

# Data Understanding

Anna Monreale  
Computer Science Department

Introduction to Data Mining, 2<sup>nd</sup> Edition  
Chapter I & Data Exploration (Additional Resources)

# Getting To Know Your Data

- For preparing data for data mining task it is essential to have an overall picture of your data
- Gain insight in your data
  - with respect to your project goals
  - and general to understand properties
- Find answers to the questions
  - What kind of attributes do we have?
  - How is the data quality?
  - Does a visualization helps?
  - Are attributes correlated?
  - What about outliers?
  - How are missing values handled?
  - Do we need to extract other attributes

**Which is the type of data?**

# Types of data sets

- Record
  - Data Matrix
  - Document Data
  - Transaction Data
- Graph
  - World Wide Web
  - Molecular Structures
- Ordered
  - Spatial Data
  - Temporal Data
  - Sequential Data
  - Genetic Sequence Data

# What is Data?

- Collection of **data objects** and their **attributes**
- An **attribute** is a property or characteristic of an object
  - Examples: eye color of a person, temperature, etc.
  - Attribute is also known as variable, field, characteristic, dimension, or feature
- A collection of attributes describe an **object**
  - Object is also known as record, point, case, sample, entity, or instance

Objects

Attributes

<i>Tid</i>	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

# Data Matrix

- If data objects have the same fixed set of numeric attributes, then the data objects can be thought of as points in a multi-dimensional space, where each dimension represents a distinct attribute
- Such data set can be represented by an  $m$  by  $n$  matrix, where there are  $m$  rows, one for each object, and  $n$  columns, one for each attribute

<b>Projection of x Load</b>	<b>Projection of y load</b>	<b>Distance</b>	<b>Load</b>	<b>Thickness</b>
10.23	5.27	15.22	2.7	1.2
12.65	6.25	16.22	2.2	1.1

# Document Data

- Each document becomes a ‘term’ vector
  - Each term is a component (attribute) of the vector
  - The value of each component is the number of times the corresponding term occurs in the document.

	team	coach	play	ball	score	game	win	lost	timeout	season
Document 1	3	0	5	0	2	6	0	2	0	2
Document 2	0	7	0	2	1	0	0	3	0	0
Document 3	0	1	0	0	1	2	2	0	3	0

# Transaction Data

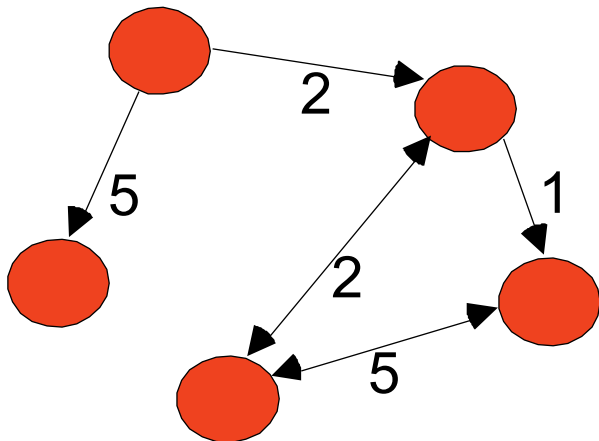
- A special type of record data, where
  - Each record (transaction) involves a set of items.
  - For example, consider a grocery store. The set of products purchased by a customer during one shopping trip constitute a transaction, while the individual products that were purchased are the items.

<i>TID</i>	<i>Items</i>
1	Bread, Coke, Milk
2	Beer, Bread
3	Beer, Coke, Diaper, Milk
4	Beer, Bread, Diaper, Milk
5	Coke, Diaper, Milk



# Graph Data

- Examples: Generic graph, a molecule, and webpages



## Useful Links:

- [Bibliography](#)
- Other Useful Web sites
  - [ACM SIGKDD](#)
  - [KDnuggets](#)
  - [The Data Mine](#)

## Knowledge Discovery and Data Mining Bibliography

(Gets updated frequently, so visit often!)

- [Books](#)
- [General Data Mining](#)

## Book References in Data Mining and Knowledge Discovery

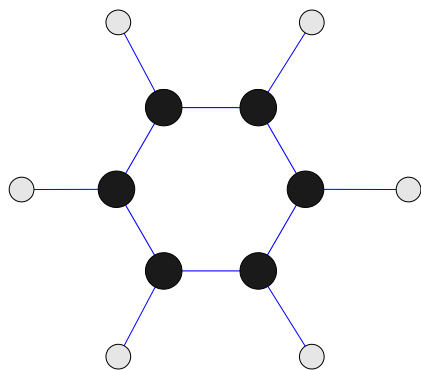
Usama Fayyad, Gregory Piatetsky-Shapiro, Padhraic Smyth, and Ramasamy uthurasamy, "Advances in Knowledge Discovery and Data Mining", AAAI Press/the MIT Press, 1996.

J. Ross Quinlan, "C4.5: Programs for Machine Learning", Morgan Kaufmann Publishers, 1993.  
Michael Berry and Gordon Linoff, "Data Mining Techniques (For Marketing, Sales, and Customer Support)", John Wiley & Sons, 1997.

## General Data Mining

Usama Fayyad, "Mining Databases: Towards Algorithms for Knowledge Discovery", Bulletin of the IEEE Computer Society Technical Committee on data Engineering, vol. 21, no. 1, March 1998.

Christopher Matheus, Philip Chan, and Gregory Piatetsky-Shapiro, "Systems for knowledge Discovery in databases", IEEE Transactions on Knowledge and Data Engineering, 5(6):903-913, December 1993.



Benzene Molecule: C6H6

# Ordered Data

- Sequences of transactions

## Items/Events

( A B ) ( D ) ( C E )  
( B D ) ( C ) ( E )  
( C D ) ( B ) ( A E )



An element of  
the sequence

## Retail data



# Ordered Data

- Genomic sequence data

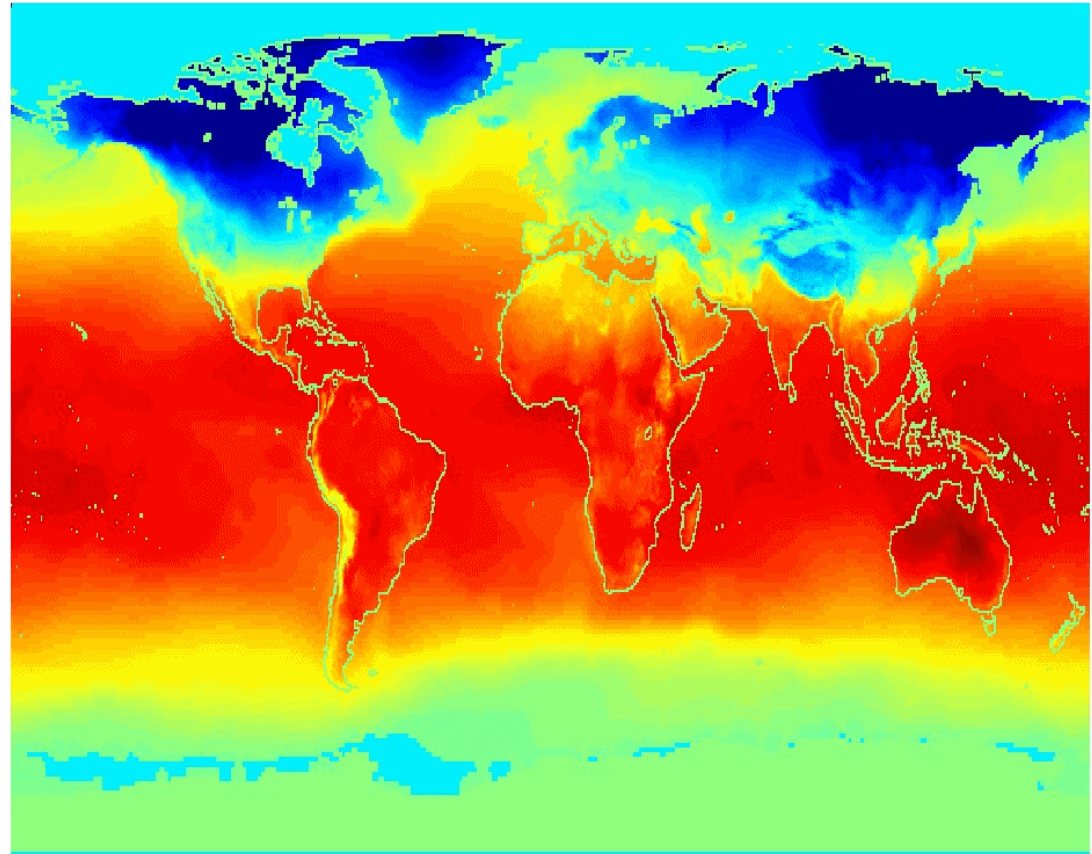
**GGTTC CGCCTTCAGCCCCGCGCC  
CGCAGGGCCCGCCCCGCGCCGTC  
GAGAAGGGCCCGCCTGGCGGGCG  
GGGGGAGGCGGGGCCGCCCGAGC  
CCAACCGAGTCCGACCAGGTGCC  
CCCTCTGCTCGGCCTAGACCTGA  
GCTCATTAGGCGGCAGCGGACAG  
GCCAAGTAGAACACGCGAAGCGC  
TGGGCTGCCTGCTGCGACCAGGG**

## Ordered Data

- Spatio-Temporal Data

**Average Monthly  
Temperature of  
land and ocean**

Jan



# Types of Attributes

- There are different types of attributes
  - **Nominal/Categorical:** attribute values in a finite domain, categories, “name of things”
    - **Examples:** ID numbers, eye color, zip codes
  - **Binary:** Nominal attribute with only 2 states (0 and 1)
    - **Symmetric binary:** both outcomes equally important (e.g., gender)
    - **Asymmetric binary:** outcomes not equally important. (e.g., medical test positive vs. negative) The convention is to assign 1 to most important outcome (e.g., having cancer)
  - **Ordinal:** finite domain with a meaningful ordering on the domain
    - **Examples:** rankings (e.g., taste of potato chips on a scale from 1-10), grades, height {tall, medium, short}

# Types of Attributes

- **Numeric:** quantity (integer or real-valued)
  - **Interval-Scaled**
    - Measured on a scale of equal-sized units
    - Values have order
  - **Examples:** calendar dates, temperatures in Celsius
- **Ratio-Scaled:** We can speak of values as being an order of magnitude larger than the unit of measurement
  - **Examples:** length, counts, elapsed time (e.g., time to run a race)
  - A baseball game lasting 3 hours is **50% longer** than a game lasting **2 hours**.

