Universitat Pompeu Fabra
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Data, Methods, and Scenarios

Mining Massive Datasets

Materials provided by Prof. Carlos Castillo — https://chato.cl/teach

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Main Sources

- Data Mining, The Textbook (2015) by Charu Aggarwal (Chapter 1) + slides by Lijun Zhang
- Mining of Massive Datasets, 2nd edition (2014) by Leskovec et al. (Chapter 1)
- Data Mining Concepts and Techniques, 3rd edition (2011) by Han et al. (Chapters 1-2)

Contents

- Types of data
- Types of problem
- Example scenarios
- Major challenges

Data types

Nondependency / Dependency

- **Nondependency oriented** data can be structured so items are separate
  - Relational data, text data
- **Dependency oriented** data includes relationships between items
  - Graphs, time series

Mixed attribute data

- Most attributes we will deal with are numerical, they quantify something
- Sometimes attributes are categorical
  - Example: elephant, tiger, moose, ...
  - Binary (two categories)
    - Example: present, absent
  - Ordinal (two or more categories that can be naturally sorted)
    - Example: low, medium, high
- Real-world datasets include a mixture of types

Binary attributes, sets, dummy vars.

- Every binary attribute can be used as a marker of belonging to a set and viceversa
- **One-hot encoding**: every categorical attribute taking one of k values can be encoded as k “dummy” binary attributes

Name	Zip code	Parent	Capacity
Moog	08001	NULL	Small
Macarena	08002	NULL	Small
Input	08038	NULL	Medium
Loft	08018	Razzmatazz	Large
Nitsa	08004	Apolo	Large

Question

- Suppose you encode *capacity* using one-hot encoding. How many columns will your new dataset have?

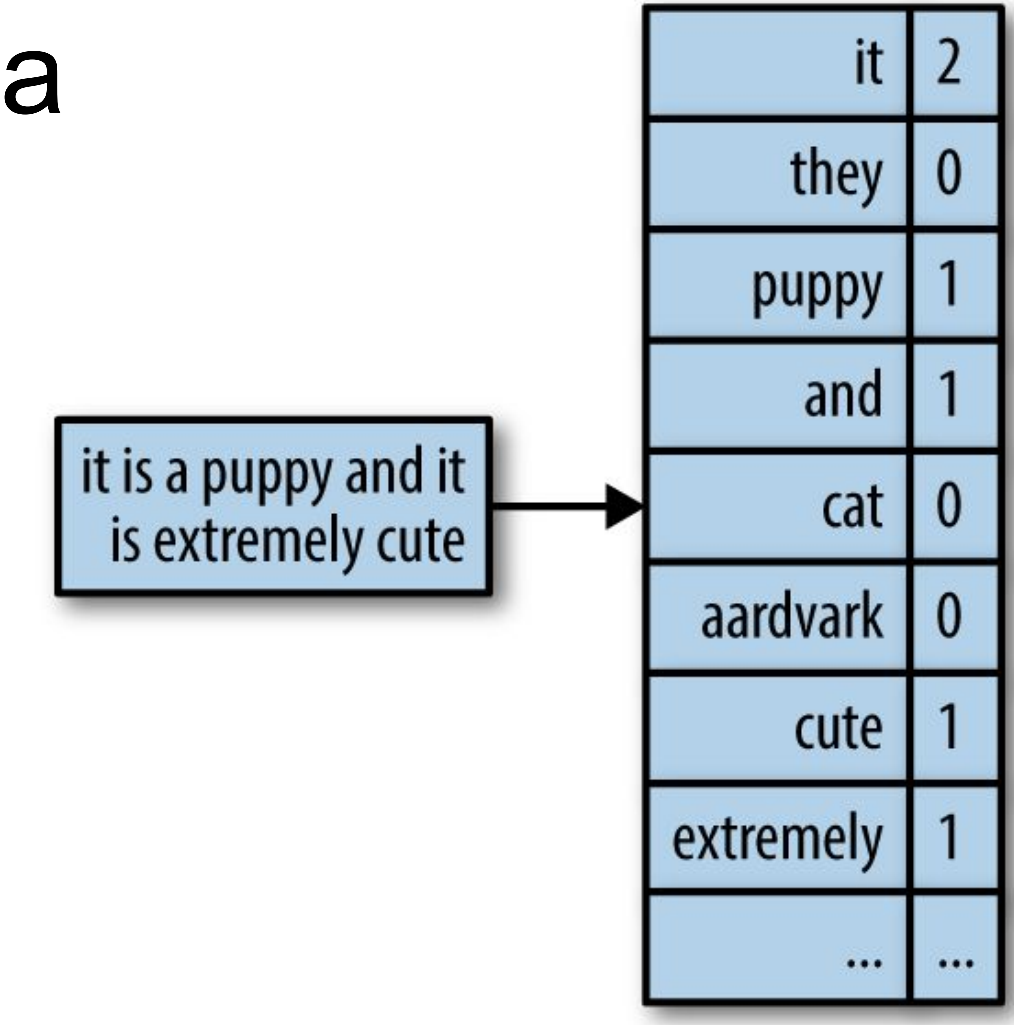
Name	Zip code	Parent	Capacity
Moog	08001	NULL	Small
Macarena	08002	NULL	Small
Input	08038	NULL	Medium
Loft	08018	Razzmatazz	Large
Nitsa	08004	Apolo	Large

