extract-Transform-Load (ETL)
  - Copy & paste
- Business Intelligence & Analytics
  - Excel functions
  - Excel charts
  - 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
- Business Intelligence & Analytics
  - Numpy, pandas, Matplotlib, R, Octave, …

Instantiations(3) - Enterprises

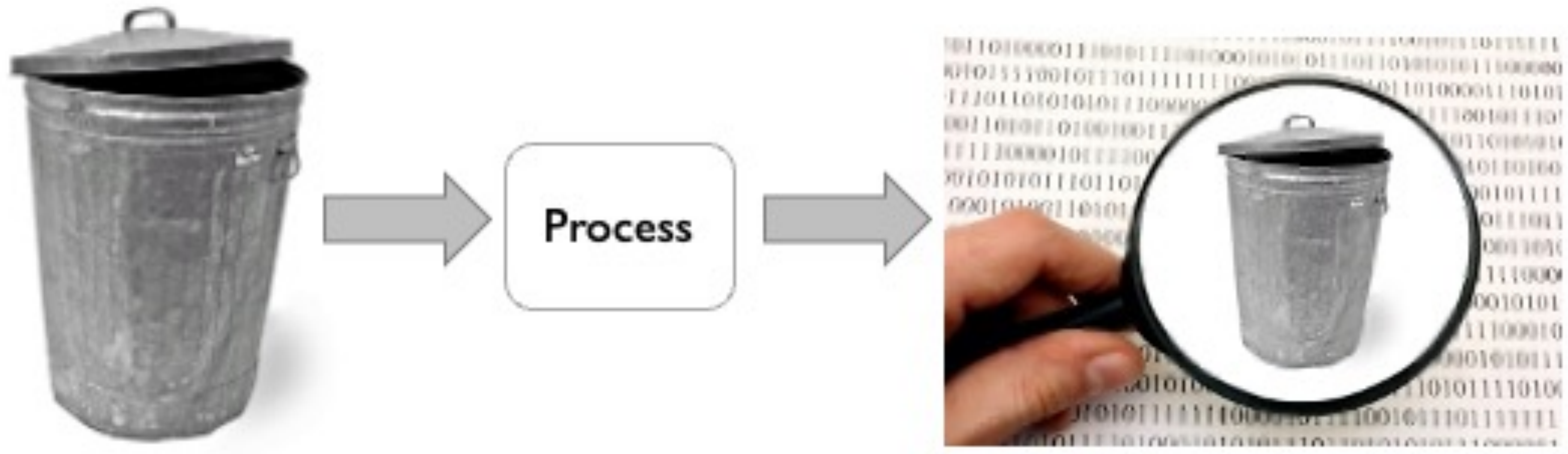
- Data Sources
  - Application databases(Oracle, IBM, …)
  - Intranet files
  - Application log files
- ETL
  - Infomatica, IBM DataStage, …
- Data Warehouse
  - Teradata, Oracle, IBM DB2, …
- Business Intelligence & Analytics
  - SAS, SPSS, R, …
  - Power BI, Tableau, Spotfire, …