# Discrete and Continuous Attributes

- **Discrete Attribute**

- Has only a finite or countably infinite set of values
- **Examples:** zip codes, counts, or the set of words in a collection of documents
- Often represented as integer variables.
- Note: **binary attributes** are a special case of discrete attributes

- **Continuous Attribute**

- **Has real numbers** as attribute values
- **Examples:** temperature, height, or weight.
- Practically, real values can only be measured and represented using a finite number of digits.
- Continuous attributes are typically represented as floating-point variables.

# Properties of Attribute Values

The type of an attribute depends on which of the following properties/operations it possesses:

- Distinctness:        =  $\neq$
- Order:                < >
- Differences are     + -  
  meaningful :
- Ratios are            \* /  
  meaningful
  
- Nominal attribute: distinctness
- Ordinal attribute: distinctness & order
- Interval attribute: distinctness, order & meaningful differences
- Ratio attribute: all 4 properties/operations



Categorical  
QualitativeNumeric  
Quantitative

Attribute Type	Description	Examples	Operations
Nominal	Nominal attribute values only distinguish. (=, ≠)	zip codes, employee ID numbers, eye color, sex: { <i>male</i> , <i>female</i> }	mode, entropy, contingency correlation, $\chi^2$ test
Ordinal	Ordinal attribute values also order objects. (<, >)	hardness of minerals, { <i>good</i> , <i>better</i> , <i>best</i> }, grades, street numbers	median, percentiles, rank correlation, run tests, sign tests
Interval	For interval attributes, differences between values are meaningful. (+, -)	calendar dates, temperature in Celsius or Fahrenheit	mean, standard deviation, Pearson's correlation, <i>t</i> and <i>F</i> tests
Ratio	For ratio variables, both differences and ratios are meaningful. (*, /)	temperature in Kelvin, monetary quantities, counts, age, mass, length, current	geometric mean, harmonic mean, percent variation

# Data Quality

- Poor data quality negatively affects many data processing efforts
- “The most important point is that poor data quality is an unfolding disaster.
- Poor data quality costs the typical company at least ten percent (10%) of revenue; twenty percent (20%) is probably a better estimate.”

Thomas C. Redman, DM Review, August 2004

- Data mining example: a classification model for detecting people who are loan risks is built using poor data
  - Some credit-worthy candidates are denied loans
  - More loans are given to individuals that default

# Data Quality ...

- What kinds of data quality problems?
- How can we detect problems with the data?
- What can we do about these problems?
  
- Examples of data quality problems:
  - Wrong data
  - Duplicate data
  - Noise and outliers
  - Missing values

# Data Quality issues ...

- **Syntactic accuracy:** Entry is not in the domain.
  - **Examples:** **female** in gender, text in numerical attributes, ... Can be checked quite easy.
- **Semantic accuracy:** Entry is in the domain but not correct
  - **Example:** John Smith is female
  - Needs more information to be checked (e.g. “business rules”).
- **Completeness:** is violated if an entry is not correct although it belongs to the domain of the attribute.
  - **Example:** Complete records are missing, the data is biased (A bank has rejected customers with low income.)
- **Unbalanced data:** The data set might be biased extremely to one type of records.
  - **Example:** Defective goods are a very small fraction of all.
- **Timeliness:** Is the available data up to date?

# Duplicate Data

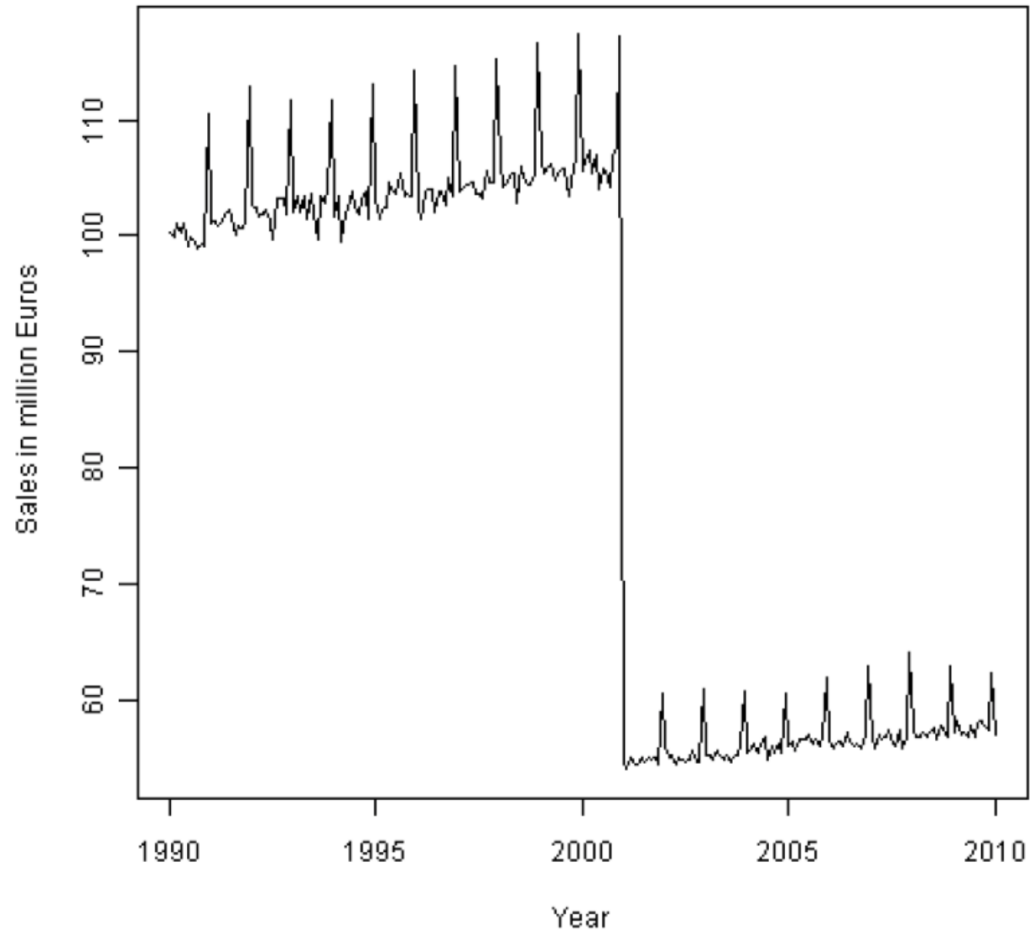
- Data set may include data objects that are duplicates, or almost duplicates of one another
  - Major issue when merging data from heterogeneous sources
- Examples:
  - Same person with multiple email addresses
- Data cleaning
  - Process of dealing with duplicate data issues

# Statistics & Visualization

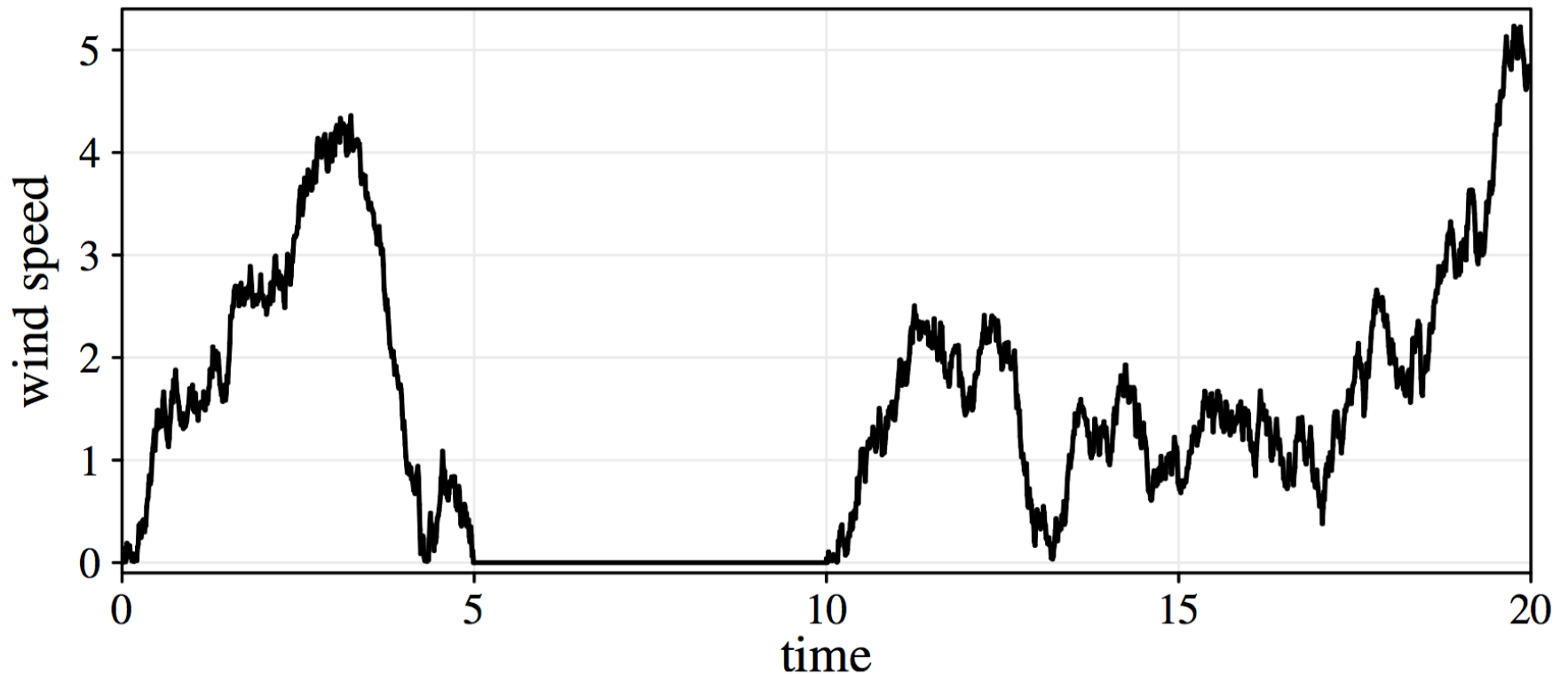
In order to know our data and discovery quality issues we need:

- Use descriptive statistics for getting a global picture and summarize properties of data
- Compare statistics with the expected behaviour
- Exploit visualization techniques that can help in detecting
  - general patterns and trends
  - outliers and unusual patterns

# Data Visualization



# Data Visualization

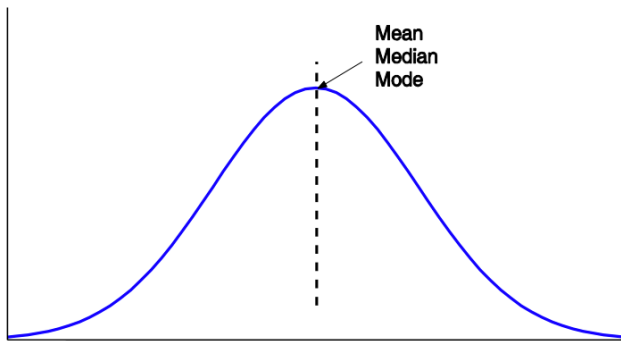


The zero values might come from a broken or blocked sensor and might be considered as missing values.