Answer: 6 columns

1. Name
2. Zipcode
3. Parent
4. Capacity_Small
5. Capacity_Medium
6. Capacity_Large

Textual data

- Text can be represented as:
  - As a string
  - **“Bag of words”**: a set of binary variables, one for each word in the dictionary, with value True iff the word belongs to the text
  - **“Vector space”**: a set of numerical variables indicating number of occurrences (often normalized by collection frequency)



it is a puppy and it is extremely cute

it	2
they	0
puppy	1
and	1
cat	0
aardvark	0
cute	1
extremely	1
...	...

http://uc-r.github.io/creating-text-features

Time series data

- **Contextual** attributes
  - Timestamps, sequence number, …
- **Behavioral** attributes
  - Readings of a sensor, value of the variable, …

Multivariate time series data has multiple behavioral attributes

Spatial data

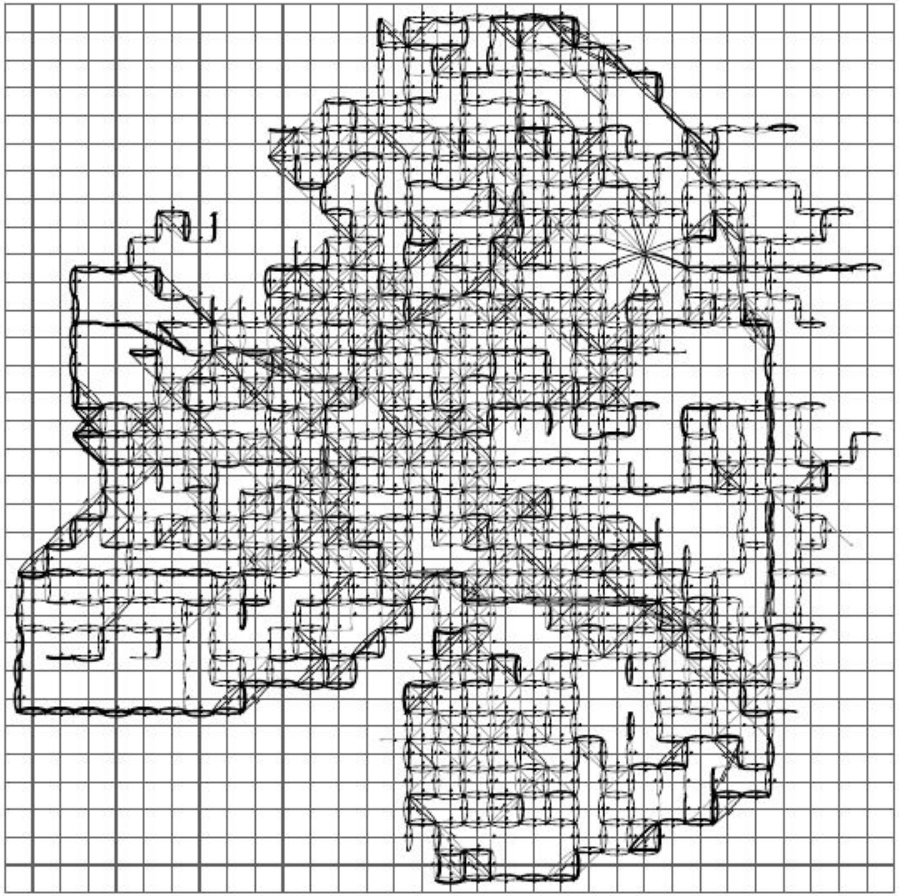
- **Two** (lat/long) or **three** (lat/long/elevation) spatial attributes
- **Remote sensing** data, including satellite and aerial photos

