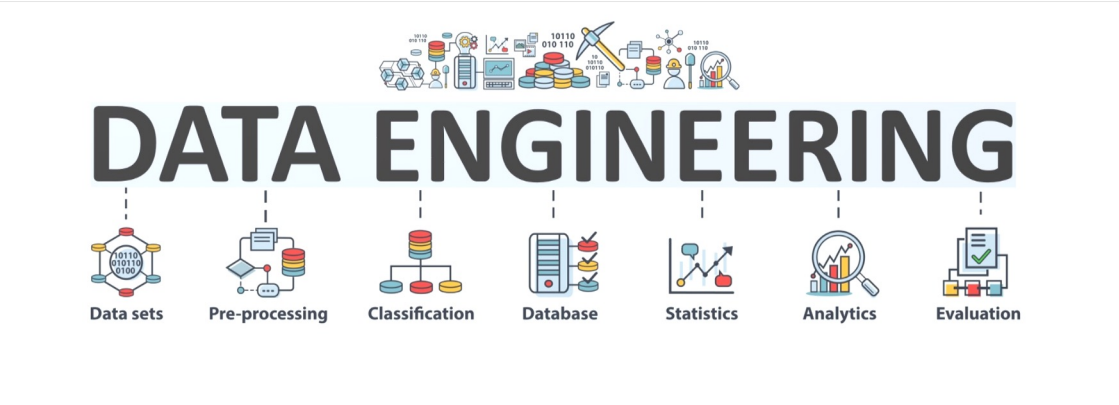


Lecture 11:

Course Review

CS5481 Data Engineering

Instructor: Yifan Zhang

Outline

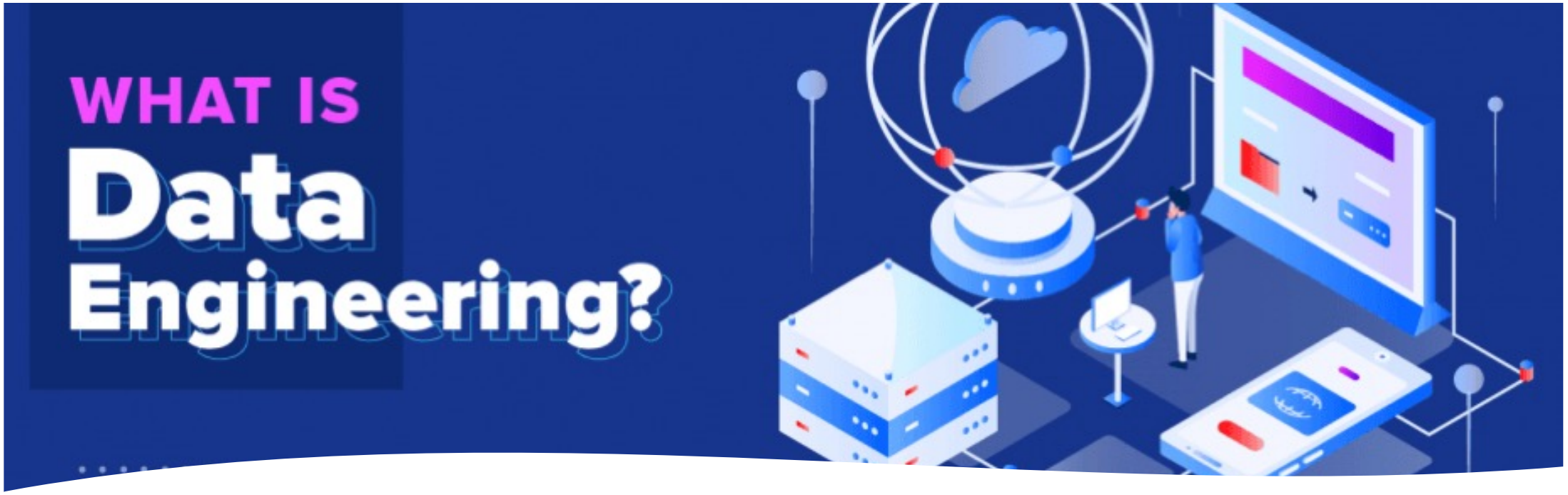
1. Final exam
2. Course review

Final exam

- It will be a closed-book exam. No materials and electronics are allowed.
- The scope of the exam includes all lectures, tutorials, and homework assignments.
- The key focus will be put on understanding basic concepts and principles, understanding fundamentals techniques, analyzing advantages and disadvantages of different techniques, and proposing solutions for specific problems.
- There will be in total 5 questions.
  - Short questions to ask your understanding of some concepts, principles, reasons, key features of some techniques, etc. (around 50%)
  - A little bit design, analysis, calculation, program, etc. (around 50%)
- We will hold an office hour via Teams (to be announced later) to answer questions approximately one week before the final exam. Welcome to join if you have questions.

L1: introduction

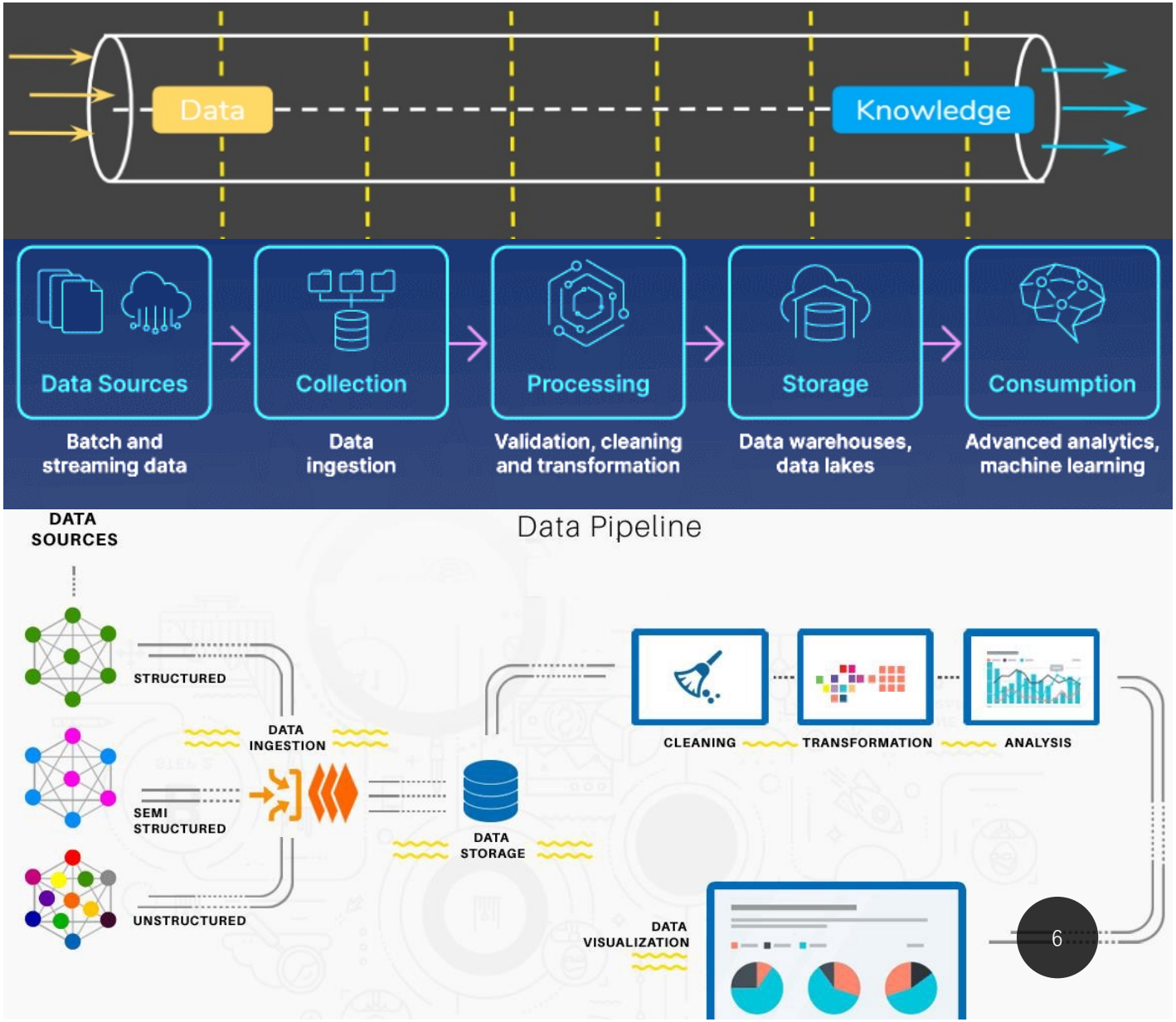
- 1. Overview of the data engineering ecosystem
- 2. Types of data
- 3. Languages and tools for data professionals



- Big data is changing the way we do business and creating a need for data engineers who can collect and manage large quantities of data.
- Data engineering is the practice of designing and building systems for collecting, storing, and analyzing data at scale.

Data engineering pipeline

- **The Goal of Data Engineering** is to provide organized, standard data flow to enable data-driven models such as machine learning models, data analysis.



Types of data

Unstructured data

The university has 5600 students.
John's ID is number 1, he is 18 years old and already holds a B.Sc. degree.
David's ID is number 2, he is 31 years old and holds a Ph.D. degree. Robert's ID is number 3, he is 51 years old and also holds the same degree as David, a Ph.D. degree.

Semi-structured data

```
<University>
 <Student ID="1">
   <Name>John</Name>
   <Age>18</Age>
   <Degree>B.Sc.</Degree>
 </Student>
 <Student ID="2">
   <Name>David</Name>
   <Age>31</Age>
   <Degree>Ph.D. </Degree>
 </Student>
....
</University>
```

Structured data

ID	Name	Age	Degree
1	John	18	B.Sc.
2	David	31	Ph.D.
3	Robert	51	Ph.D.
4	Rick	26	M.Sc.
5	Michael	19	B.Sc.

Languages for data professionals

Query Languages

For example, SQL for querying and manipulating data

Programming Languages

For example, Python for developing data applications

Shell and Scripting Languages

For repetitive and time-consuming operational tasks

L2: data acqusition

- 1. Data sources
- 2. Web scraping
- 3. From web scraping to web crawling

Sources of data

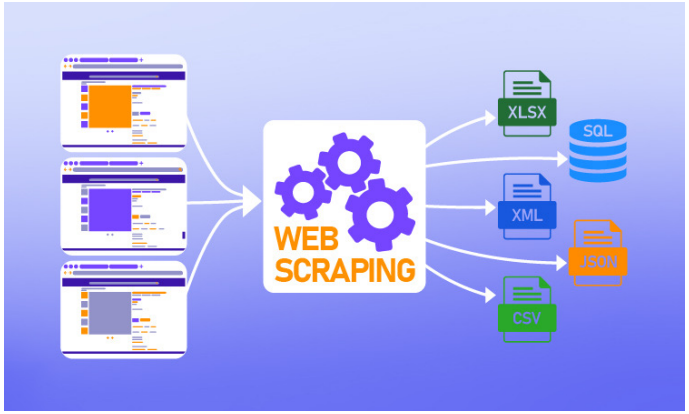
Relational databases

Flat files and XML datasets

APIs and web services

Web scraping

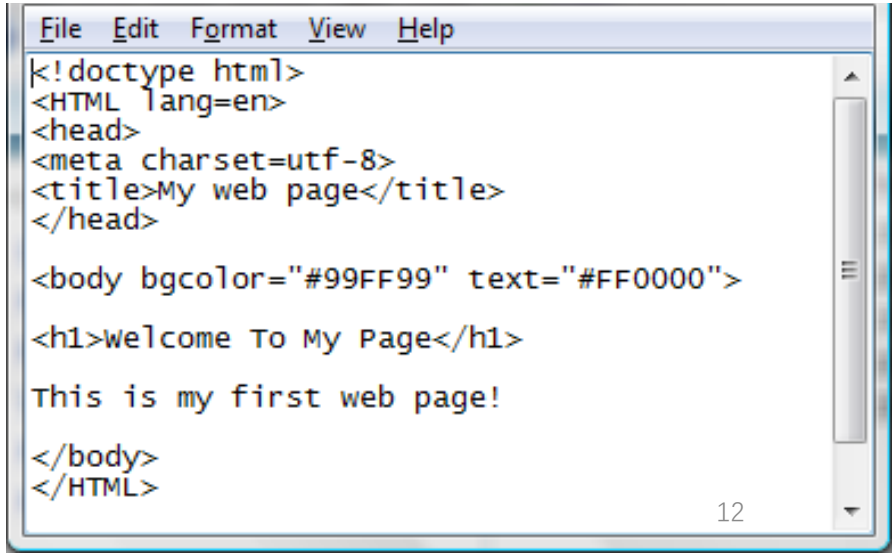
- The construction of an agent to download, parse, and organize data from the web in an automated manner
- Extract relevant data from unstructured sources on the Internet
- Also known as screen scraping, web harvesting, and web data extraction
- Can extract text, contact information, images, videos, product items, etc.