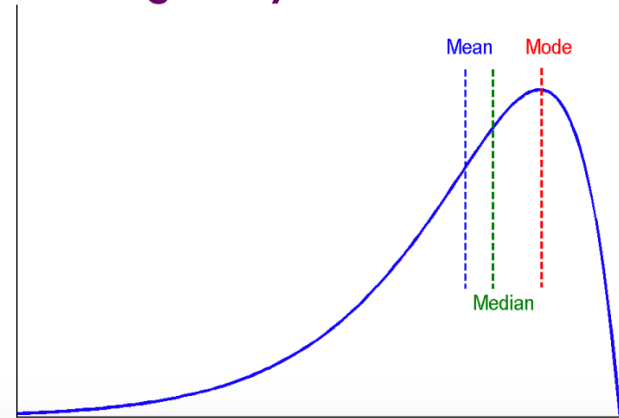


# Observing Data Distribution

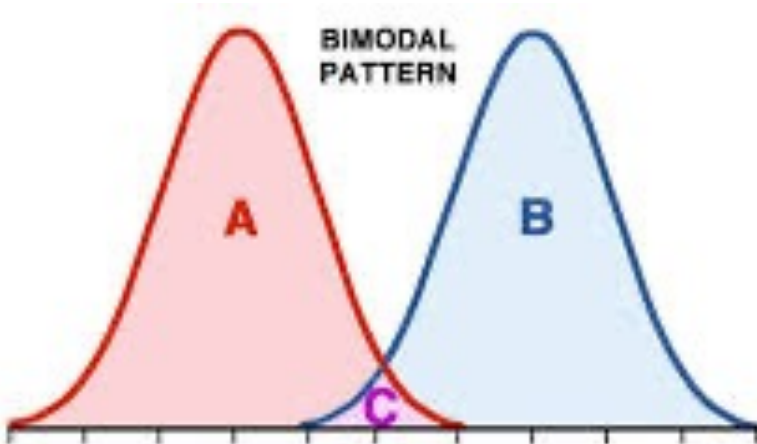
Symmetric data



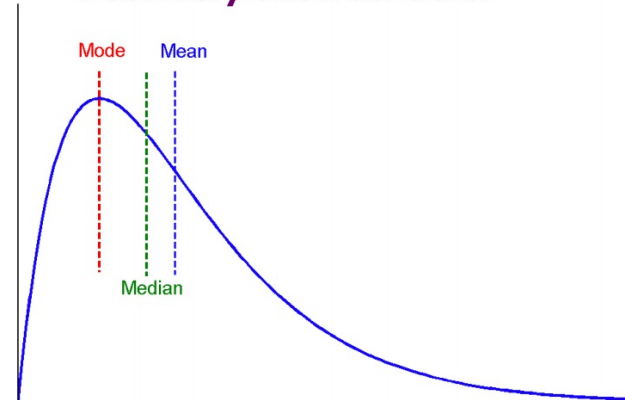
Negatively skewed data



BIMODAL PATTERN



Positively skewed data



# Example

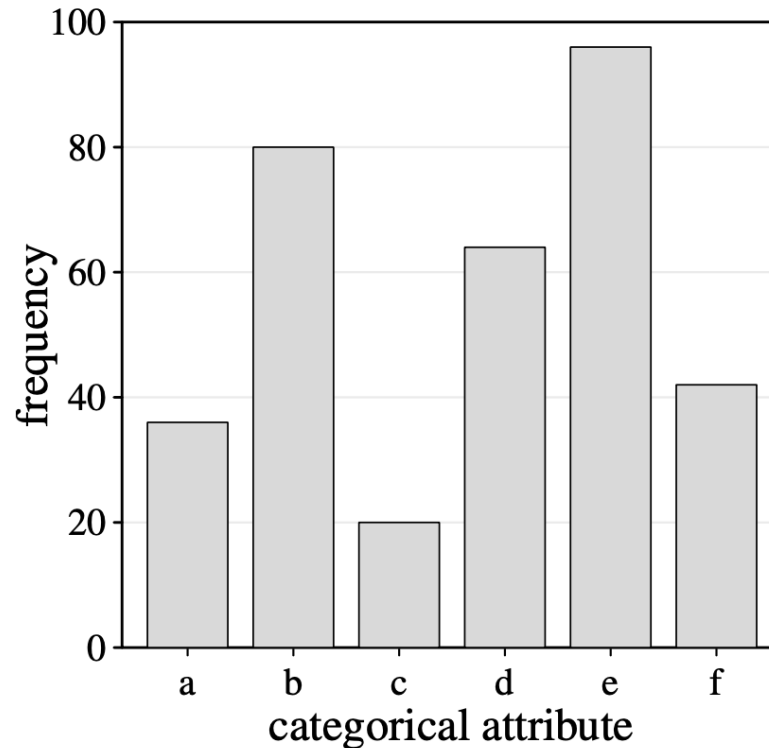
## Give an example of something having a positively skewed distribution

- **income** is a good example of a positively skewed variable: there will be a few people with extremely high incomes, but most people will have incomes bunched together below the mean.

## Give an example of something having a bimodal distribution

- bimodal distribution has some kind of underlying binary variable that will result in a separate mean for each value of this variable.
- One example can be **human weight** – the gender is binary and is a statistically significant indicator of how heavy a person is.

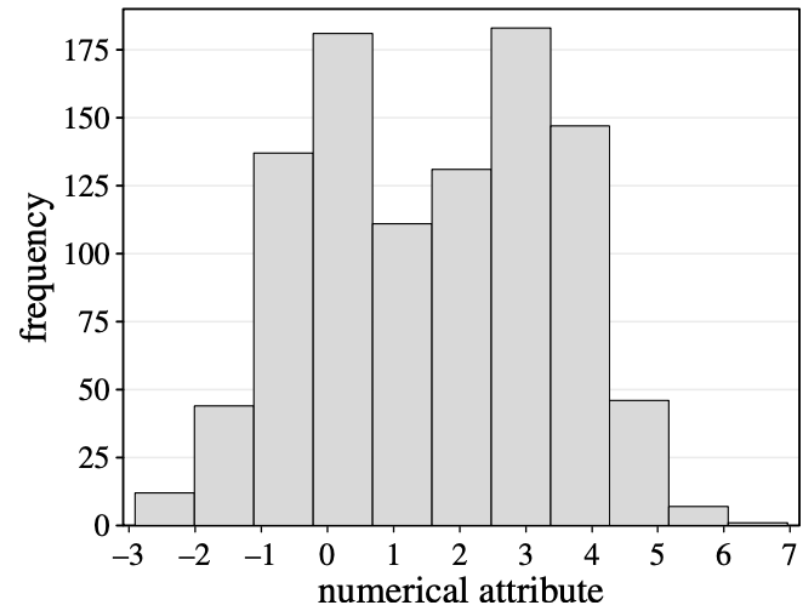
# Bar Chart for Categorical Attributes



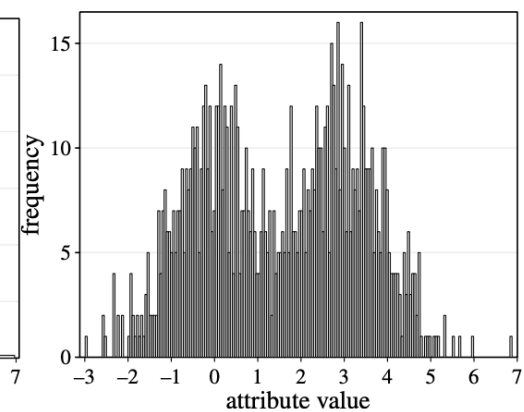
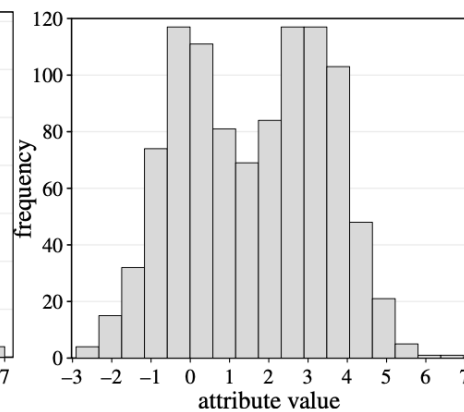
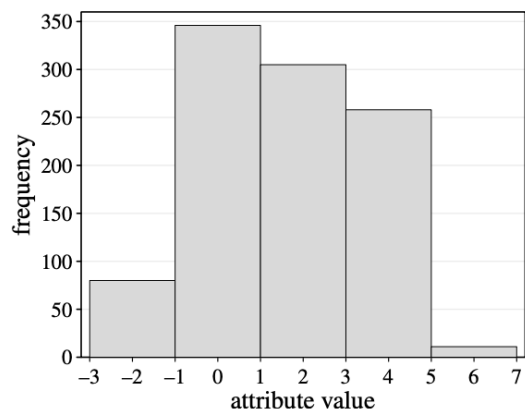
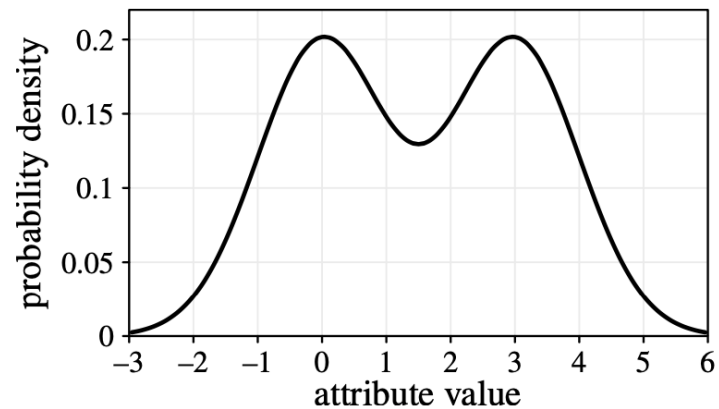
**A bar chart is a simple way to depict the frequencies of the values of a categorical attribute.**

# Histograms for Numerical Attributes

- A **histogram** shows the frequency distribution for a numerical attribute.
- The range of the numerical attribute is **discretized** into a fixed number of intervals (**bins**)
- For each interval the (absolute) **frequency** of values falling into it is indicated by the height of a bar.