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, …

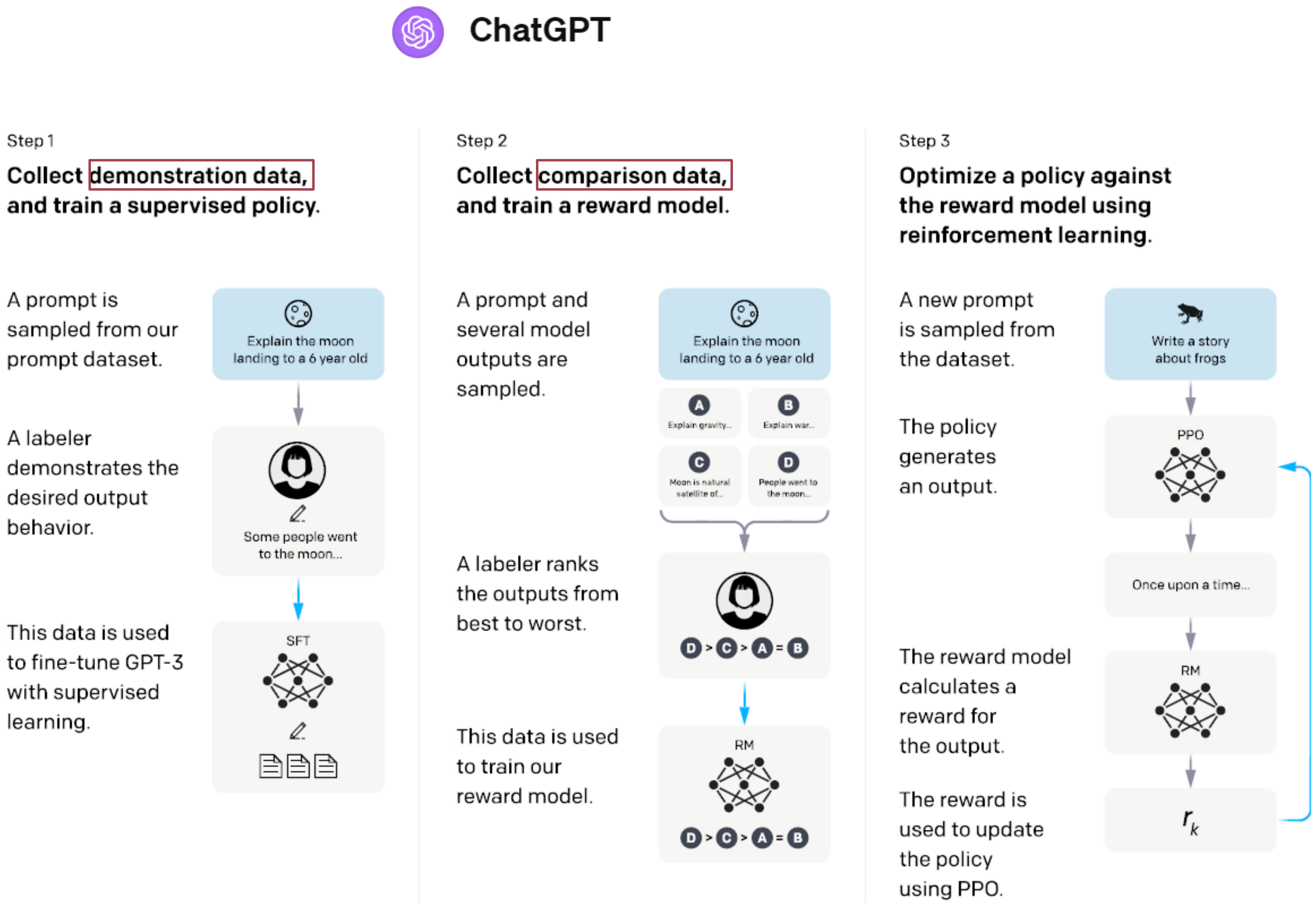
“Garbage in, garbage out.”

- <u>Raw data</u> can always be **DIRTY**!



Data Quality

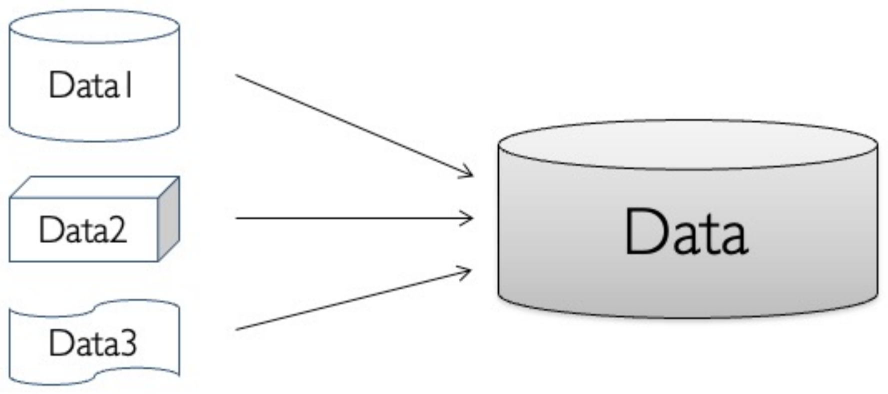
- Data quality:
  - Accuracy
  - Completeness
  - Consistency
  - Interpretability
  - …