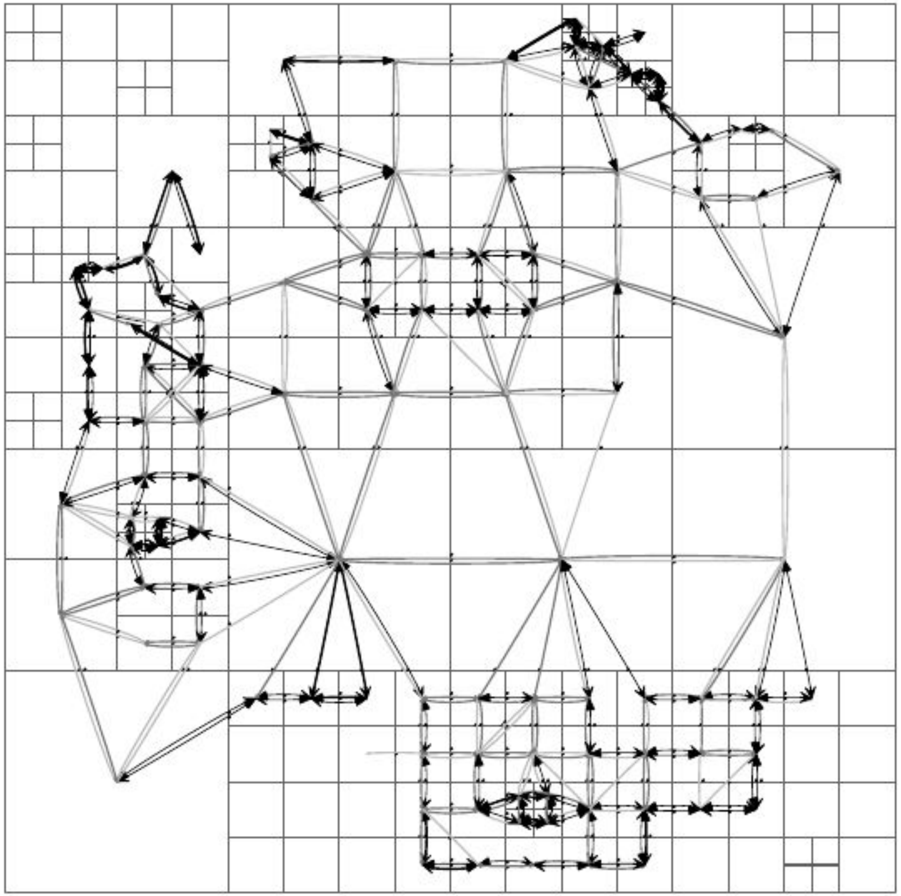
Spatiotemporal data

Two main representations:

- Spatial and temporal attributes are contextual
    - Example: sea surface temperature
- Temporal attribute is contextual, spatial attribute is behavioral
    - Example: trajectories

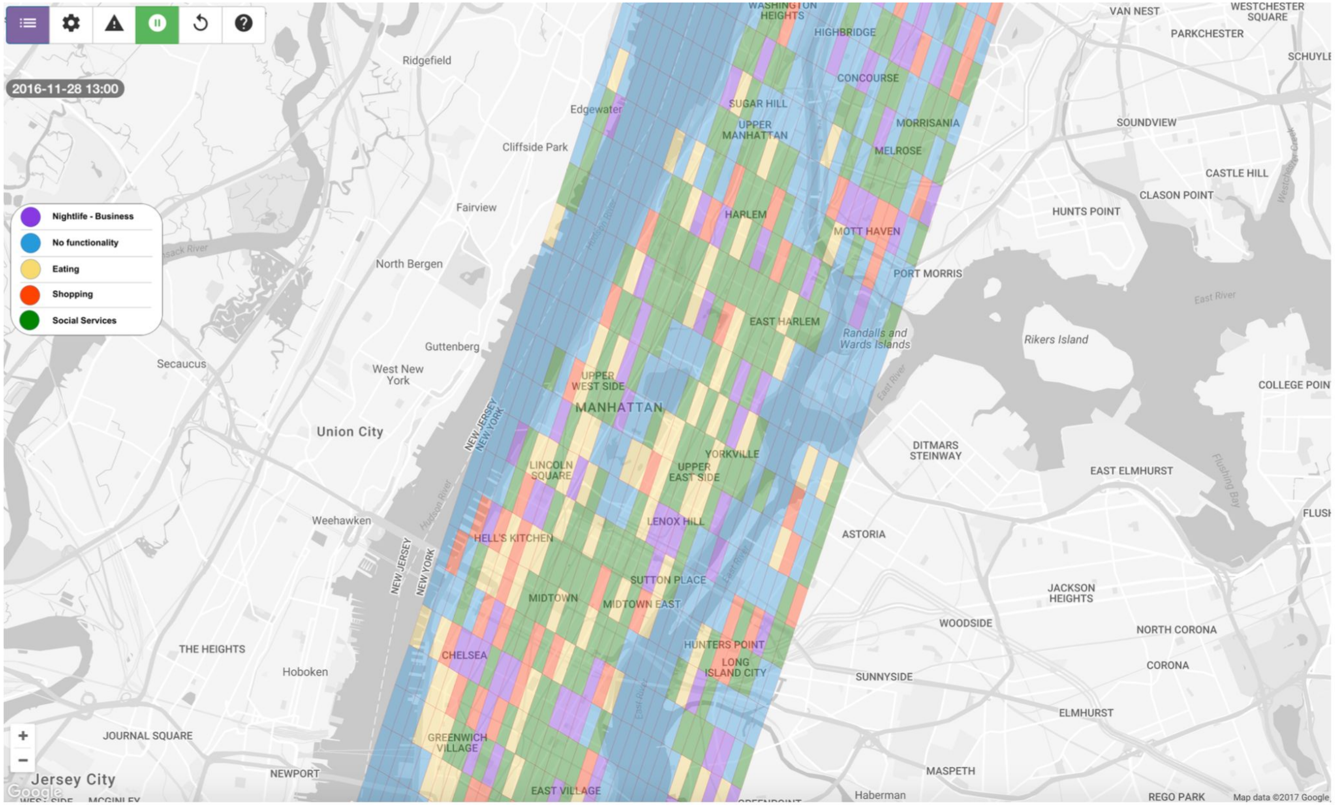
Example: trajectory data aggregation





Bonchi, F., Castillo, C., Donato, D., & Gionis, A. (2009). Taxonomy-driven lumping for sequence mining.
Data Mining and Knowledge Discovery, 19(2), 227-244.