# Histograms: Number of bins



3 histograms with 5, 17 and 200 bins for a sample from the same bimodal distribution.

# Number of bins

- Number of bins according to **Sturges' rule**:

$$k = \lceil \log_2(n) + 1 \rceil$$

where  $n$  is the sample size

- Sturges' rule is suitable for data from normal distributions and from data sets of moderate size.

# Measuring the Central Tendency

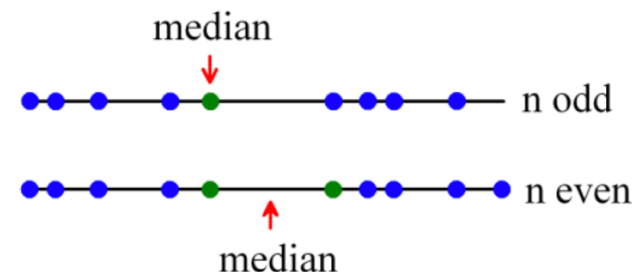
- Mean

- $m$  is the sample size
- A distributive measure can be computed by partitioning the data into smaller subsets
- However, the mean is very sensitive to outliers
- The median or a trimmed mean are also commonly used

$$\text{mean}(x) = \bar{x} = \frac{1}{m} \sum_{i=1}^m x_i$$

- Median

- Middle value if odd number of values, or average of the middle two values otherwise



- Mode

- Value that occurs **most frequently** in the data
- It is possible that several different values have the greatest frequency: Unimodal, bimodal, trimodal, multimodal
- If each data value occurs only once then **there is no mode**

# Measuring the Dispersion of Data

- The degree in which data tend to spread is called the **dispersion**, or **variance** of the data
- The most common measures for data dispersion are **range**, **standard deviation**, the **five-number summary** (based on quartiles), and the **inter-quartile range**
- **Range**: The distance between the largest and the smallest values



# Measuring the Dispersion of Data

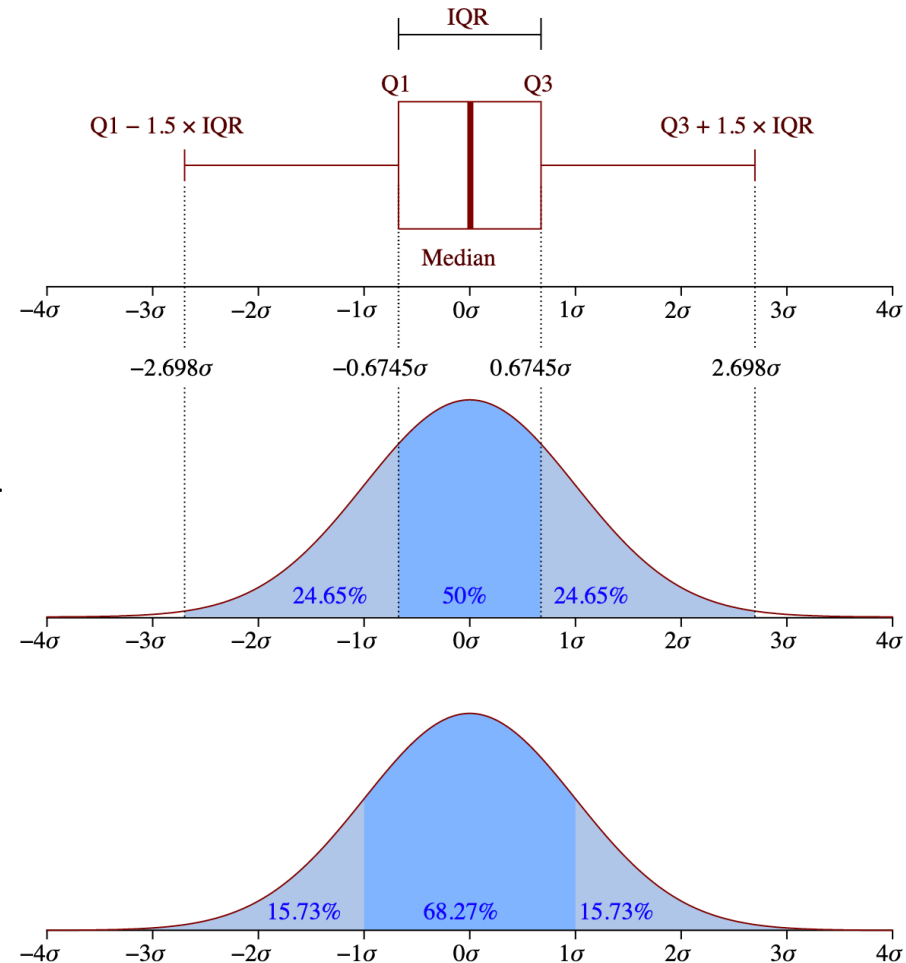
- **Variance**  $\text{variance}(x) = s_x^2 = \frac{1}{m-1} \sum_{i=1}^m (x_i - \bar{x})^2$
- **Standard deviation**  $\sigma$  is the square root of variance  $\sigma^2$ 
  - $\sigma$  measures spread about the mean and should be used only when the mean is chosen as the measure of the center
  - $\sigma=0$  only when there is no spread, that is, when all observations have the same value. Otherwise  $\sigma>0$
- **Because of outliers**, other measures are often used:
  - **absolute average deviation (AAD)**
  - **median average deviation (MAD)**

$$\text{AAD}(x) = \frac{1}{m} \sum_{i=1}^m |x_i - \bar{x}|$$

$$\text{MAD}(x) = \text{median} \left( \{|x_1 - \bar{x}|, \dots, |x_m - \bar{x}|\} \right)$$

# Box Plot: Five-number summary of a distribution

- Data represented with a **box**
- **Whiskers**: two lines outside the box extended to **Minimum** and **Maximum**
- The ends of the box are at the
  - **1<sup>st</sup> quartiles** (25%-quantile)
  - **3<sup>rd</sup> quartiles** (75%-quantile)
- **Median**: value in the middle (values in increasing order) is the **2<sup>nd</sup> quartile** (50%-quantile)
- The height of the box is **Interquartile range (IQR)**: 3rd quartile - 1st quartile
- **p%-quantile** ( $0 < p < 100$ ): The value  $x$  s.t.  $p\%$  of the values are smaller and  $100-p\%$  are larger.
- **Outliers**: points beyond whiskers



# Example data set: Iris data



iris setosa



iris versicolor



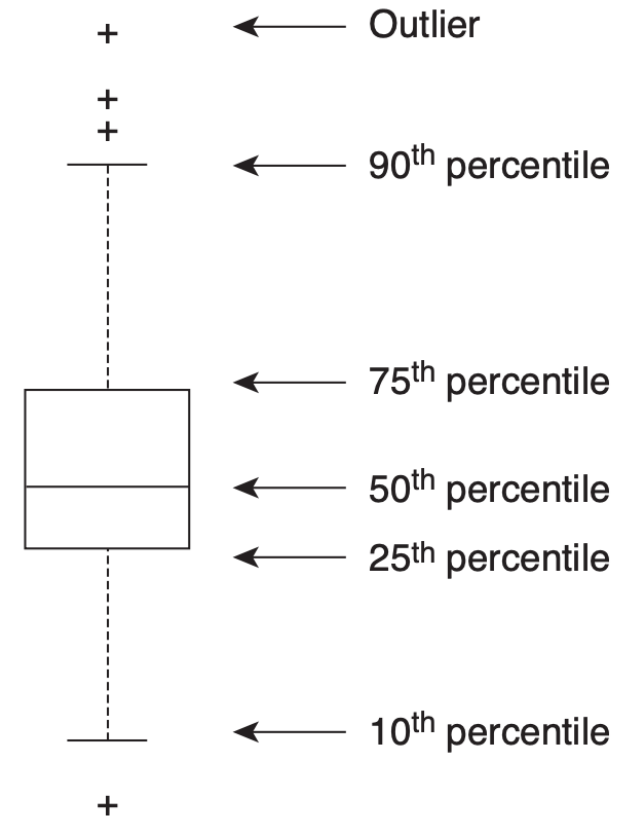
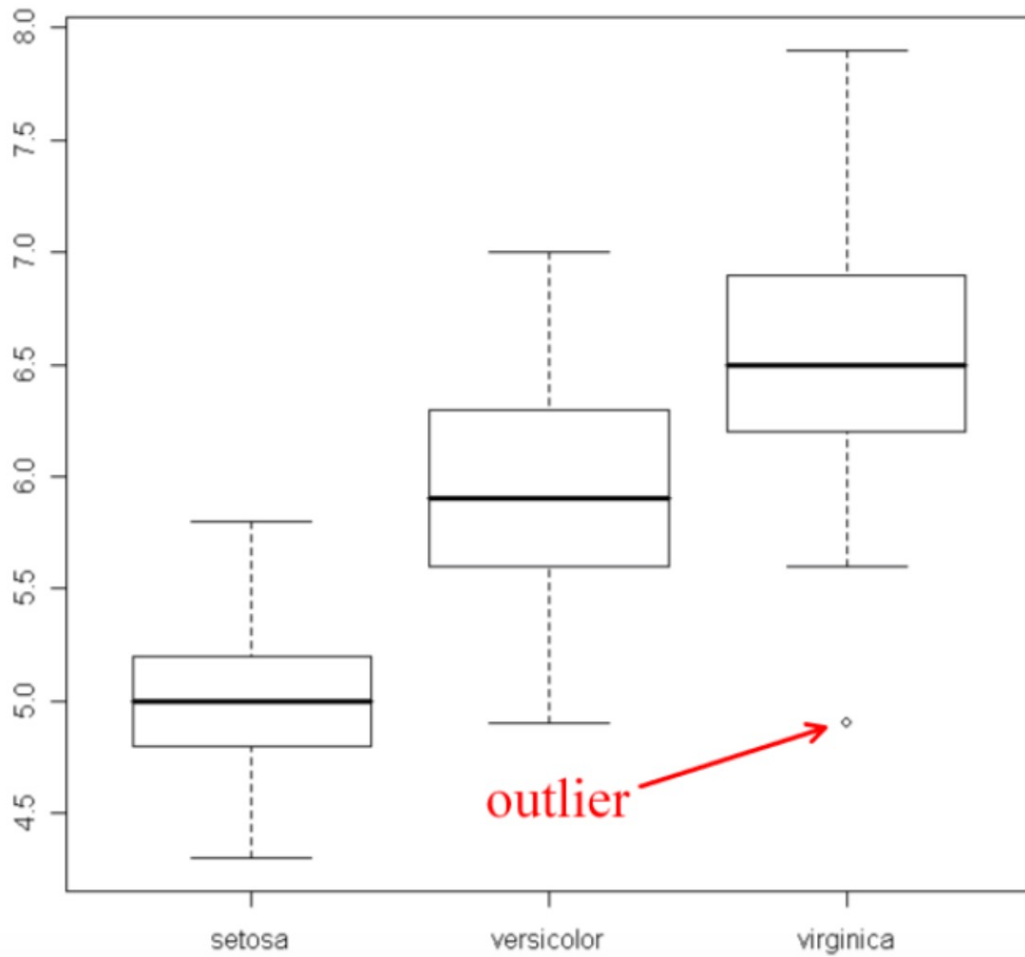
iris virginica

- collected by E. Anderson in 1935
- contains measurements of four real-valued variables:
  - sepal length, sepal widths, petal lengths and petal width of 150 iris flowers of types *Iris Setosa*, *Iris Versicolor*, *Iris Virginica* (50 each)
- The fifth attribute is the name of the flower type.