HTML file to scrape

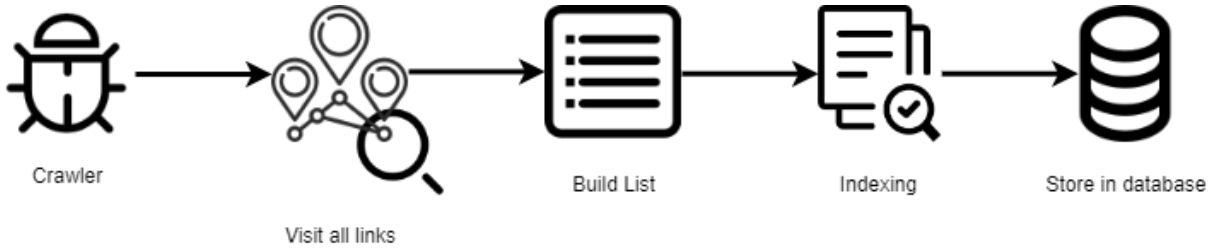
- HTML is a standard markup language for creating web pages.
- HTML provides the building blocks to provide structure and formatting to documents.
- Python ‘requests’ library could get the html content from a webpage.

```
import requests

url = 'https://en.wikipedia.org/w/index.php' + \
      '?title=List_of_Game_of_Thrones_episodes&oldid=802553687'

r = requests.get(url)
print(r.text)
```

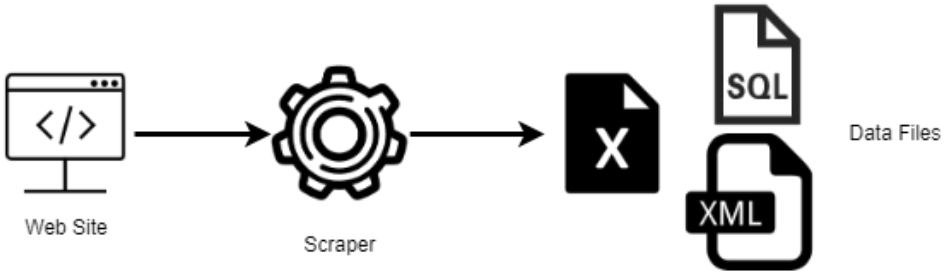


From web scraping to web crawling

Web Crawling: Using tools to read, copy and store the content of the websites for archiving or indexing purposes. Crawling usually deals with a network of webpages



Web Scraping: Extracting a large amount of specific data usually from a single webpage or a single website



L3: data preprocessing

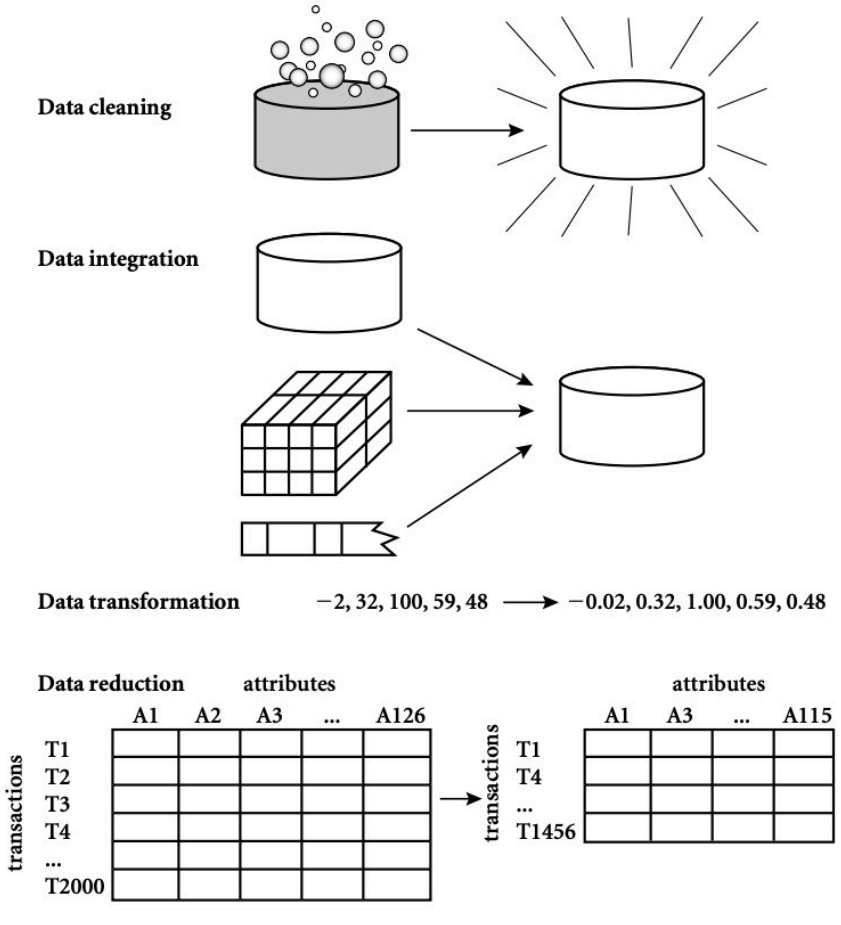
1. Why data preprocessing?
2. Data Cleaning
3. Data Integration
4. Data Transformation
5. Data Reduction
6. Data Discretization

Why data preprocessing - dirty data

- Data in the real world is dirty: Lots of potentially incorrect data, e.g., instrument faulty, human or computer error, transmission error
  - **Incomplete**: lacking attribute values, lacking certain attributes of interest, or containing only aggregate data
    - e.g., Occupation=“ ” (missing data)
  - **Noisy**: containing noise, errors, or outliers
    - e.g., Salary=“−10” (an error)
  - **Inconsistent**: containing discrepancies in codes or names, e.g.,
    - Age=“42”, Birthday=“03/07/2010”
    - Was rating “1, 2, 3”, now rating “A, B, C”
    - discrepancy between duplicate records
  - **Intentional** (e.g., disguised missing data)
    - Jan. 1 as everyone’s birthday?

Major tasks in data preprocessing

- **Data cleaning:** Fill in missing values, smooth noisy data, identify or remove outliers, and resolve inconsistencies.
- **Data integration:** Integration of multiple databases, data cubes, files, or notes.
- **Data transformation:** Normalization (scaling to a specific range), aggregation.
- **Data reduction:** Obtains reduced representation in volume but produces the same or similar analytical results.
- **Data discretization:** Reduce the number of values for a given continuous attribute by dividing the range of the attribute into intervals. Interval labels can then be used to replace actual data values.



Data cleaning – handling missing data

1. **Ignore** the tuple: usually done when class label is missing (assuming the task is classification—not effective in certain cases)
2. Fill in the missing value **manually**: tedious + infeasible
3. Automatically:
    1) Use a **global constant** to fill in the missing value: e.g., “unknown”, a new class
    2) Use the **attribute mean** to fill in the missing value
    3) Use the **attribute mean for all samples of the same class** to fill in the missing value: smarter
    4) Use the **most probable value** to fill in the missing value: inference-based such as regression, Bayesian formula, decision tree

Data cleaning – handling noisy data

- **Binning method**
  - First sort data and partition into bins
  - Then one can **smooth by bin means, median, and boundaries**, etc.
  - Used also for discretization
- **Clustering**
  - Detect and remove outliers
- **Semi-automated method**
  - Combined computer and human inspection
  - Detect suspicious values and check manually
- **Regression**
  - Smooth by fitting the data into regression functions

A useful tool: Regular expressions (Regex)

- **What is Regex**
  - A regular expression is a sequence of characters that specifies a search pattern in text.
  - It can be used when
    - testing the pattern within the string
    - identify specific text in a document, delete the text completely, or replace it with other text
    - extract substrings from strings based on pattern matching
- **Regex examples**

- `.at` matches any three-character string ending with "at", including "hat", "cat", "bat", "4at", "#at" and " at" (starting with a space).
- `[hc]at` matches "hat" and "cat".
- `[^b]at` matches all strings matched by `.at` except "bat".
- `[^hc]at` matches all strings matched by `.at` other than "hat" and "cat".
- `^[hc]at` matches "hat" and "cat", but only at the beginning of the string or line.
- `[hc]at$` matches "hat" and "cat", but only at the end of the string or line.
- `\[.\]` matches any single character surrounded by "[" and "]" since the brackets are escaped, for example: "[a]", "[b]", "[7]", "[@]", "[]]", and "[ ]" (bracket space bracket).
- `s.*` matches s followed by zero or more characters, for example: "s", "saw", "seed", "s3w96.7", and "s6#h%(>>>m n mQ".

Refer to https://en.wikibooks.org/wiki/Regular_Expressions

Data transformation

- **Normalization:** scaled to fall within a small, specified range
  - ➢ min-max normalization
  - ➢ z-score normalization
  - ➢ normalization by decimal scaling
- **Attribute/feature construction**
  - New attributes constructed from the given ones

Data reduction example – dimensionality reduction

Feature selection (i.e., attribute subset selection):

- Select a minimum set of features such that the probability distribution of different classes given the values for those features is as close as possible to the original distribution given the values of all features.
- Nice side-effect: reduces # of attributes in the discovered patterns, easier to understand.

Data discretization

Discretization and concept hierarchy generation for **numeric data**

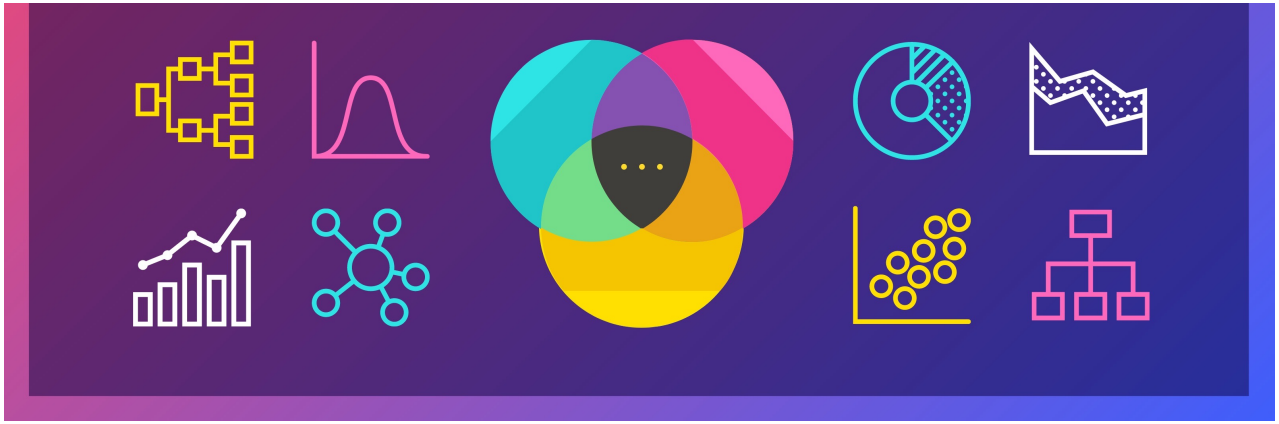
1. **Hierarchical and recursive decomposition** using:
   - Binning (data smoothing)
   - Histogram analysis (numerosity reduction)
   - Clustering analysis (numerosity reduction)
2. **Entropy-based discretization**
3. **Segmentation by natural partitioning**

L4: data visualization

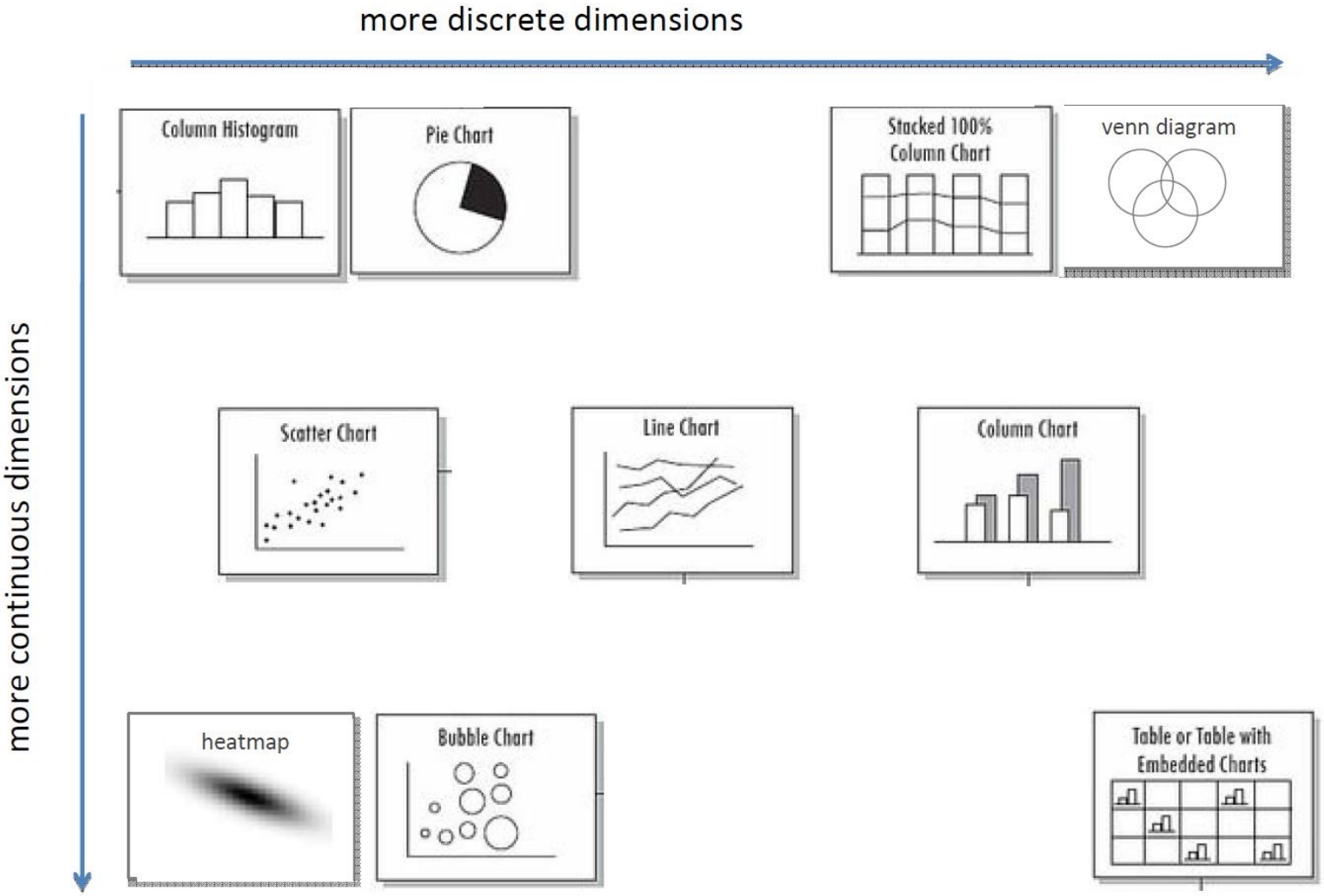
1. Introduction to Data Visualization
2. Conventional Visualizations
3. Data Visualization Skills
4. Tips and Tricks
5. Data Visualization Traps
6. Visualization and Dashboard Software

Data visualization

- **Data visualization is the study of visual representations of abstract data to reinforce human cognition.** Its goal is to make information easy to comprehend, interpret, and retain.
- The discipline of communicating information through the use of visual elements such as graphs, charts, and maps.