Example: Functional regions in cities



H. Assem, B. Caglayan, T.S. Buda, D. O'Sullivan. ST-DenNetFus: Deep Spatio-Temporal Dense Networks for Network Demand Prediction. The European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases, 2018

Problem types

Data mining methods try to find relationships

- **Between columns**
  - Find associations, correlations, …
  - If there is *one* key column: classification, prediction, ...
- **Between rows**
  - Find clusters
  - Detect outliers

Example:
Association pattern mining

- Sparse binary databases representing, e.g., items a person is interested in

$$\begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix} \in \{0,1\}^{5\times 4}$$

- The relative frequency of a pattern is its support

https://cs.nju.edu.cn/zlj/Course/DM_15.html

Association pattern mining (cont.)

- Given a binary $n \times d$ data matrix D,
  - determine all subsets of columns such that all the values in these columns take on the value True for at least a fraction *min_support* of the rows in the matrix.
- The relative frequency of a pattern is referred to as its support

Association pattern mining (cont.)

- The confidence of a rule A→B is
  - support(A U B) / support(A)
- Example:
  - { Chips, Olives } → { Beer }

Exercise

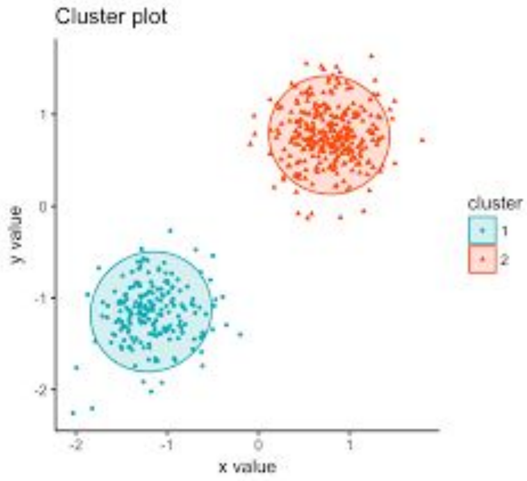
- The confidence of a rule A→B is
  - support(A U B) / support(A)
- Suppose
  - 10 people buy only Chips and Beer
  - 20 people buy only Chips and Olives
  - 30 people buy only Olives and Beer
  - 40 people buy all three: Chips, Olives, and Beer.

Answer

- The confidence of a rule A→B is: support(A U B) / support(A)
- Suppose
  - 10 people buy only Chips and Beer
  - 20 people buy only Chips and Olives
  - 30 people buy only Olives and Beer
  - 40 people buy all three: Chips, Olives, and Beer.
- Confidence of the rule { Chips, Olives } → { Beer } ?

support({Chip, Olives, Beer} / support({Chip, Olives}) = 40 / (40+20) = 2/3

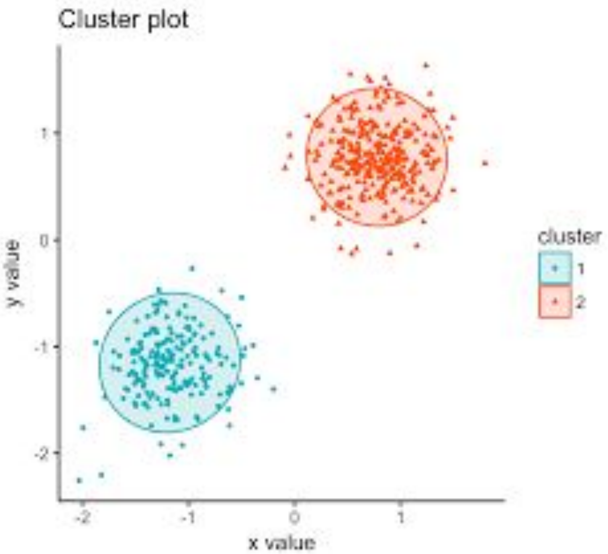
Clustering



- Partition records/rows in a way that
  - elements in the same partition are similar
  - elements in different partitions are different
- Applications:
  - Segmentation, summarization, …
  - Sometimes a step in a larger DM algorithm