# Example data set: Iris data

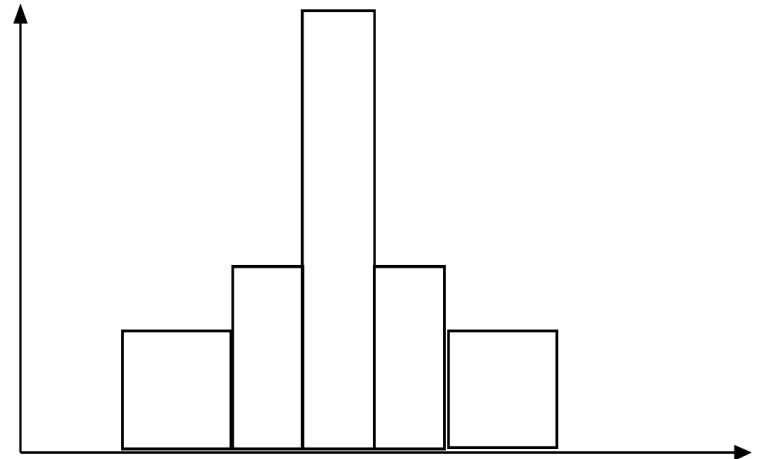
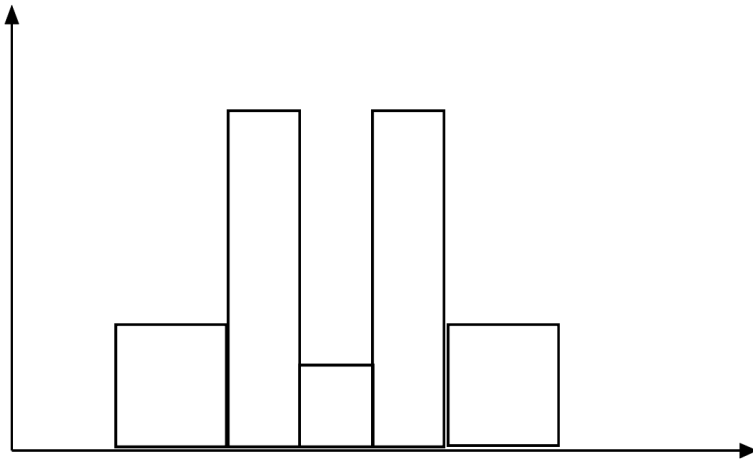
Sepal Length	Sepal Width	Petal Length	Petal Width	Species
5.1	3.5	1.4	0.2	Iris-setosa
...				
...				
5.0	3.3	1.4	0.2	Iris-setosa
7.0	3.2	4.7	1.4	Iris-versicolor
...				
...				
5.1	2.5	3.0	1.1	Iris-versicolor
5.7	2.8	4.1	1.3	Iris-versicolor
...				
...				
5.9	3.0	5.1	1.8	Iris-virginica

# Example of Conditional Box Plot



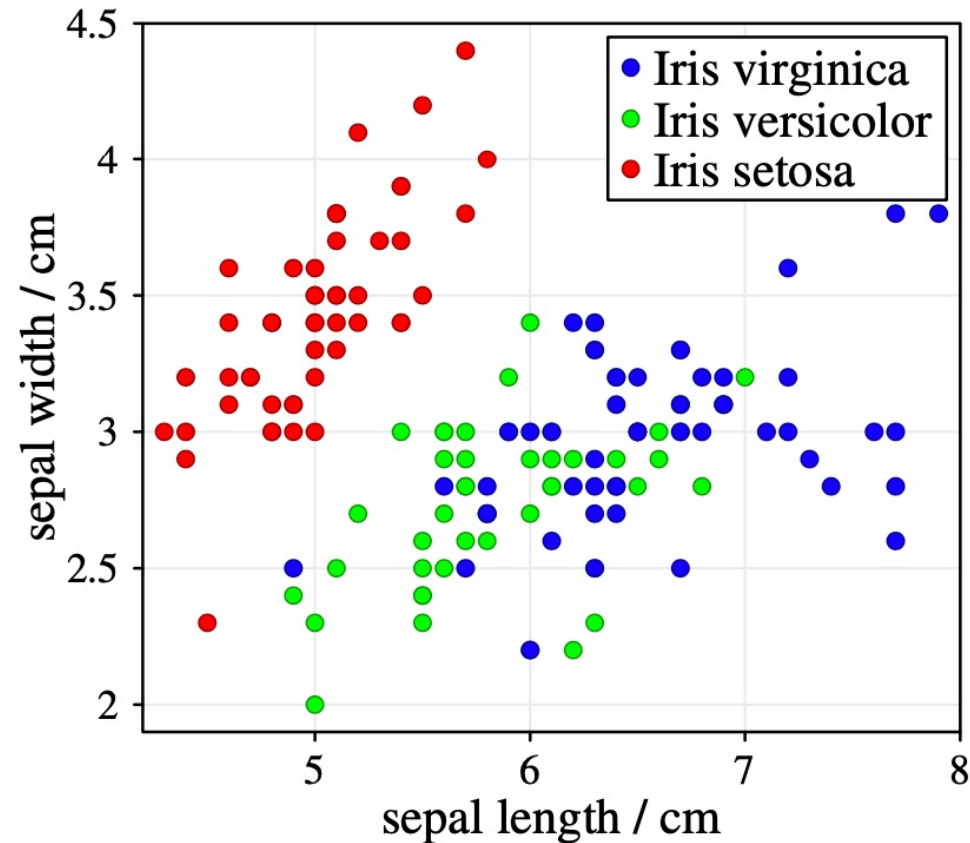
# Histograms Often Tell More than Boxplots

- The two histograms may have the same boxplot representation
  - **The same values** for: **min, Q1, median, Q3, max**
  - But they have rather **different data distributions**



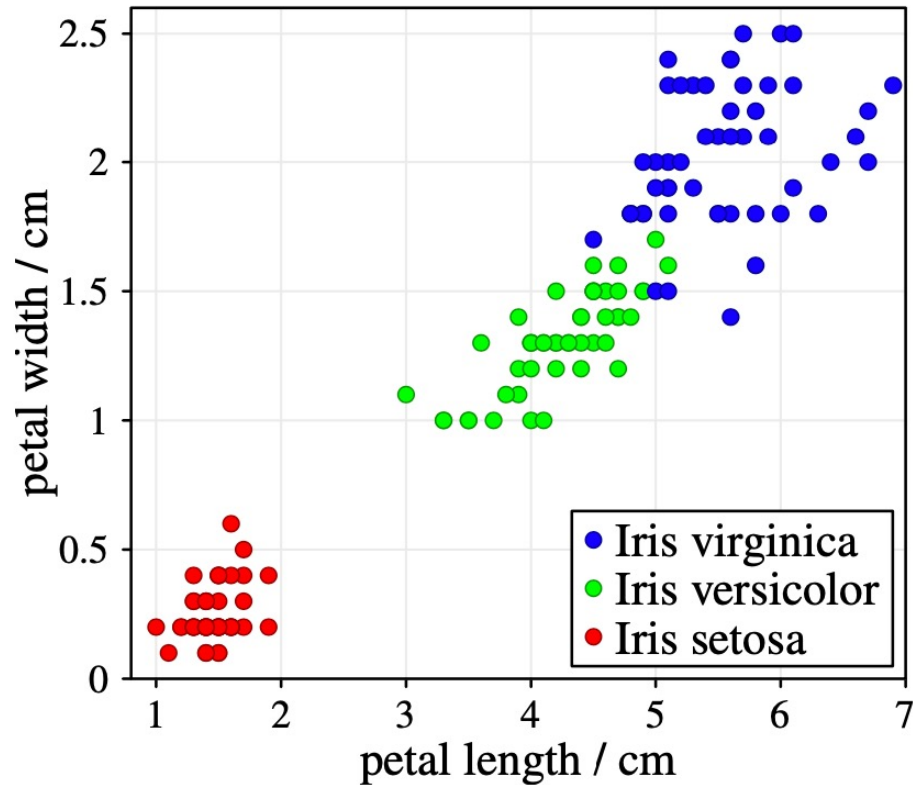
# Scatter Plot

- Provides a first look at **bivariate data** to see **clusters** of points, **outliers**, **correlations**
- Each pair of values is treated as a **pair of coordinates** and plotted as points in the plane



Scatter plots can be enriched with additional information: **Colour** or **different symbols** to **incorporate a third attribute** in the scatter plot.