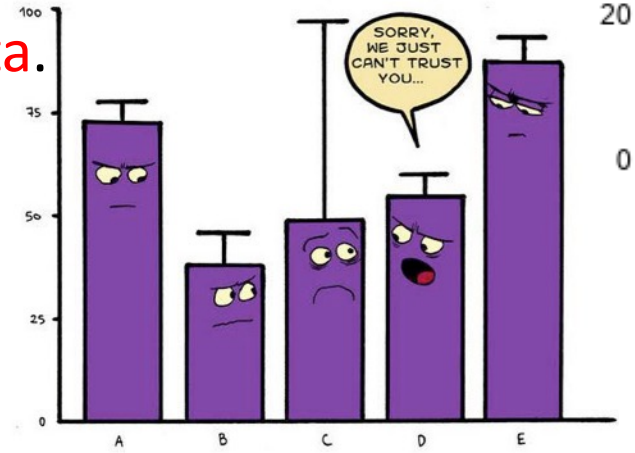
Conventional visualizations

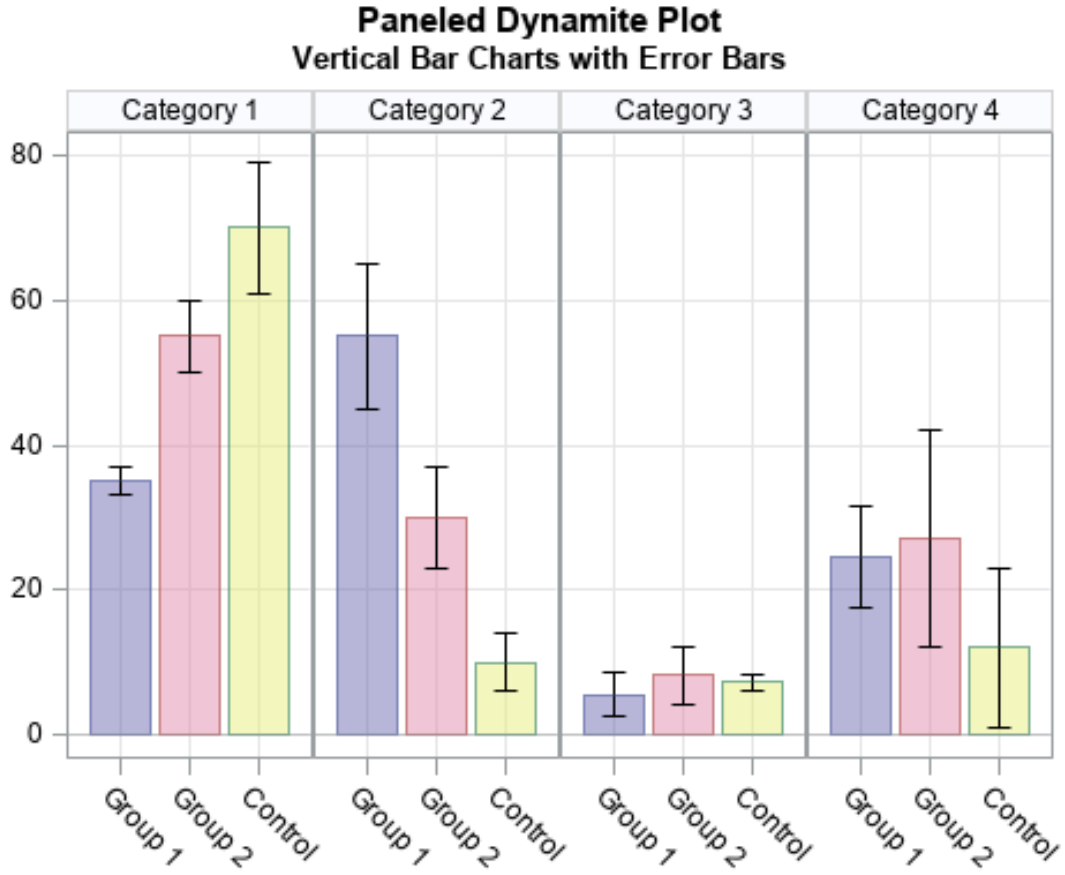


Visualization example – dynamite plots

Dynamite Plot

- Can be used for lots of discrete grouping factors.
- Natural semantics of grouping
- Conceals data.





Data visualization skills

There are usually 6 reasons to make a chart:

1. To **compare**
2. To show the **distribution**
3. To explain **parts of the whole**
4. To tell the **trend over time**
5. To find out the **deviations**
6. To understand the **relationship**

2 tradeoffs

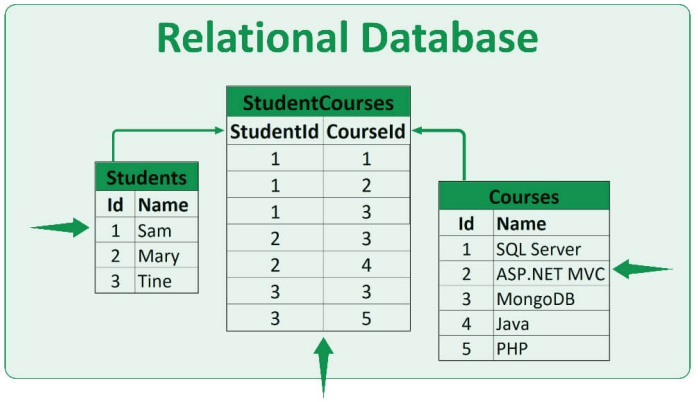
- **Informativeness vs. readability**
  - Too little information can conceal data.
  - But too much information can be overwhelming.
  - Possible solution: hierarchical organization.
- **Data-centric vs. viewer-centric**
  - Viewers are accustomed to certain types of visualization.
  - But novel visualization can be truer to data.

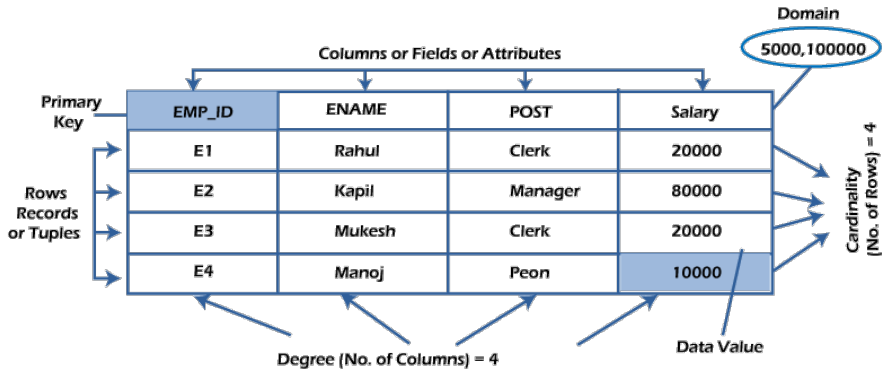
L5: data indexing

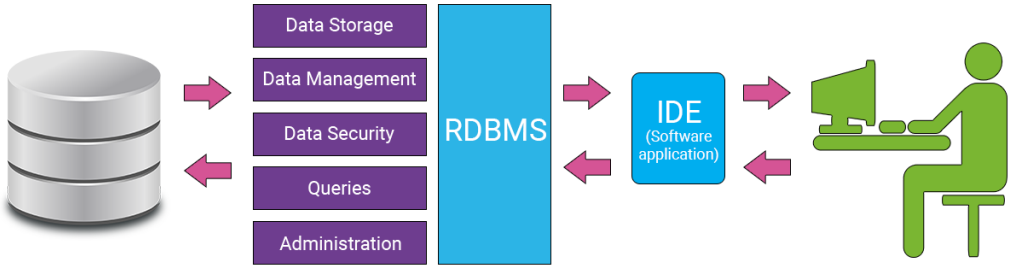
1. Data Storage
2. Records and Files
3. Hashed Files
4. Indexing Techniques
5. Tree Data Structure

Relational databases

- A relational database is based on the relational model of data.
- A relational database management system (RDBMS) is a system to maintain relational databases.
- Many relational database systems are equipped with the option of using the SQL (Structured Query Language) for querying and maintaining the database.



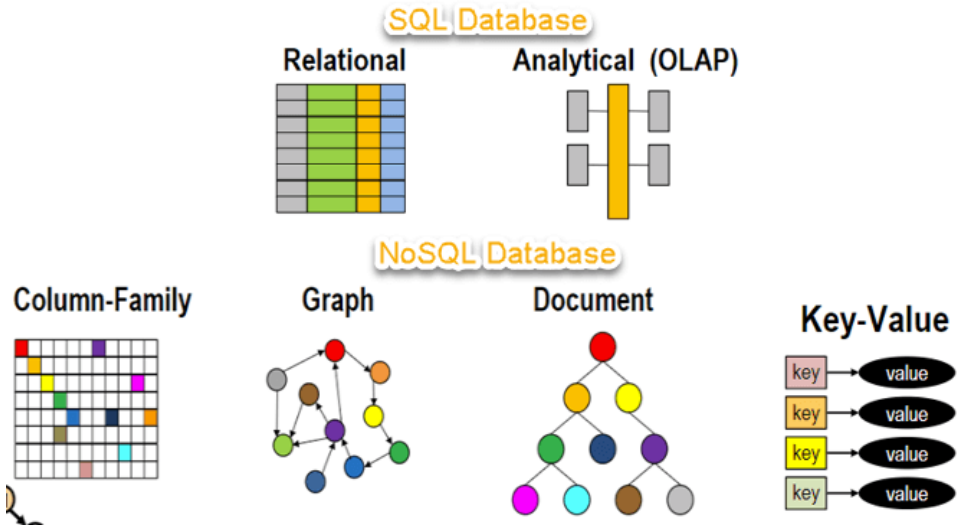




NoSQL databases

NoSQL databases are geared toward managing large sets of varied and frequently updated data, often in distributed systems or the cloud. They avoid the rigid schemas associated with relational databases. But the architectures themselves vary and are separated into four primary classifications, although types are blending over time.

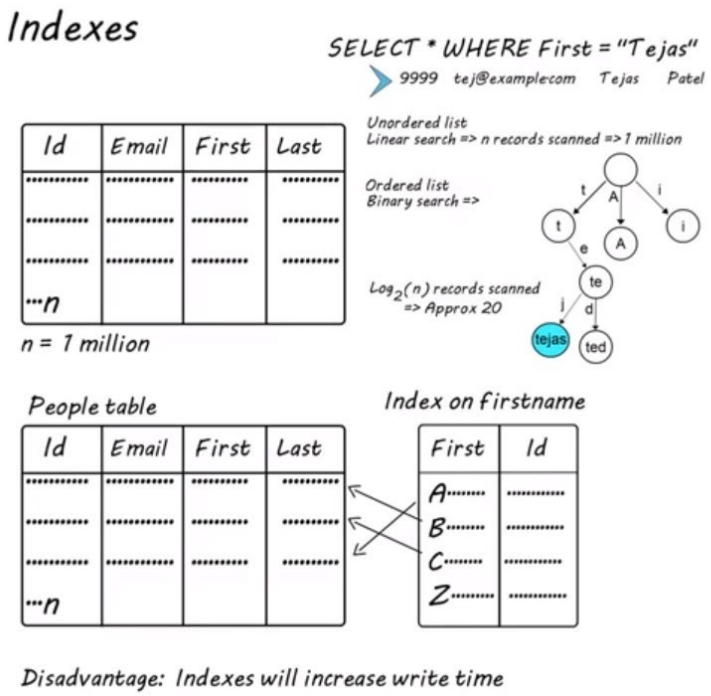
- NoSQL stands for:
  - No Relational
  - No RDBMS
  - Not Only SQL

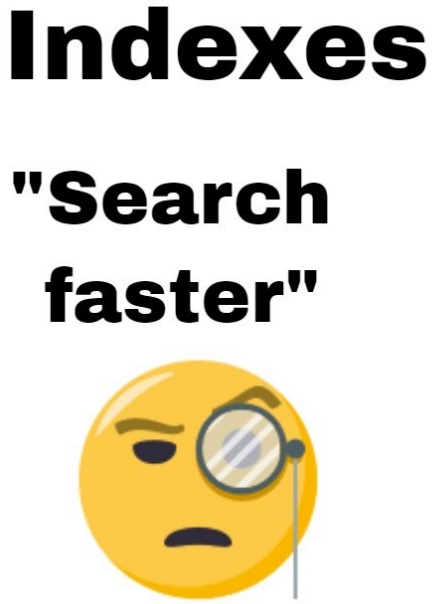


- NoSQL is an umbrella term for all databases and data stores that don't follow the RDBMS principles
  - A class of products
  - A collection of several (related) concepts about data storage and manipulation
  - Often related to large data sets

Data indexing

A **database index** is a data structure that improves the speed of data retrieval operations on a database table at the cost of additional writes and storage space to maintain the index data structure.





Unordered records (Heap files)

Ordered records (Sorted files)

Hashed records

B and B+ tree data structure for indexing

B+ tree index

- Most implementations of a dynamic multilevel index use a variation of the B-tree data structure called a B+-tree.
- In a B+-tree, data pointers are stored only at the leaf nodes of the tree.
  - The pointers in internal nodes are tree pointers to blocks that are tree nodes.
  - The pointers in leaf nodes are data pointers to the data file records.
- Because entries in the internal nodes of a B+-tree does not include data pointers, more entries (tree pointers) can be packed into an internal node and thus fewer levels (higher capacity).
- The leaf nodes of a B+-tree are usually linked to provide ordered access on the search field to the records.