Image credit: http://www.sthda.com/english/articles/tag/pam-clustering/

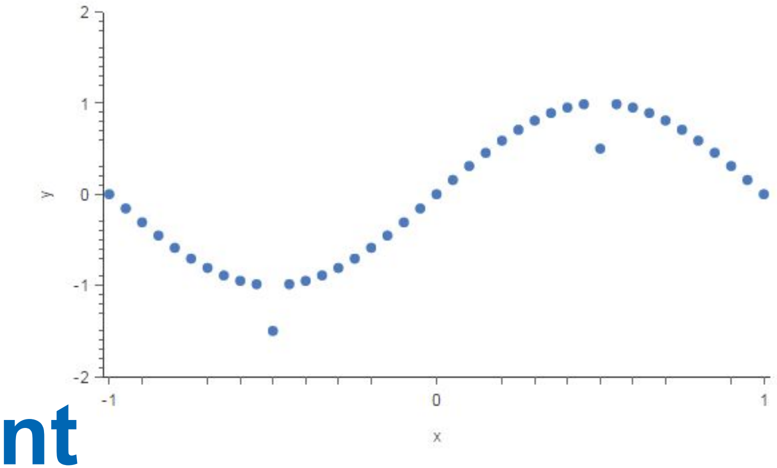
Clustering is not easy



- What does it mean to be similar?
- How many sets?
- Can a record/row belong to more than one set?
- Can a record/row belong to no set at all? ...

Image credit: sthda.com

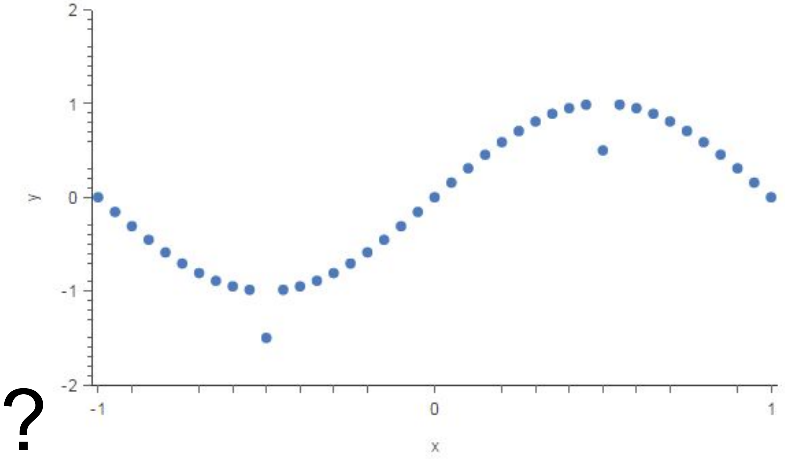
Outlier detection



- Given a database, find records/rows that are **different** from the rest of the database
- Applications:
  - Intrusion detection, credit card fraud, interesting sensor events, medical diagnosis, ...

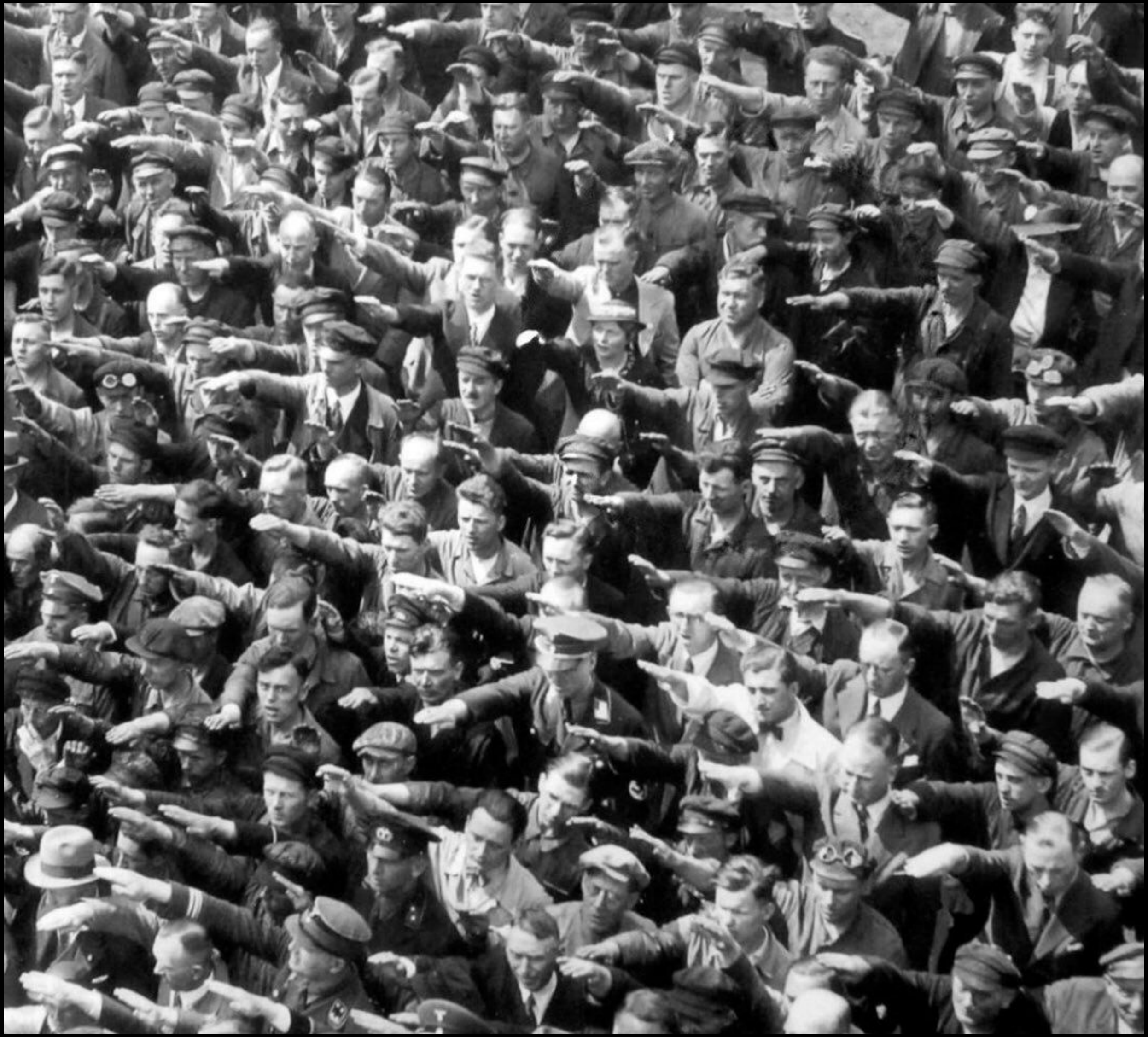
Image credits: https://www.kdnuggets.com/2017/01/3-methods-deal-outliers.html