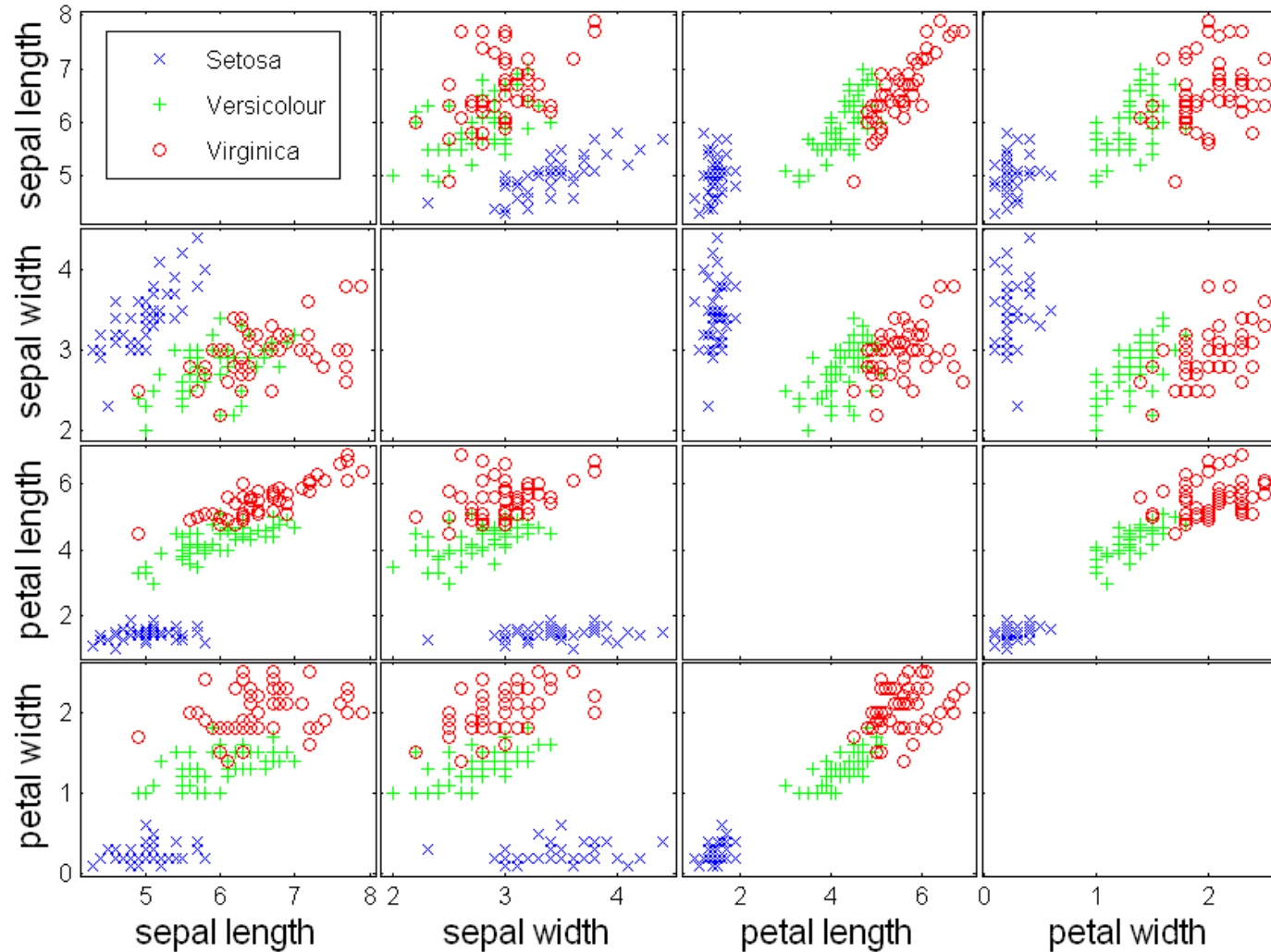
# Scatter Plot



The two attributes petal length and width provide a **better separation of the classes** Iris versicolor and Iris virginica than the sepal length and width.

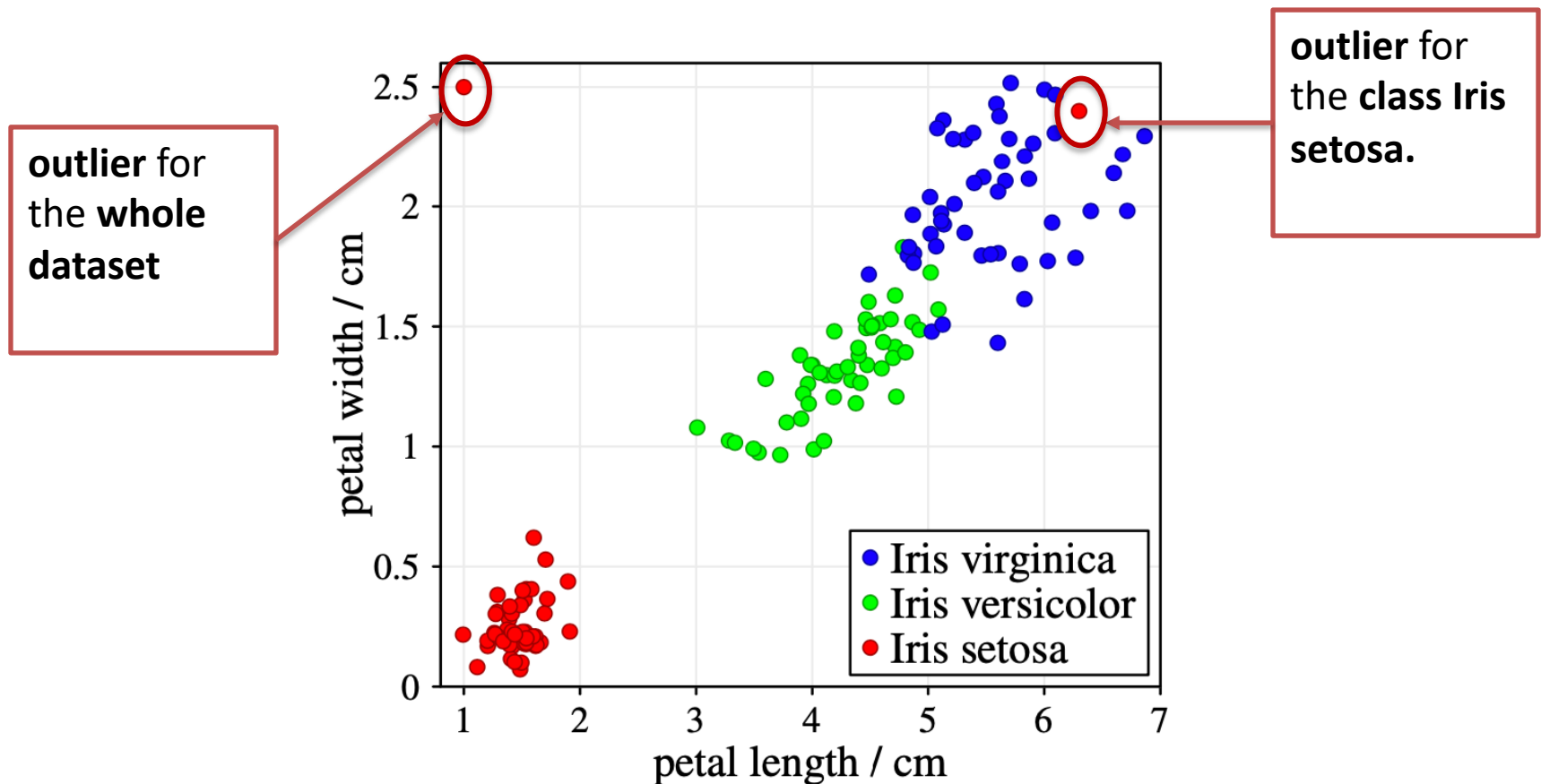


# Scatter Matrix of Iris Attributes



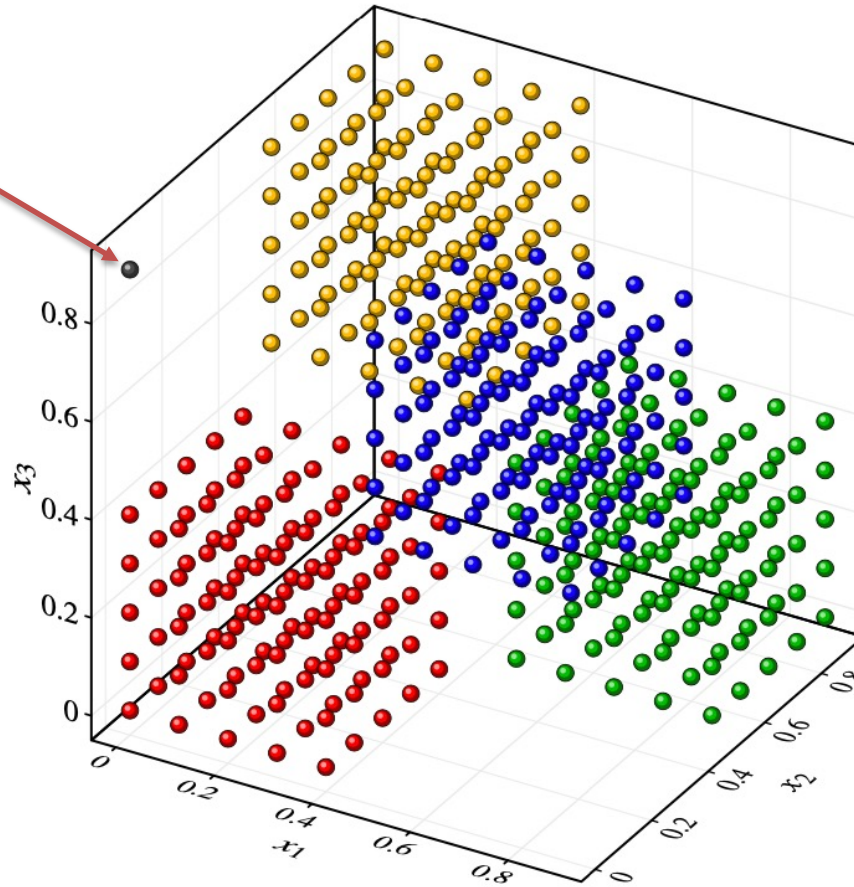
# Scatter Plot & Outliers

The Iris data set with two (additional artificial) outliers



# 3D Scatter Plot

Outlier



# Visualization as a Test

- When visualisations reveal patterns or exceptions, then there is “something” in the data set.
- When visualisations do not indicate anything specific, there might still be patterns or structures in the data that cannot be revealed by the corresponding (simple) visualisation techniques.