L6: data querying

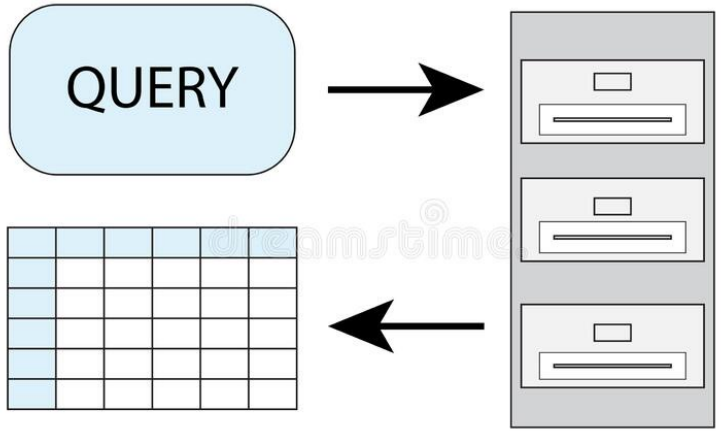
1. Overview of data querying
2. Relational algebra and SQL querying
3. NoSQL querying

Data querying

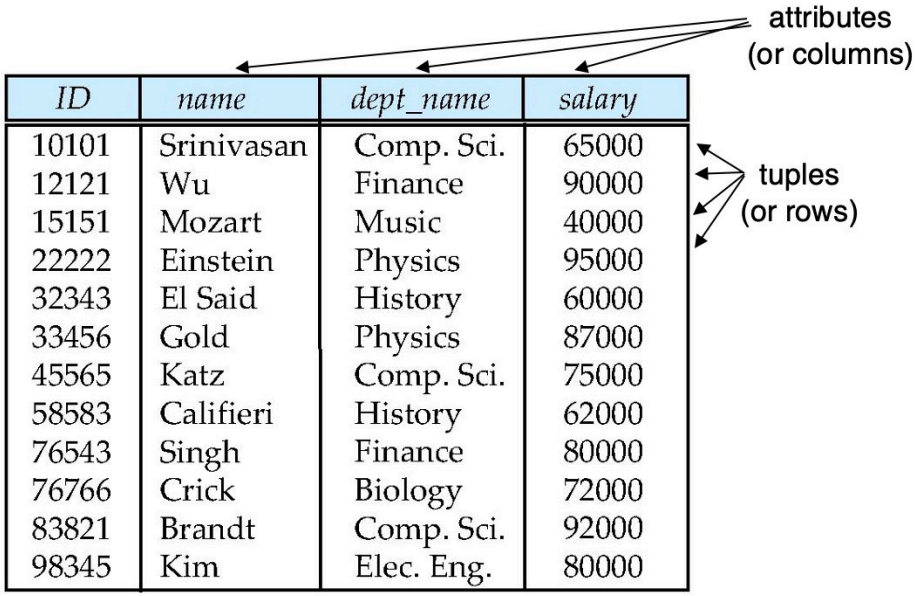
A data query is either an action query or a select query.

A select query is one that retrieves data from a database.

An action query asks for additional operations on data, such as insertion, updating, deleting or other forms of data manipulation.



Relational databases and relational algebra



ID	*name*	*dept_name*	*salary*
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Relational databases

Six basic operators
- select: σ
- project: Π
- union: $\cup$
- set difference: –
- Cartesian product: x
- rename: ρ

Additional operations that simplify common queries
- set intersection
- join
- assignment
- outer join

Relational algebra

SQL – Select

Select *<List of Columns and expressions (usually involving columns)>*

From *<List of Tables & Join Operators>*

Where *<List of Row conditions joined together by And, Or, Not>*

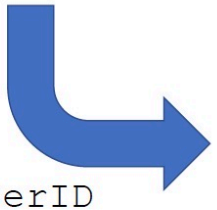
Group By *<list of grouping columns>*

Having *<list of group conditions connected by And, Or, Not >*

Order By *<list of sorting specifications>*

Payroll

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	120000
789	Dan	Prof	100000



Name	UserID
Jack	123
Allison	345

```
SELECT P.Name, P.UserID
  FROM Payroll AS P
 WHERE P.Job = 'TA';
```

NoSQL querying – document databases as an example

- E.g., MongoDB querying: Mongo query language
  - Targets a specific collection of documents
  - Specifies criteria that identify the returned documents
  - May include a projection to specify returned fields
  - May impose limits, sort, orders, …
- Basic query - all documents in the collection:
  - db.users.find()
  - db.users.find({})
- E.g.,

```
db.inventory.find({ type: "snacks" })
```

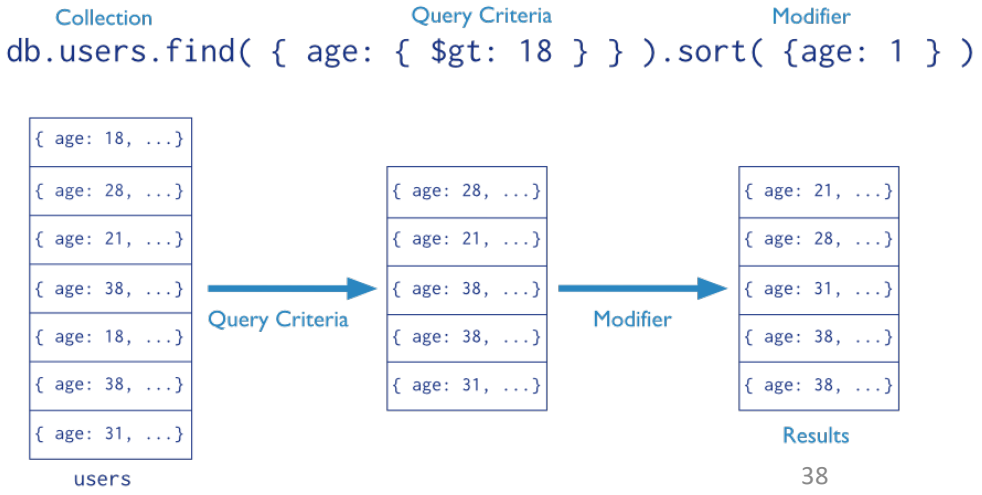
All documents from collection inventory where the type field has the value snacks

```
db.inventory.find({ type: { $in: [ 'food', 'snacks' ] } } )
```

All inventory docs where the type field is either food or snacks

```
db.inventory.find( { type: 'food', price: { $lt: 9.95 } } )
```

All ... where the type field is food and the price is less than 9.95

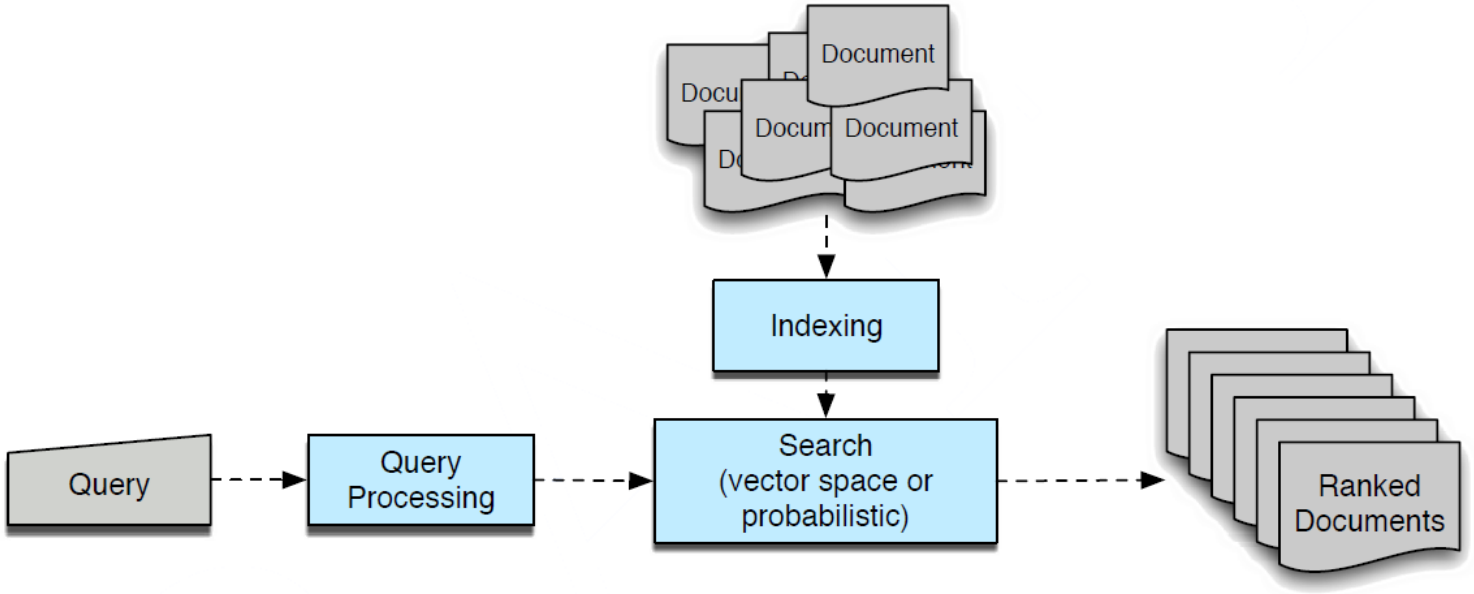


L7&L8: data-driven applications

1. Information retrieval
2. Recommendations
3. Social network analysis
4. Anomaly detection

Process of information retrieval

- Some of the key issues
  - Information need: query and query processing
  - Relevance: indexing documents and search algorithm
  - Evaluation: document ranking, precision-recall, etc.

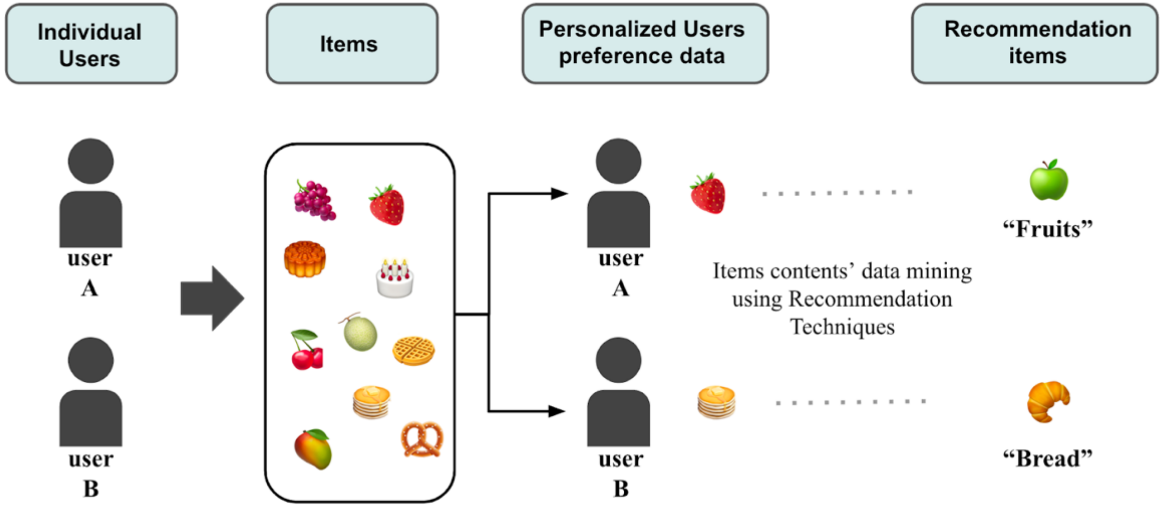


How to find relevant documents for a query?

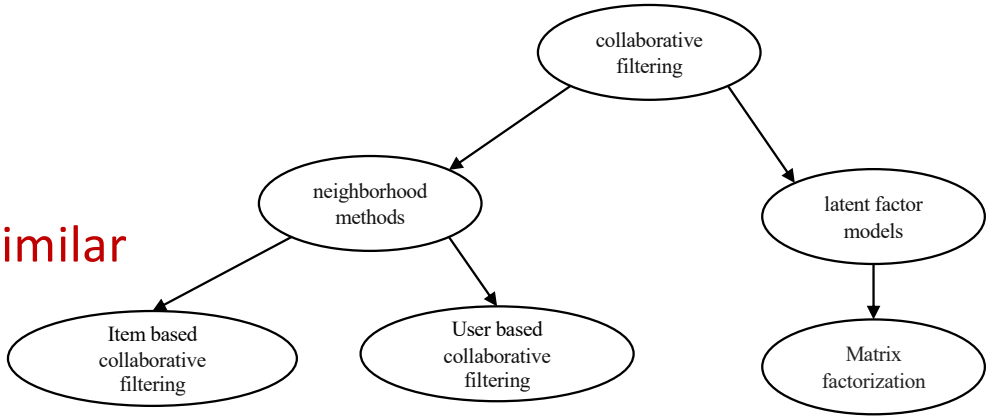
- By keyword matching
  - ❑Boolean model
- By similarity
  - ❑Vector space model
- By imaging how to write out a query
  - ❑How likely a query is written with this document in mind.
  - ❑Generate with some randomness
  - ❑Query generation language model
- By trusting how other web pages think about the web page
  - ❑Pagerank, hits
- By trusting how other people find relevant documents for the same or similar query
  - ❑Learning to rank

Recommender systems

- Recommender systems: a subclass of information filtering system that provide suggestions for items that are most pertinent (of interest) to a particular user.