Outlier detection is not easy



- How different should they be?
- How many can be different?
- What does it mean to be different?
- What should we do with outliers?

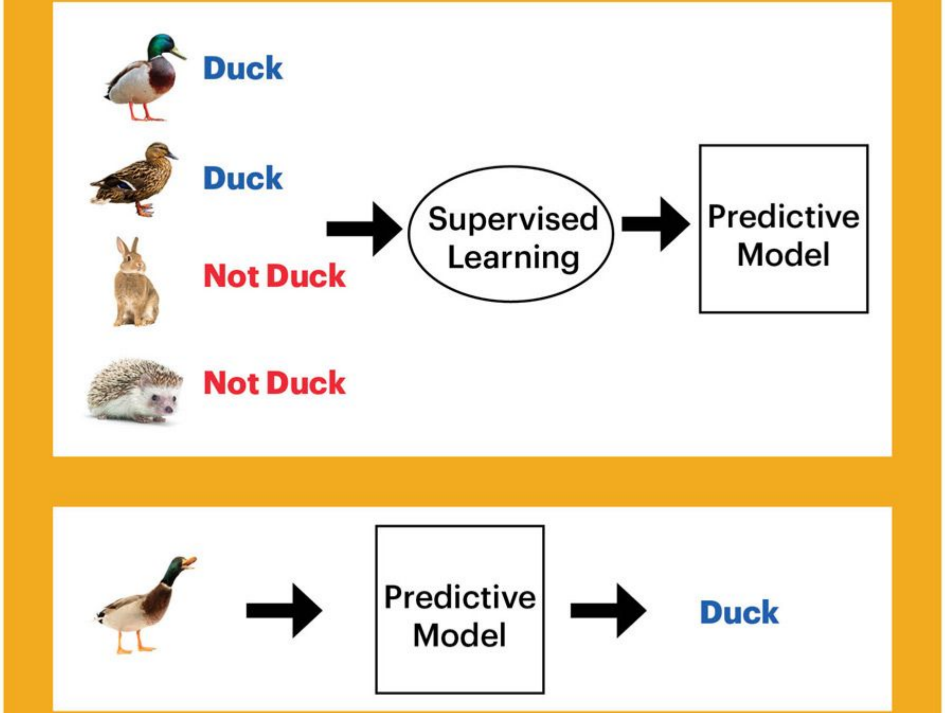
Image credits: https://www.kdnuggets.com/2017/01/3-methods-deal-outliers.html



Data classification

- Sometimes data has a feature known as a **class label**
- A model can **learn** from previous data to associate a record/row to a class label
- *One of the most useful tools in your belt!*

Supervised Learning (Classification Algorithm)