# Parallel Coordinates

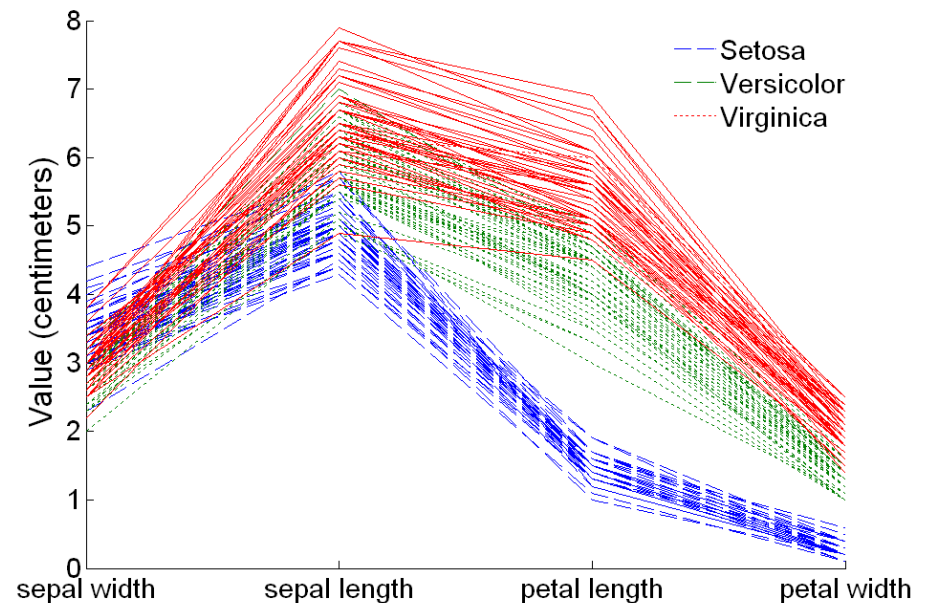
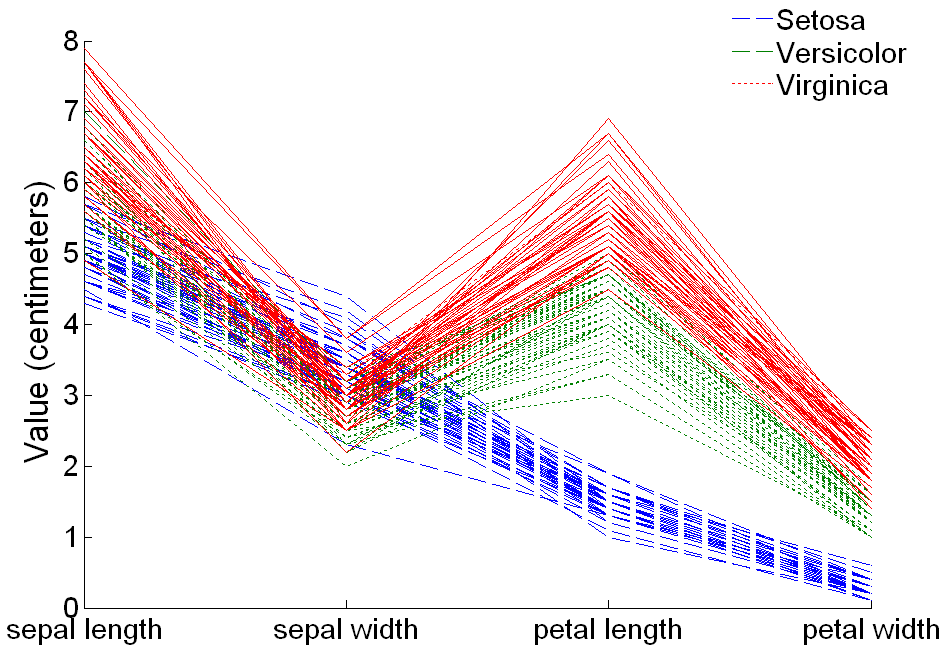
- **Parallel Coordinates**

- Used to plot the attribute values of high-dimensional data
- Instead of using perpendicular axes, use a set of parallel axes

The attribute values of each object are plotted as a point on each corresponding coordinate axis and the points are connected by a line

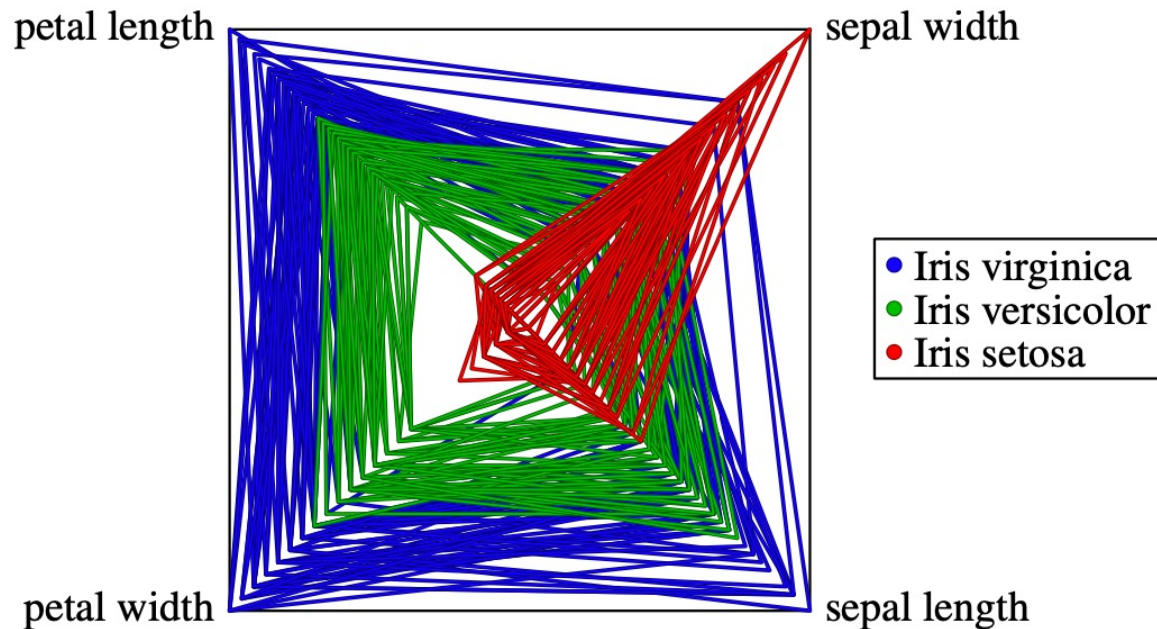
- Thus, each object is represented as a line
- Often, the lines representing a distinct class of objects group together, at least for some attributes
- Ordering of attributes is important in seeing such groupings

# Parallel Coordinates Plots for Iris Data



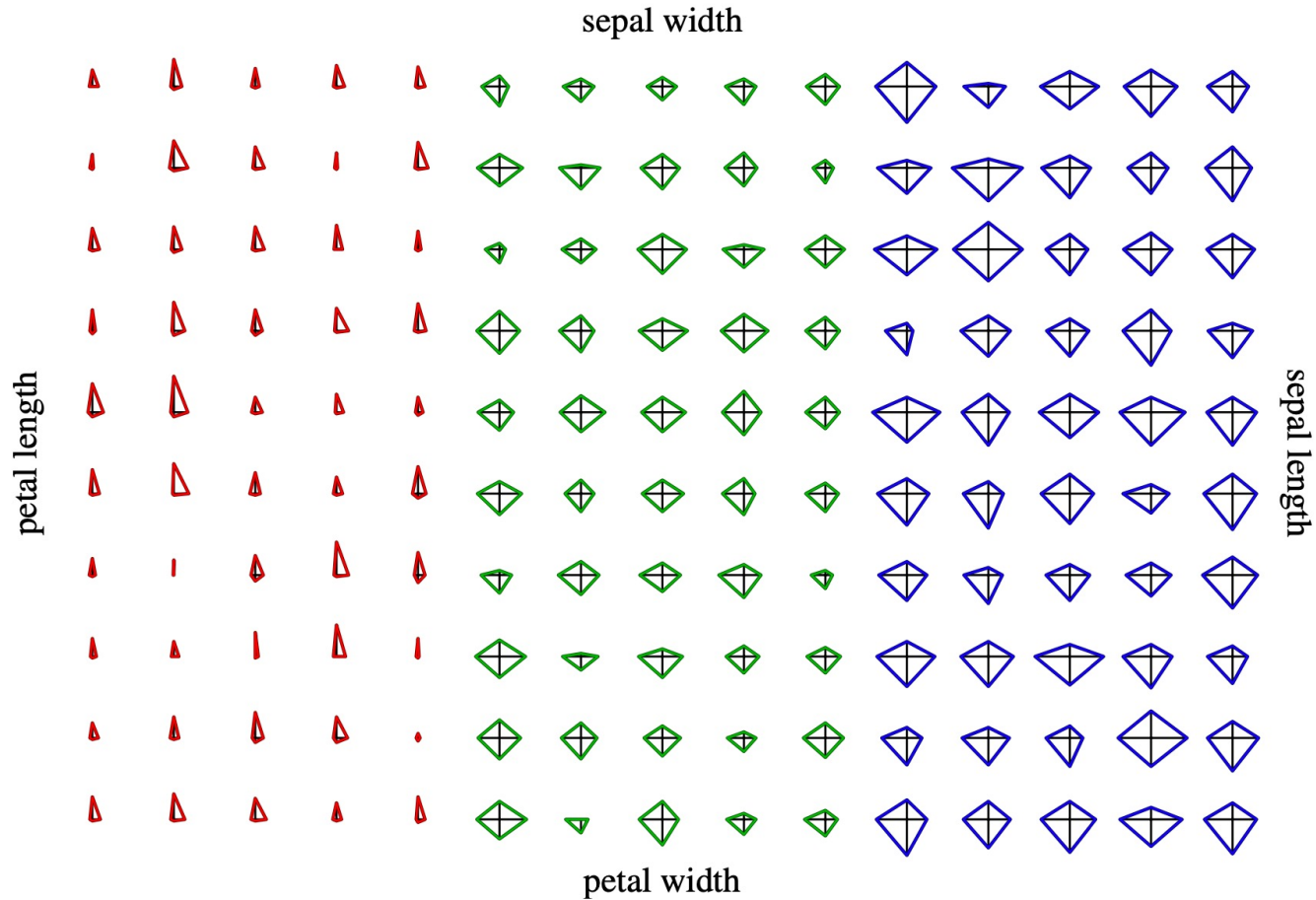
# Radar Plot for Iris Data

- Similar idea as parallel coordinates
- **Coordinate axes are drawn as parallel lines, but in a star-like fashion intersecting in one point**
- Axes radiate from a central point
- The line connecting the values of an object is a polygon



# Star Plots for Iris Data

Star plots are the same as radar plots where **each data object is drawn separately**.