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 multiple sources



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

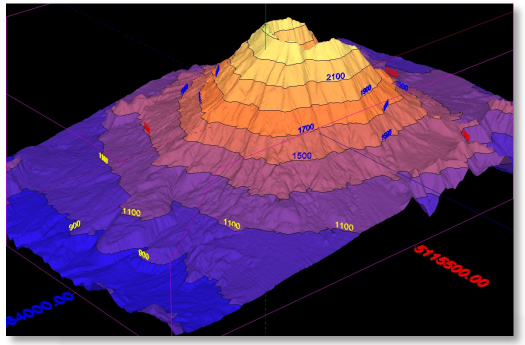
Data Analysis

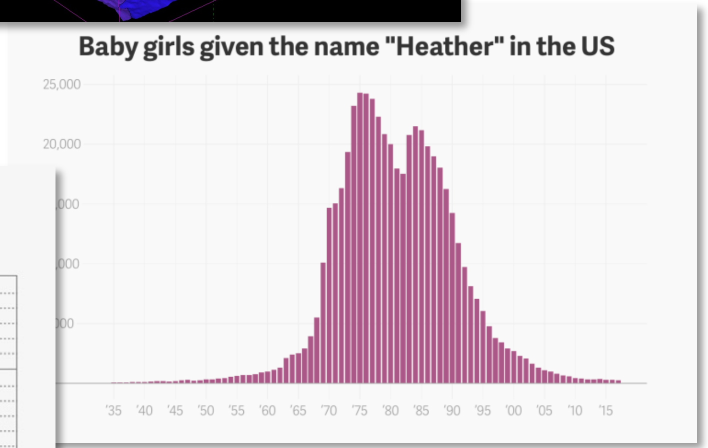
- Exploratory Data Analysis
- Data Mining

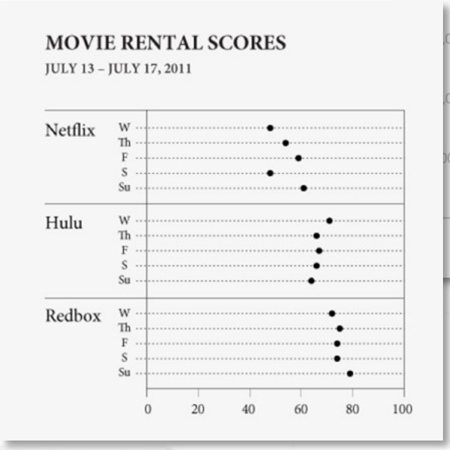
Exploratory Data Analysis (EDA)

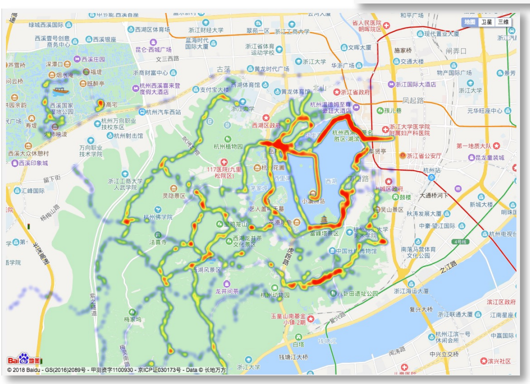
- Based on statistics
  - Data visualization-driven method
  - Summary of main characteristics in easy-to-understand form

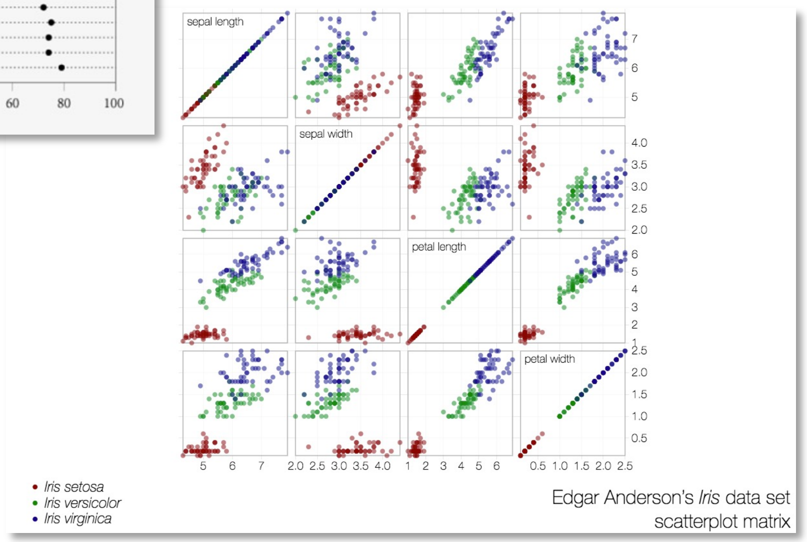
- Types of data visualization methods in EDA:
  - Plotting of raw data
  - Plotting of statistical values
  - Multiple coordinated views (Dashboard)