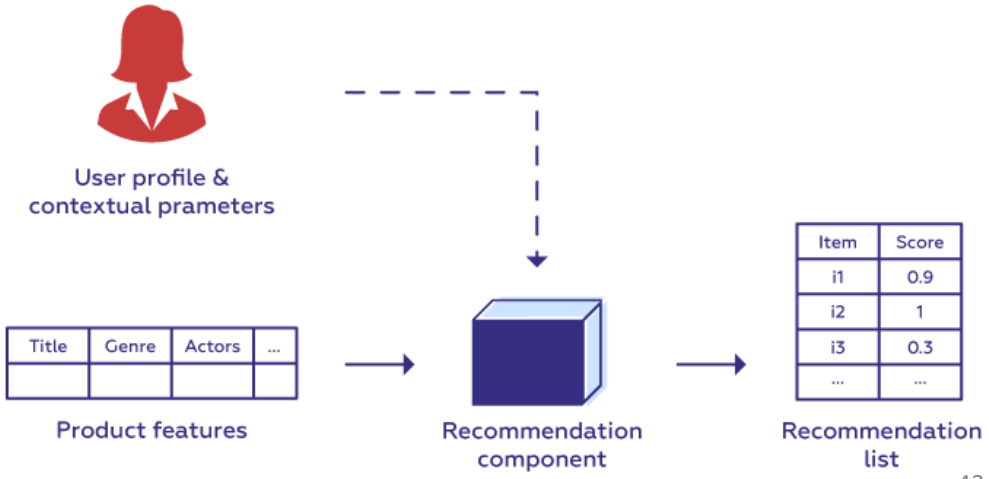


Collaborative filtering



- Item/User based collaborative filtering: find similar items/users and recommend similar items.
- Matrix factorization: represent each item and user as an embedding vector and calculate their preference score (e.g., inner product).

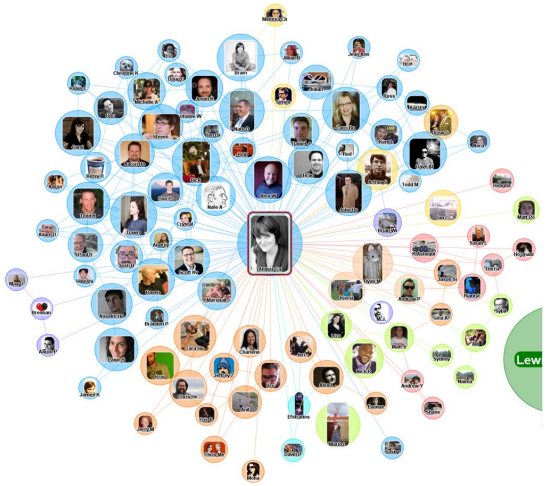
A user/An item profile is a collection of settings and information associated with a user/an item.

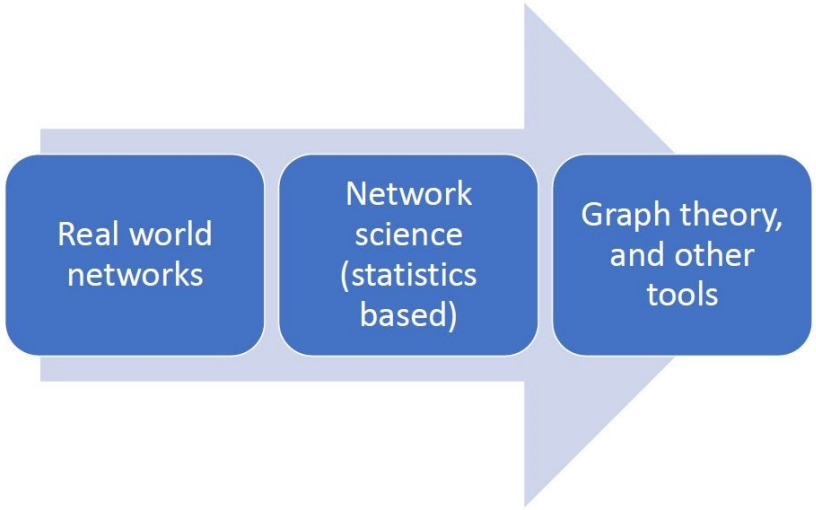


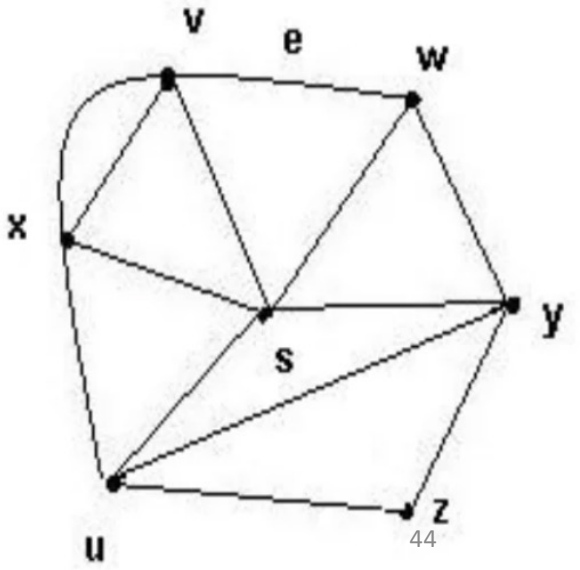
Social network analysis – graph theory

Graph theory is a branch of discrete mathematics concerned with proving theorems and developing algorithms for arbitrary graphs (e.g. random graphs, lattices, hierarchies).

Graph theory and network science

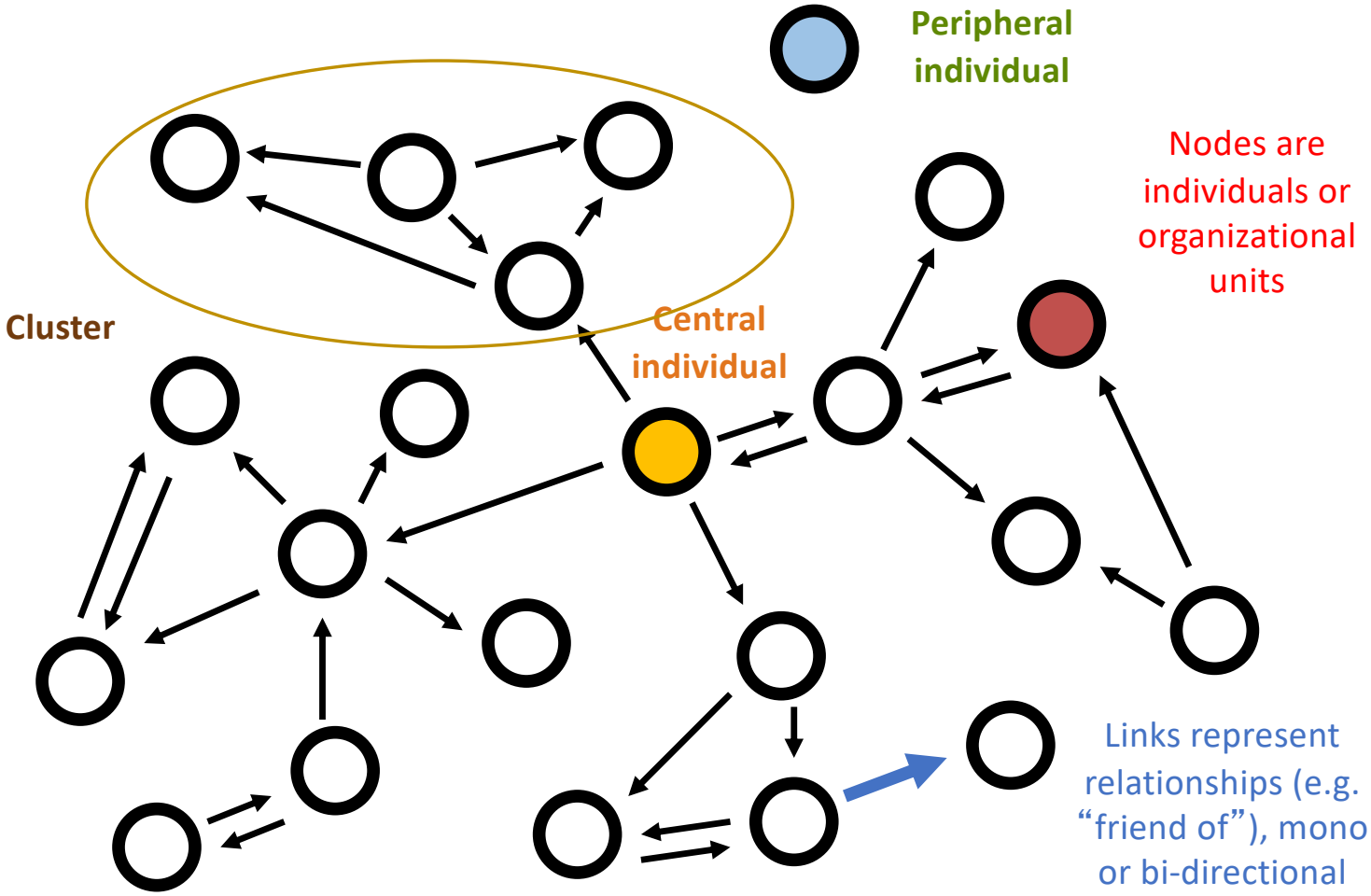






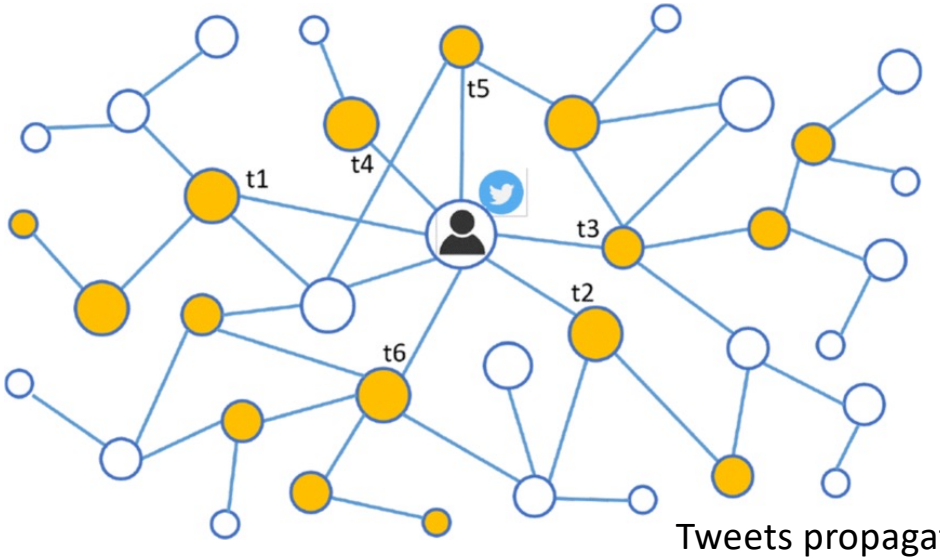
Sociograms

A **sociogram** is a graphic representation of social links that a person has. It is a graph drawing that plots the structure of interpersonal relations in a group situation.

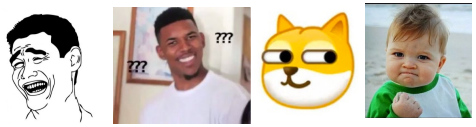


Social network analysis example – network propagation

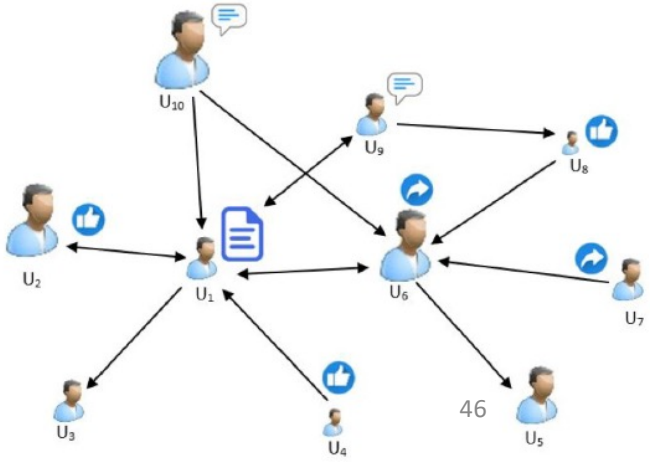
- **Network propagation** refers to a class of algorithms that integrate information from input data across connected nodes in a given network.
- Study the dynamics of network propagation, i.e., how data/information is spread across networks, and how networks are influenced in the meantime.
  - Epidemic/Virus spread model
- Applications
  - News/Tweets/Memes/Trends propagation
  - Rumer/Fake news detection



Tweets propagation



Memes = social genes



Fake news detection

Anomaly detection overview

Anomaly detection: the identification of rare items, events or observations which deviate significantly from the majority of the data and do not conform to a well defined notion of normal behavior.

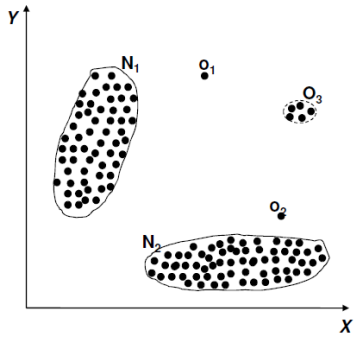
Historically, the field of statistics tried to find and remove outliers as a way to improve analyses.

There are now many fields where the outliers / anomalies are the objects of greatest interest.

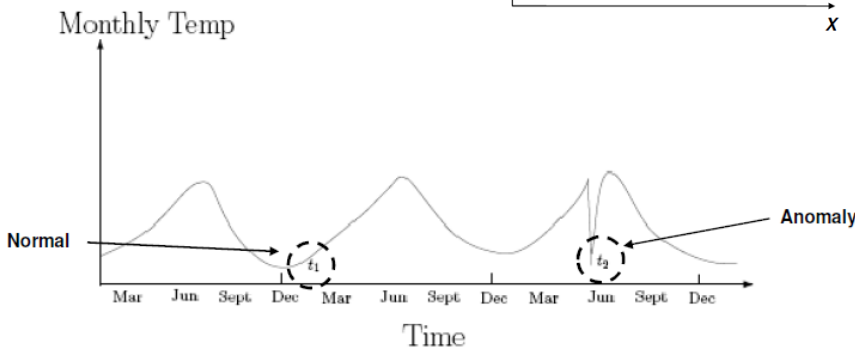
- The rare events may be the ones with the greatest impact, and often in a negative way.