# Correlation Analysis

- Correlation measures the linear relationship between objects
- Captures similar behaviour of two attributes

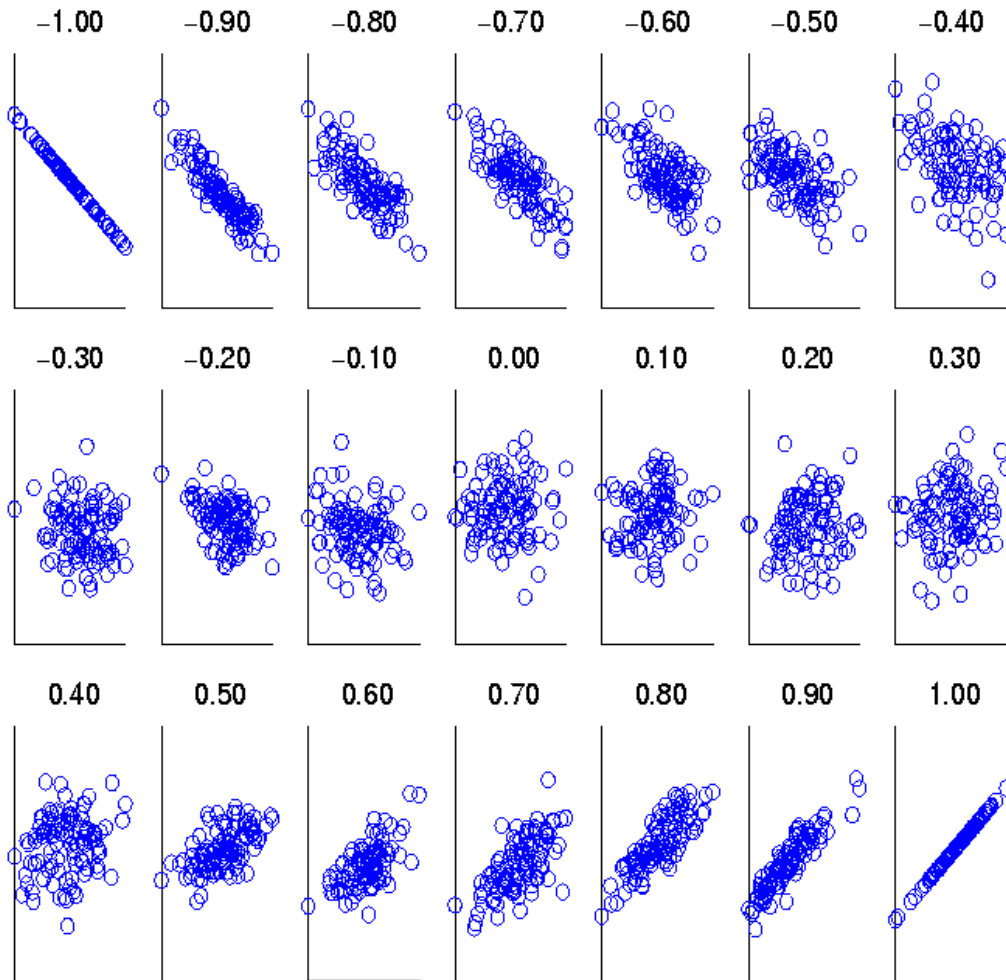
# Pearson's correlation coefficient

The (sample) **Pearson's correlation coefficient** is a measure for a linear relationship between two numerical attributes X and Y and is defined as

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{(n - 1)s_x s_y} \quad -1 \leq r_{xy} \leq 1$$

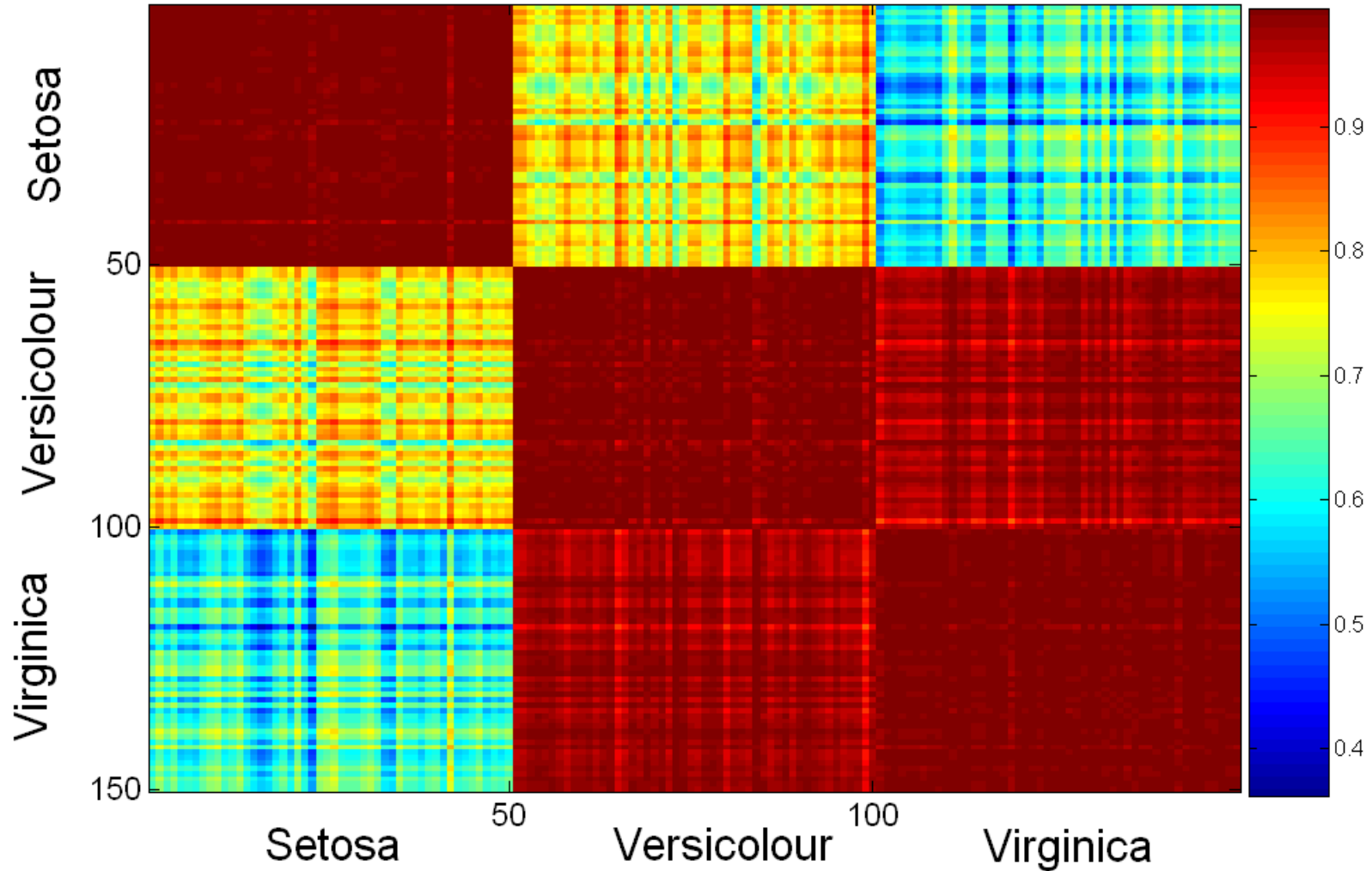
- where  $\bar{x}$  and  $\bar{y}$  are the mean values of the attributes X and Y, respectively.  $s_x$  and  $s_y$  are the corresponding (sample) standard deviations.
- The larger the absolute value of the Pearson correlation coefficient, the stronger the linear relationship between the two attributes.
- For  $|r_{xy}| = 1$  the values of X and Y lie exactly on a line.
- Positive (negative) correlation indicates a line with positive (negative) slope.

# Visually Evaluating Correlation



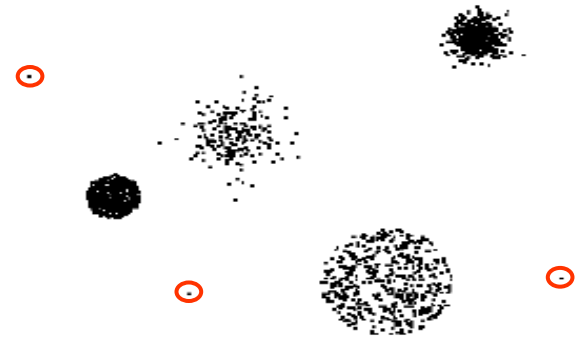
**Scatter plots showing the similarity from  $-1$  to  $1$ .**

# Visualization of the Iris Correlation Matrix



# Outliers

- **Outliers** are data objects with characteristics that are considerably different than most of the other data objects in the data set
  - **Case 1:** Outliers are noise that interferes with data analysis
  - **Case 2:** Outliers are the goal of our analysis
    - Credit card fraud
    - Intrusion detection
- **Causes:**
  - Data quality problems (erroneous data coming from wrong measurements or typing mistakes)
  - Exceptional or unusual situations/data objects.



# Outliers as noise

- Outliers coming from erroneous data should be excluded from the analysis
- Even if the outliers are correct (exceptional data), it is sometime useful to exclude them from the analysis.
- For example, a single extremely large outlier can lead to completely **misleading values for the mean value.**

# Outlier Detection

- **Single attribute:**
  - **Categorical** attributes: An outlier is a value that occurs with a frequency extremely lower than the frequency of all other values.
  - **Numerical** attributes: box plots
- **Multidimensional attribute:**
  - Scatter plots for (visually detecting) outliers w.r.t. two attributes
  - PCA plots for (visually detecting) outliers
  - Cluster analysis techniques: Outliers are those points which cannot be assigned to any cluster.

# Missing Values

- For some instances values of single attributes might be missing
- Reasons for missing values
  - **Information is not collected**  
(e.g., people decline to give their age and weight)
  - **Attributes may not be applicable to all cases**  
(e.g., annual income is not applicable to children)
  - **Broken sensors**
  - **Refusal to answer a question**
- Missing value might not necessarily be indicated as missing (instead: zero or default values).



# Checklist for Data Understanding

- Determine the quality of the data. (e.g. syntactic accuracy)
- Find outliers. (e.g. using visualization techniques)
- Detect and examine missing values. Possible hidden by default values.
- Discover new or confirm expected dependencies or correlations between attributes.
- Check specific application dependent assumptions (e.g. the attribute follows a normal distribution)
- Compare statistics with the expected behaviour.