Duck

Duck

Not Duck

Not Duck

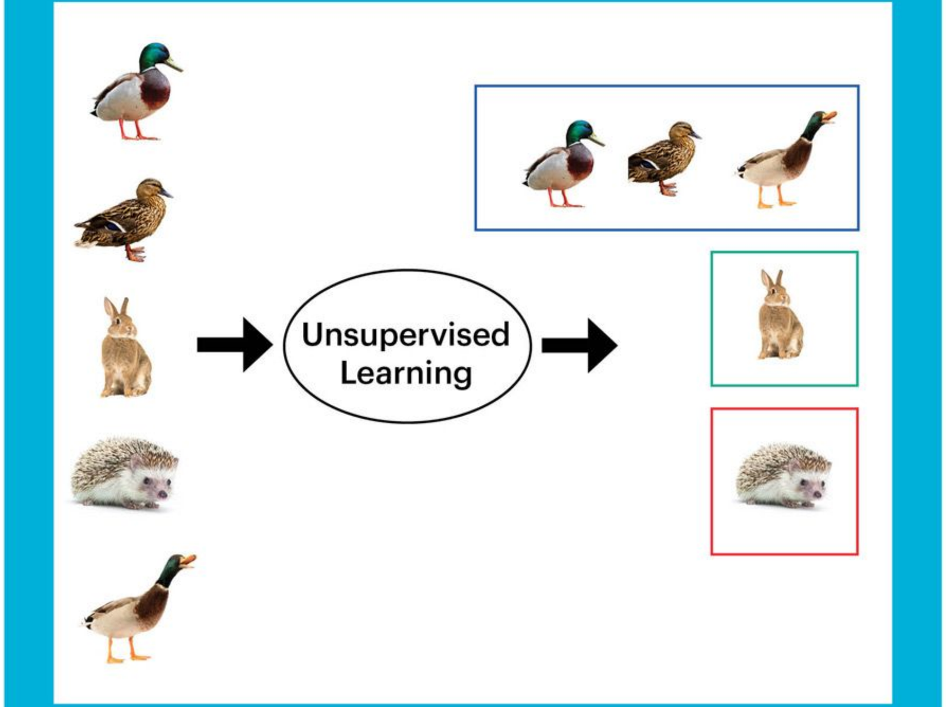
Supervised Learning

Predictive Model

Predictive Model

Duck

Unsupervised Learning (Clustering Algorithm)

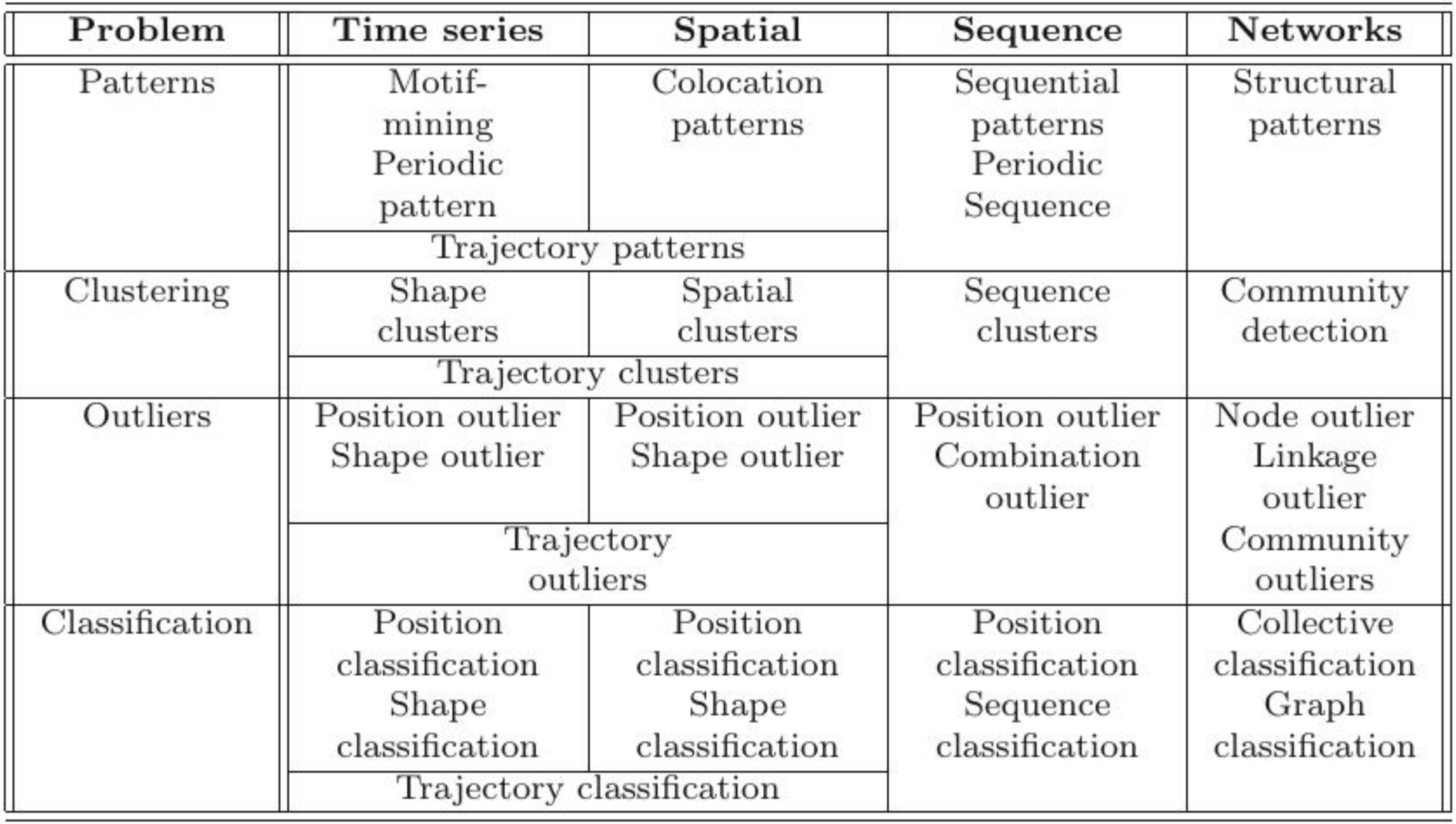


Unsupervised Learning

Tasks with complex data types

- Frequent temporal patterns
- Time series motifs
- Graph motifs
- Trajectory clusters
- Collective classification
- ...