Structure of anomalies

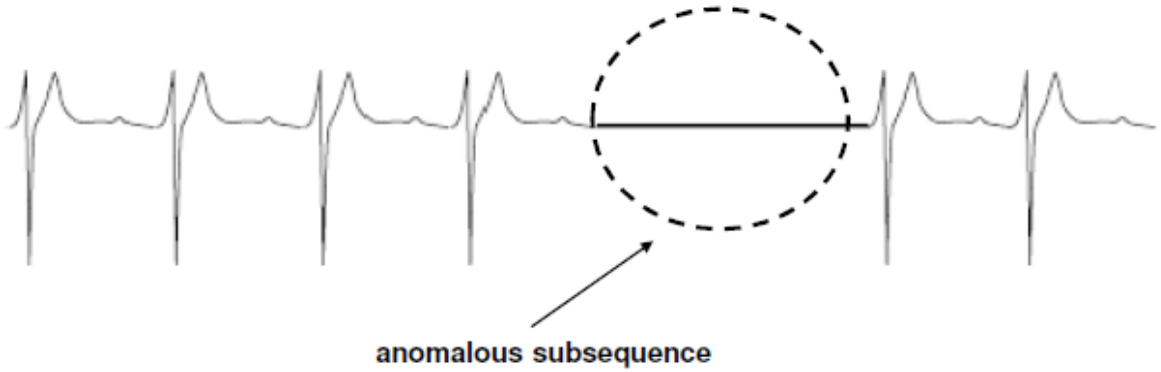
- Point anomalies



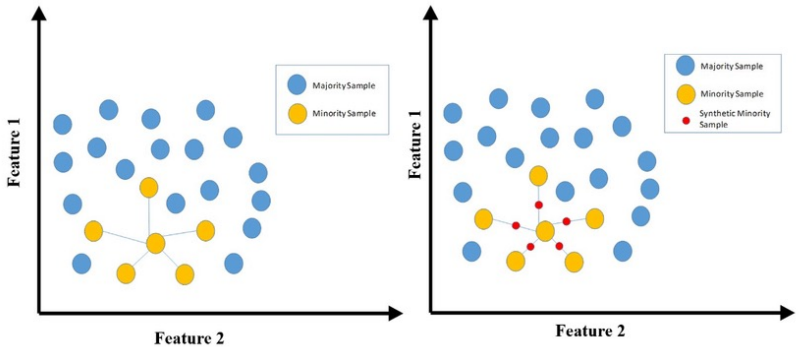
- Contextual anomalies



- Collective anomalies

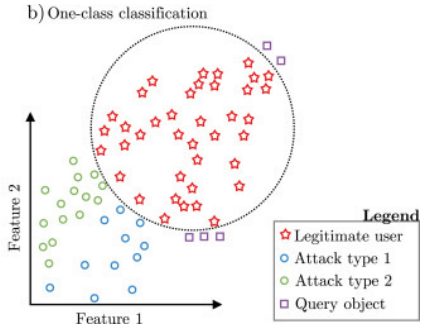


Data labels for anomaly detection



Supervised anomaly detection

- Labels available for both normal data and anomalies
- Similar to classification with high class imbalance
- Data augmentation solution: SMOTE (Synthetic Minority Oversampling TEchnique) is an oversampling technique where the synthetic samples are generated for the minority class.

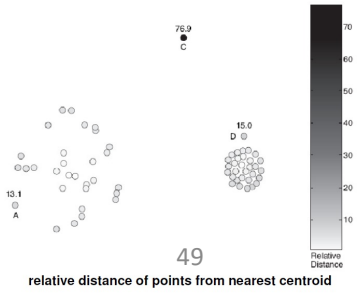


Semi-supervised anomaly detection

- Labels available only for normal data
- One class classification solution: only learning normal pattern

Unsupervised anomaly detection

- No labels assumed
- Based on the assumption that anomalies are very rare compared to normal data

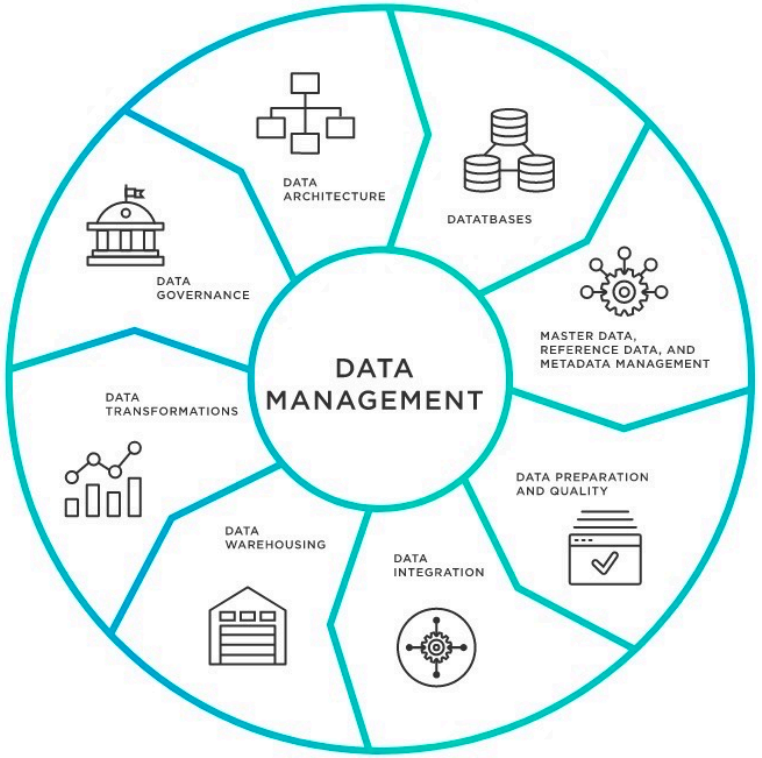


L9: data management

1. What is Data Management
2. Data Quality
3. Data Security
4. Data Privacy

What is data management?

- Data management is the practice of collecting, keeping, and using data securely, efficiently, and cost-effectively.
- As organizations create and consume data at unprecedented rates, data management solutions become essential for making sense of the vast quantities of data.
- Today's leading data management software ensures that reliable, up-to-date data is always used to drive decisions.



Data quality dimensions

Six main dimensions of data quality

Accuracy: The data should reflect actual, real-world scenarios; the measure of accuracy can be confirmed with a verifiable source.

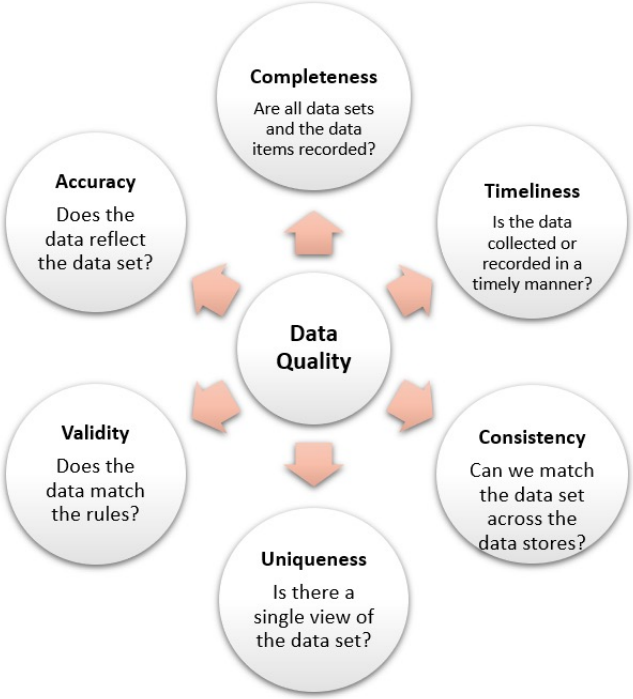
Completeness: Completeness is a measure of the data's ability to effectively deliver all the required values that are available.

Consistency: Data consistency refers to the uniformity of data as it moves across networks and applications. The same data values stored in difference locations should not conflict with one another.

Validity: Data should be collected according to defined business rules and parameters, and should conform to the right format and fall within the right range.

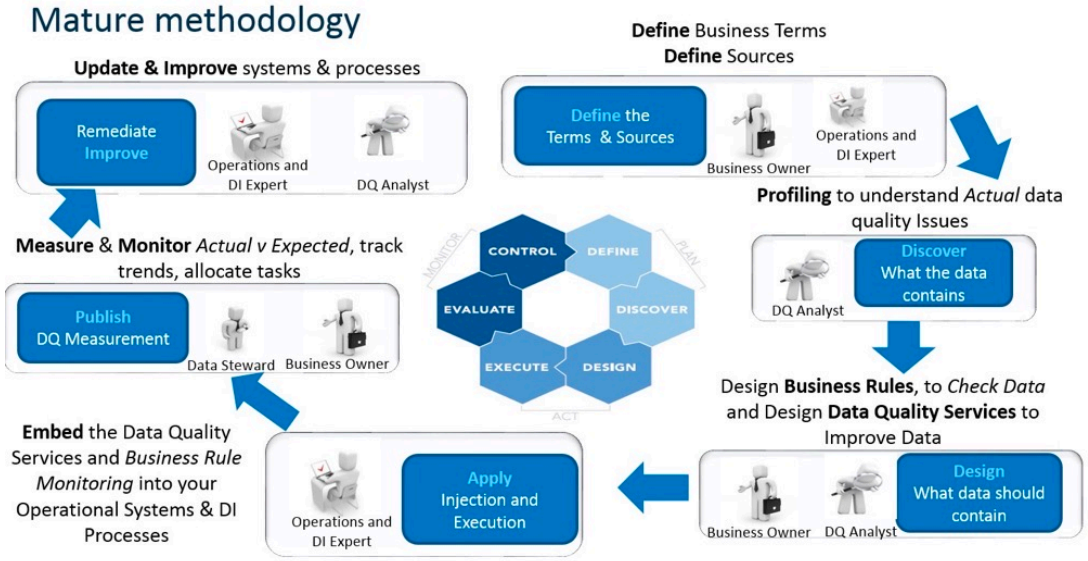
Uniqueness: Uniqueness ensures there are no duplications or overlapping of values across all data sets. Data cleansing and deduplication can help remedy a low uniqueness score.

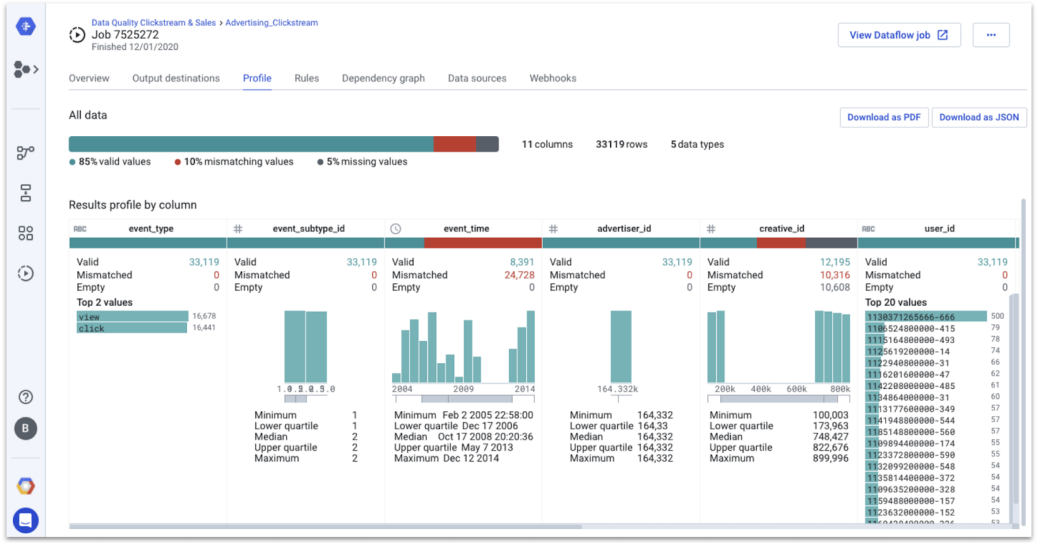
Timeliness: Timely data is data that is available when it is required. Data may be updated in real time to ensure that it is readily available and accessible.



How to improve data quality? An example

- **Data quality monitoring** - frequent data quality checks are essential. Data quality software in combination with machine learning can automatically detect, report, and correct data variations based on predefined business rules and parameters.





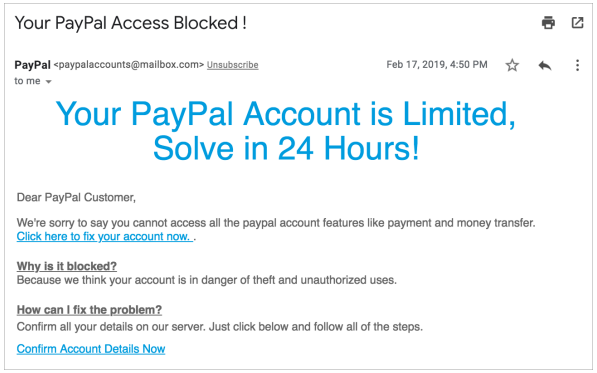
What is data security?