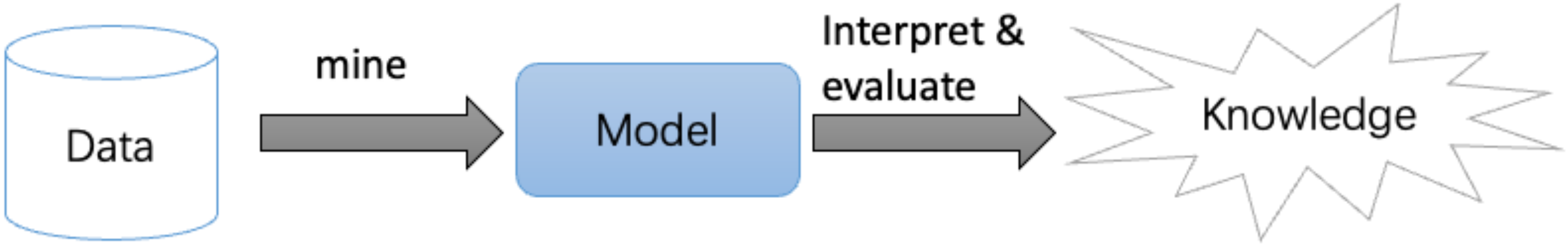




Data Mining

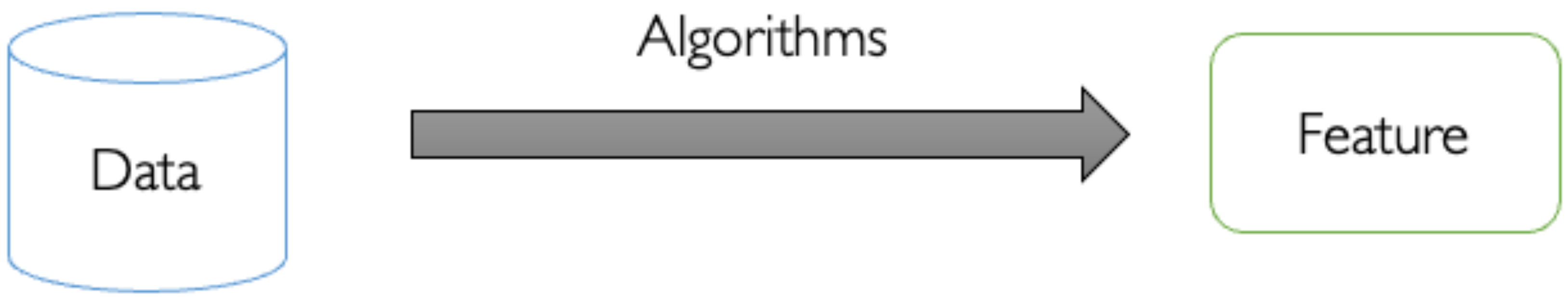
"**Data Mining**, also popularly referred to as **knowledge discovery** from data (KDD), is the automated or convenient **extraction of patterns representing knowledge** implicitly stored or captured in large databases, data warehouses, the Web, other massive repositories, or data streams."

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

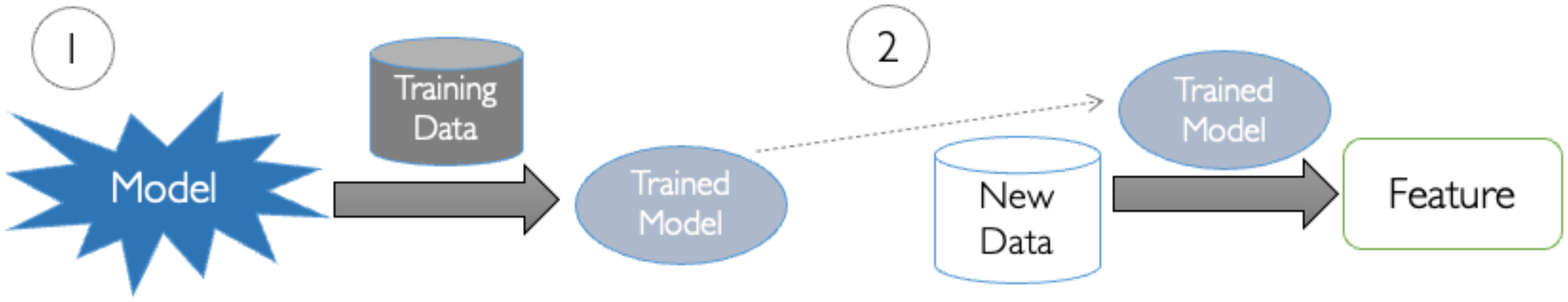


Tasks in Data Mining

- Descriptive Tasks



- Predictive Tasks



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