Data types x Prototypical problems



Problem	Time series	Spatial	Sequence	Networks
Patterns	Motif-mining Periodic pattern	Colocation patterns	Sequential patterns Periodic Sequence	Structural patterns
	Trajectory patterns			
Clustering	Shape clusters	Spatial clusters	Sequence clusters	Community detection
	Trajectory clusters			
Outliers	Position outlier Shape outlier	Position outlier Shape outlier	Position outlier Combination outlier	Node outlier Linkage outlier Community outliers
	Trajectory outliers			
Classification	Position classification Shape classification	Position classification Shape classification	Position classification Sequence classification	Collective classification Graph classification
	Trajectory classification			

Data Mining, The Textbook (2015) by Charu Aggarwal

Example scenarios

Example scenario 1

- Place products in a store to maximize co-purchases of items frequently bought together
  - Input data: baskets
  - Output: similar pairs
  - Algorithm: frequent pattern mining

Example scenario 2

- Recommend movies to users in a video-on-demand platform
  - Input data: viewing history
  - Output: recommendations for a user
  - Simple algorithm: k nearest neighbors

Example scenario 3

- Help diagnose if an electrocardiogram is associated to a health problem
  - Input data: time series, possibly multi-dimensional
  - Output: binary label or risk score
  - Algorithms: outlier detection or classification

Example scenario 4

- Help a sysadmin determine if an intruder is trying or has accessed the network
  - Input data: time series of event records
  - Output: binary label or risk score
  - Algorithms: event detection

Exercise

Which ones would you say are data mining tasks?

A) Dividing the customers of a company by postal code

B) Finding credit card scammers among customers of a company

C) Computing the total sales of a company

D) Sorting a student database by student identification number

E) Predicting the future stock price of a company using past records

F) Determine when a complex machine needs to be repaired

G) Extracting the frequencies of a sound wave

Answers

A) Dividing the customers of a company by postal code

B) Finding credit card scammers among customers of a company

C) Computing the total sales of a company

D) Sorting a student database by student identification number

E) Predicting the future stock price of a company using past records

F) Determine when a complex machine needs to be repaired

G) Extracting the frequencies of a sound wave

Major challenges

Methodological challenges

- Mining high-dimensional data
- Handling uncertainty, noise, incompleteness, ...
- Mining data from a domain in which you do not have expertise, or worse, in which you believe you have expertise
  - Conclusions are often worthless if you do not talk with domain experts

User interaction challenges

- Users should ask questions that matter to them
- Performing interactive mining
- Presenting and visualizing data mining results

Efficiency and scalability

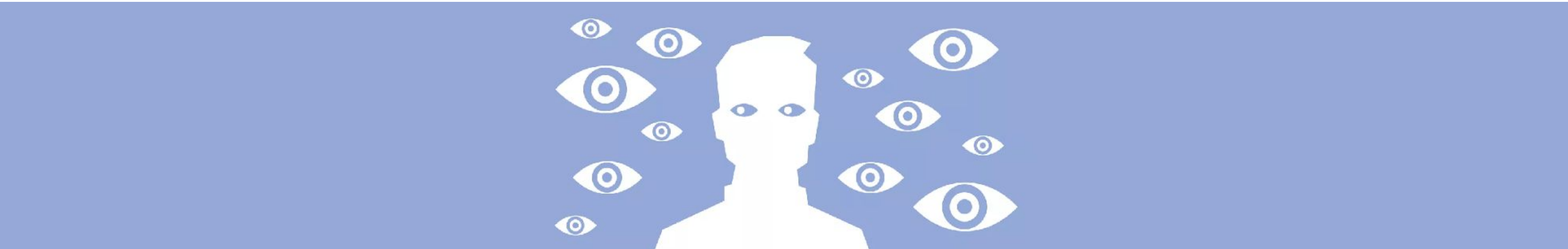
- Even for polynomial-type algorithms, a process can become unreasonably slow or require an unreasonable amount of space
- Streaming and/or distributed mining algorithms can help to some extent

Diversity of database types

- Real databases are **high dimensional** and involve a **mixture of various data types**
- Sometimes you need to **integrate** from dynamic, networked, globally distributed data sources

Data mining can be harmful

- Social impacts of data mining
  - Who wins? And more importantly, who loses?
- Privacy-preserving data mining
  - Avoid invisible, pervasive, invasive data mining



Summary

Things to remember

- Types of data
- Types of data mining methods
- Prototypical data mining scenarios
- Typical challenges of data mining

Exercises for this topic

- **Section 1.9 of Data Mining, The Textbook (2015) by Charu Aggarwal**
- Exercises 1.7 of Introduction to Data Mining, Second Edition (2019) by Tan et al.