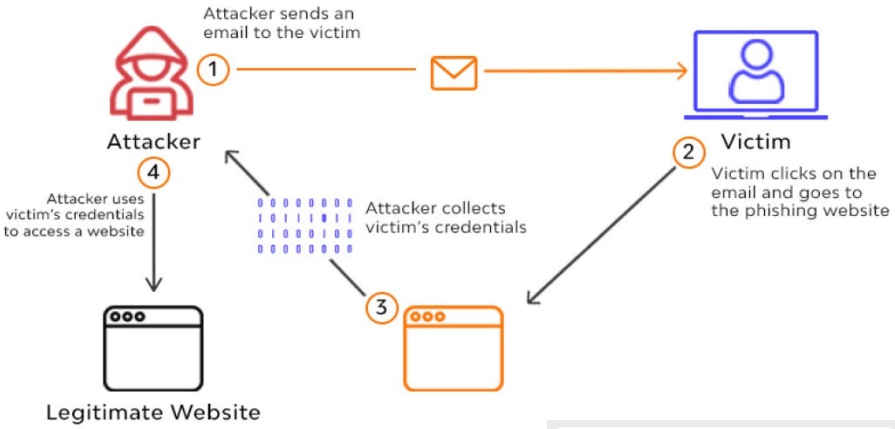
- **Data security is the process** of safeguarding digital information throughout its entire life cycle to protect it from corruption, theft, or unauthorized access.
  - It covers everything—hardware, software, storage devices, and user devices; access and administrative controls; and organizations' policies and procedures.
- **Data security uses tools and technologies** that enhance visibility of a company's data and how it is being used. These tools can protect data through processes like data masking, encryption, and redaction of sensitive information. The process also helps organizations streamline their auditing procedures and comply with increasingly stringent data protection regulations.

Data security risks example

- **Phishing Attacks**

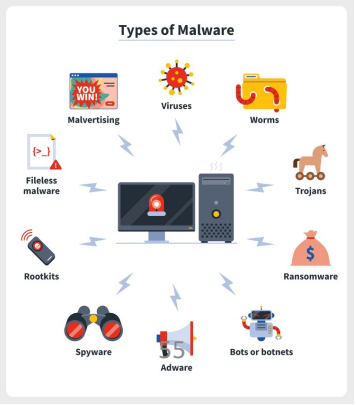
In a phishing attack, a cyber criminal sends messages, typically via email, short message service (SMS), or instant messaging services, that appear to be from a trusted sender. Messages include malicious links or attachments that lead recipients to either download malware or visit a spoofed website that enables the attacker to steal their login credentials or financial information.





- **Malware**

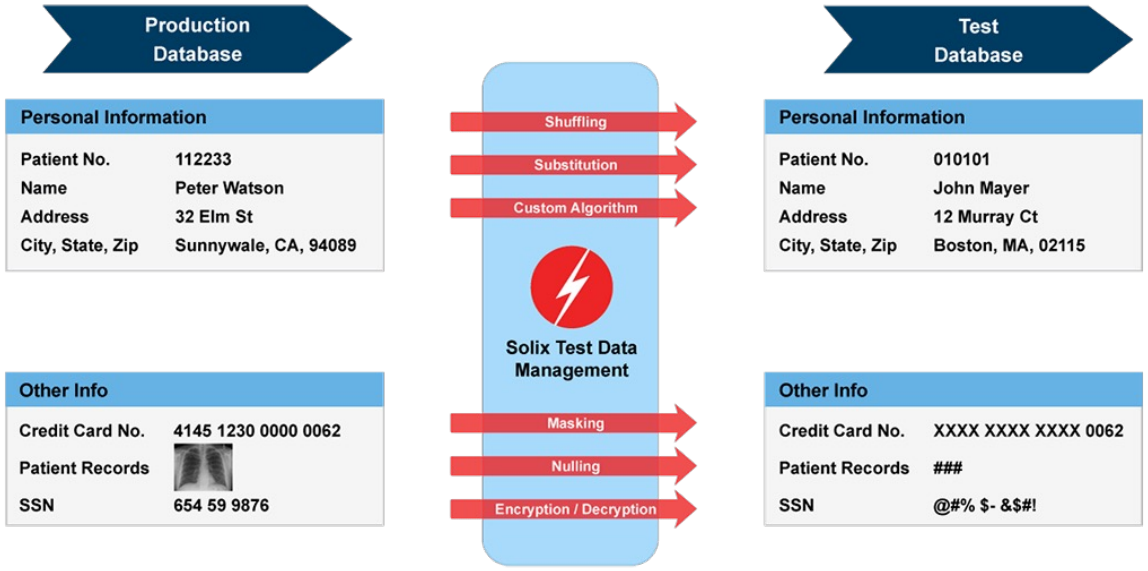
Malicious software is typically spread through email- and web-based attacks. Attackers use malware to infect computers and corporate networks by exploiting vulnerabilities in their software, such as web browsers or web applications. Malware can lead to serious data security events like data theft, extortion, and network damage.

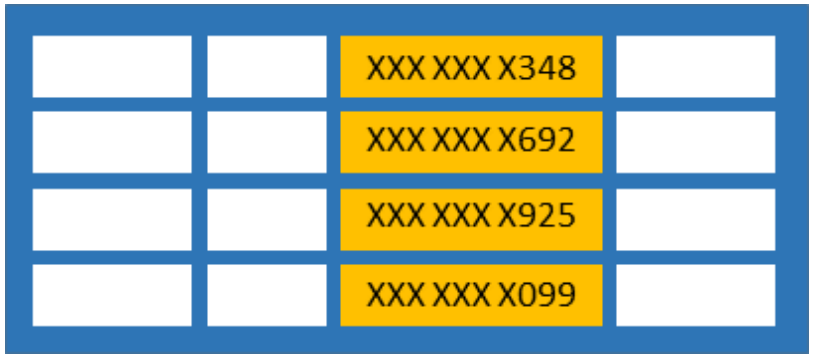


How to achieve data security? An example

- **Data Masking**

  Data masking enables an organization to hide data by obscuring and replacing specific letters or numbers. This process is a form of encryption that renders the data useless should a hacker intercept it. The original message can only be uncovered by someone who has the code to decrypt or replace the masked characters.

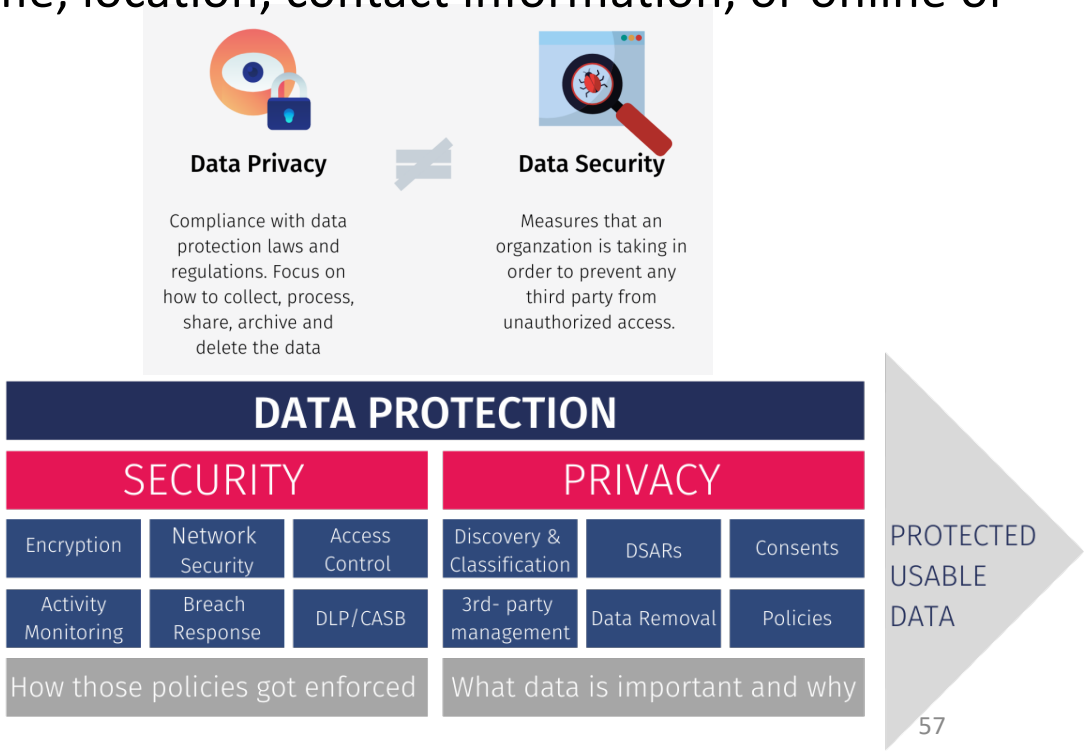




Data privacy

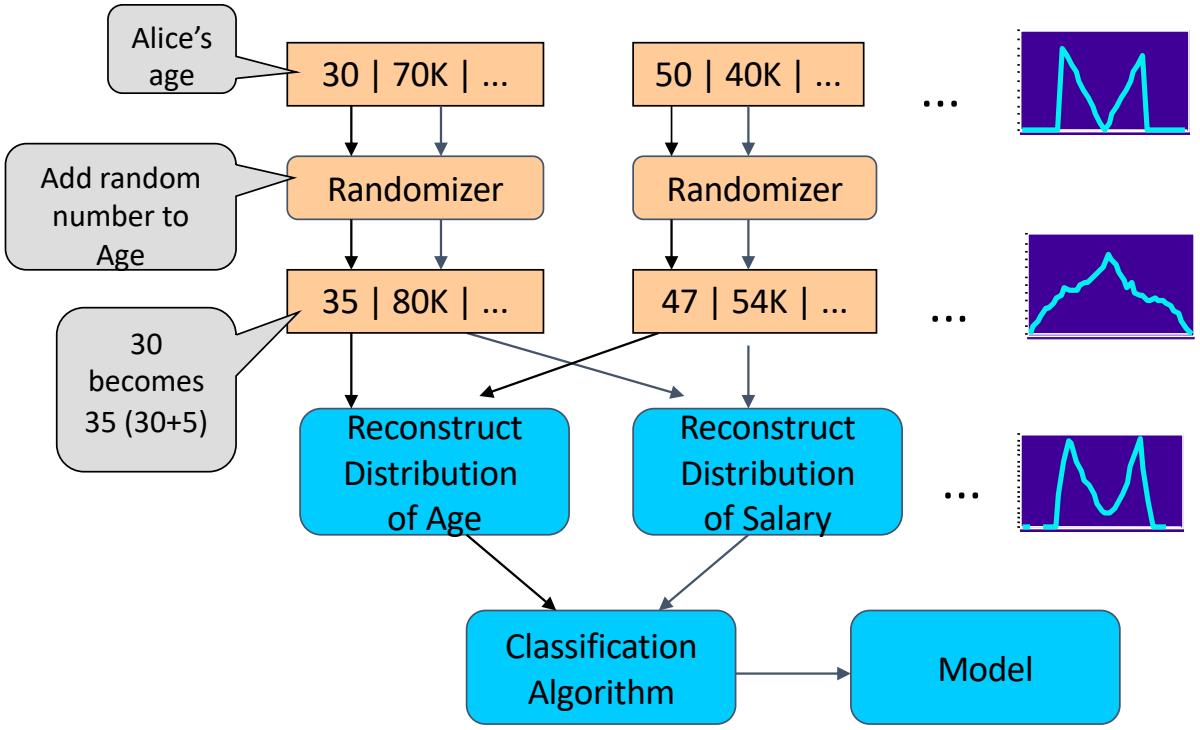
Data privacy generally means the ability of a person to determine for themselves when, how, and to what extent personal information about them is shared with or communicated to others, or being used.

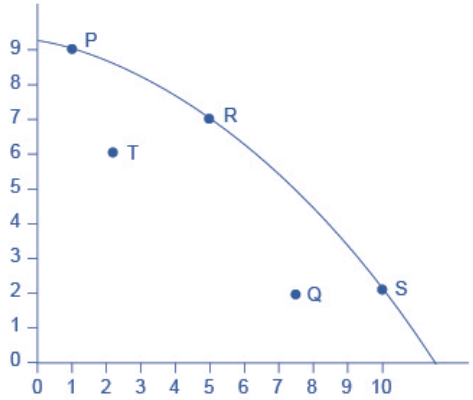
This personal information can be one's name, location, contact information, or online or real-world behavior.



Privacy preserving method example: data perturbation

- Perturb data with value distortion
  - User provides x_i+r instead of x_i
  - r is a random value
    - Uniform, uniform distribution between $[-\alpha, \alpha]$
    - Gaussian, normal distribution with $\mu = 0, \sigma$





Privacy-performance tradeoff
More noises
higher privacy, lower performance

L10: advanced topics and recent trends

1. Representation learning and multimodal learning
2. Data bias issues
3. Explainability

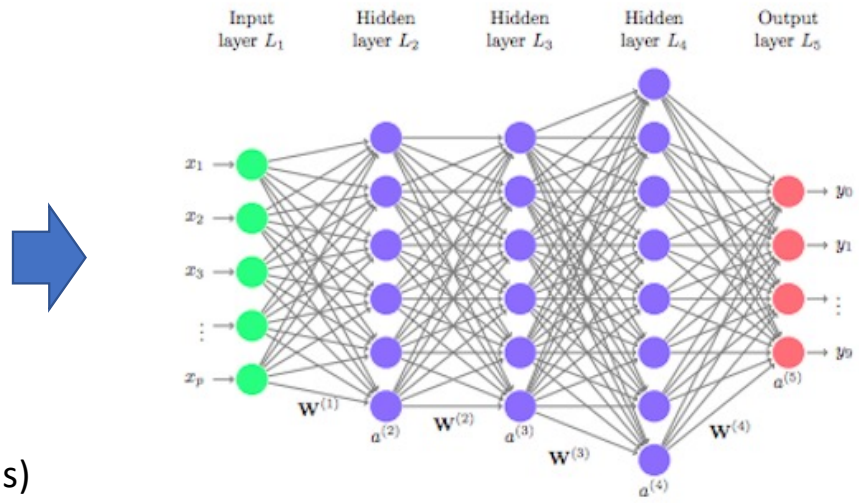
Deep learning for representation learning

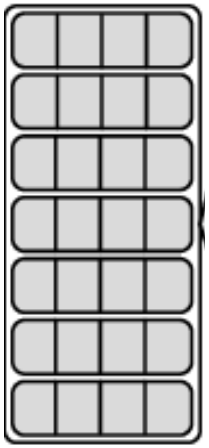
- **Deep learning maps** images, texts, speeches, etc. **into vectors** in representation spaces. If downstream tasks are trained together, then it is end-to-end.

Image pixels

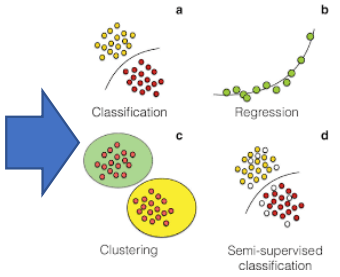
Speech signal waves

Text tokens (words)





Representations (latent vectors)



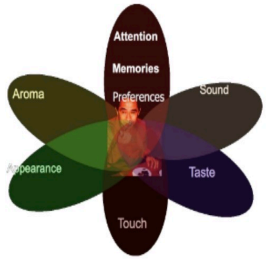
Downstream tasks

Multiple modalities

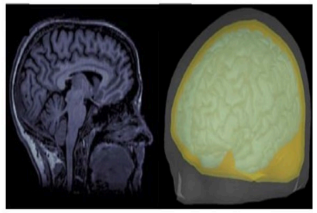
There are multiple types of modalities.

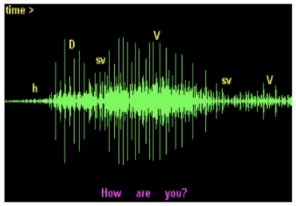
Natural language (both spoken or written)
Visual (from images or videos)
Auditory (including voice, sounds and music)
Haptics / touch
Smell, taste and self-motion
Physiological signals
- Electrocardiogram (ECG), skin conductance

Other modalities
- Infrared images, depth images, fMRI



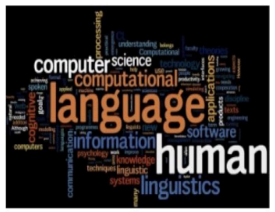
Psychology


Medical



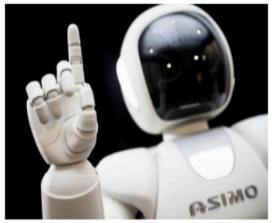
Speech


Vision

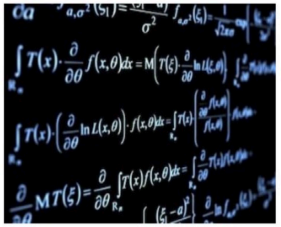


Language


Multimedia

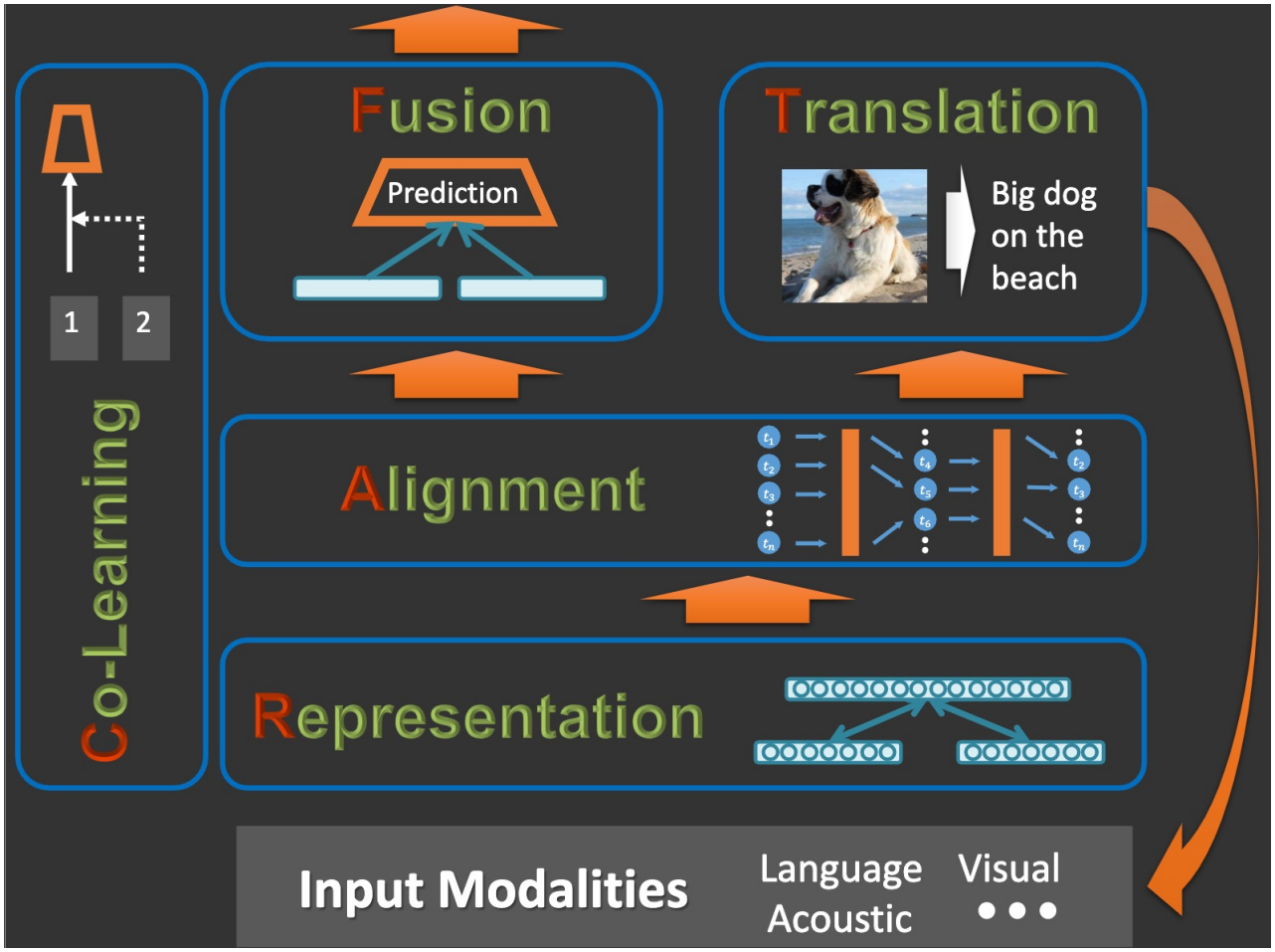


Robotics


Learning

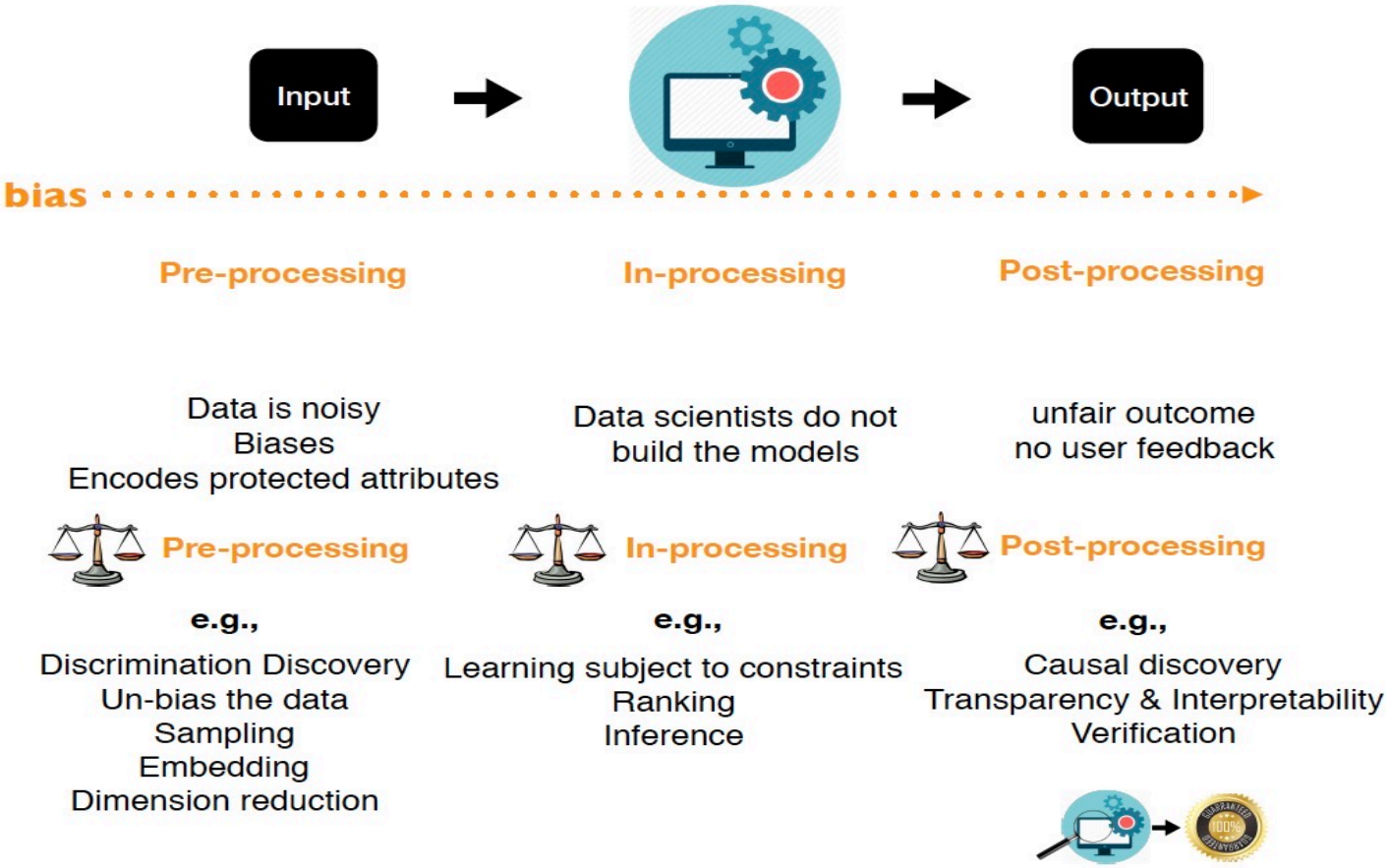
Core technical parts

- Representation
- Alignment
- Fusion
- Translation
- Co-learning



Pay attention to bias and fairness issues!

- Bias is across the data engineering pipeline!



Explainability

- Explainability can be defined as to "understand how a model arrives at its result, also referred to as the outcome explanation problem." If end-users are able to understand the reasoning behind the prediction, then it is assumed more trust will grow.

- Furthermore, this allows for a positive feedback loop from user to development interactions. Some characterizations of explainability include explanations for individual predictions or the model's prediction process as a whole.

Example: LIME surrogate model

- LIME for Local Interpretable Model-agnostic Explanations

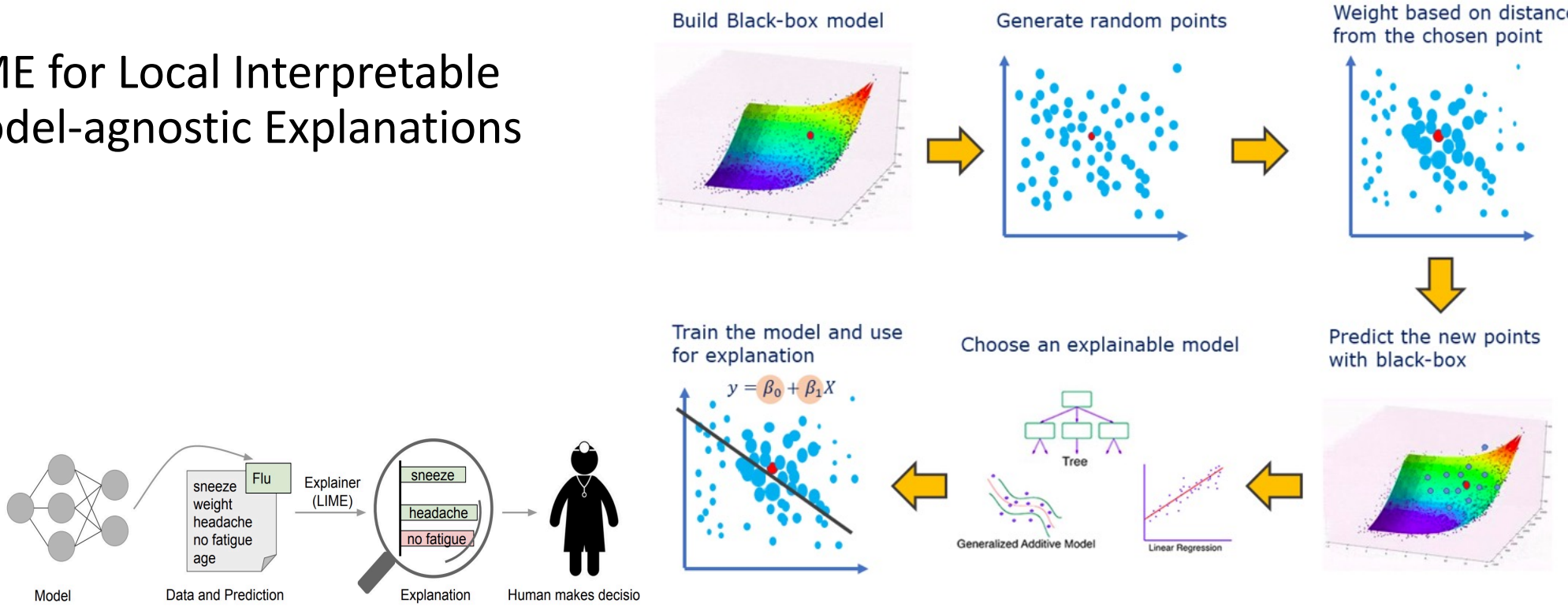


Figure 1: Explaining individual predictions. A model predicts that a patient has the flu, and LIME highlights the symptoms in the patient's history that led to the prediction. Sneeze and headache are portrayed as contributing to the "flu" prediction, while "no fatigue" is evidence against it. With these, a doctor can make an informed decision about whether to trust the model's prediction.

Assessment

- Continuous assessment (60%)
  - 2 individual homework assignments (each 15%)
  - 1 group project with presentations (30%)
- Final exam (40%)

Thanks for your attention!