

DATA MINING 1

Data Understanding

Dino Pedreschi, Riccardo Guidotti

Revisited slides from Lecture Notes for Chapter 2 “Introduction to Data Mining”, 2nd Edition by Tan, Steinbach, Karpatne, Kumar



UNIVERSITÀ DI PISA

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

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

Attributes				
Tid	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

Projection of x Load	Projection of y load	Distance	Load	Thickness
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

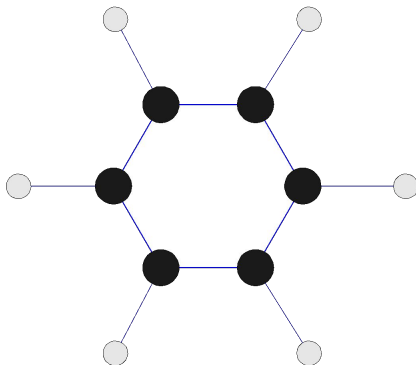
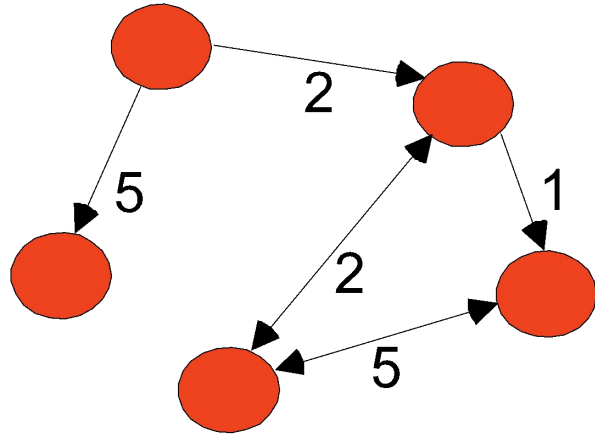
Transaction Data

- 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



Benzene Molecule: C₆H₆

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

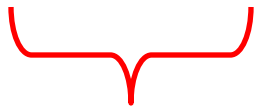
Usama Fayyad, "Mining Databases: Towards Algorithms for Knowledge Discovery", Bulletin of the IEEE Computer Society Technical Committee on data Engineering, vol. 21, no. 1, March 1998.

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.

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

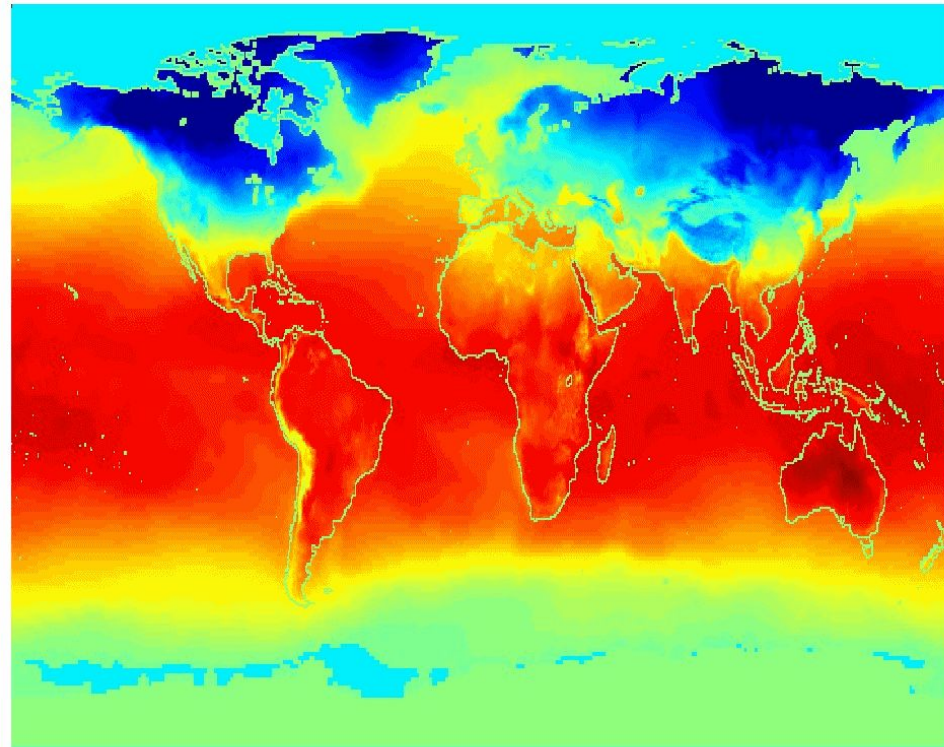
```
GGTTCCGCCTTCAGCCCCGCGCC
CGCAGGGCCCGCCCCGCGCCGTC
GAGAAGGGCCCGCCTGGCGGGCG
GGGGGAGGCGGGGCCGCCCGAGC
CCAACCGAGTCCGACCAGGTGCC
CCCTCTGCTCGGCCTAGACCTGA
GCTCATTAGGCGGCAGCGGACAG
GCCAAGTAGAACACGCGAAGCGC
TGGGCTGCCTGCTGCGACCAGGG
```

Ordered Data

- Spatio-Temporal Data

**Average Monthly
Temperature of
land and ocean**

Jan



Types of Attributes

- Five are different types of attributes
 - **Nominal/Categorical:** attribute values in a finite domain, categories
 - **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

		Attribute Type	Description	Examples	Operations
Categorical Qualitative		Nominal	Nominal attribute values only distinguish. (=, ≠)	zip codes, employee ID numbers, eye color, sex: { <i>male</i> , <i>female</i> }	mode, entropy, contingency correlation, χ^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
Numeric Quantitative		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:** **fmale** 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:** Dataset might be extremely biased 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

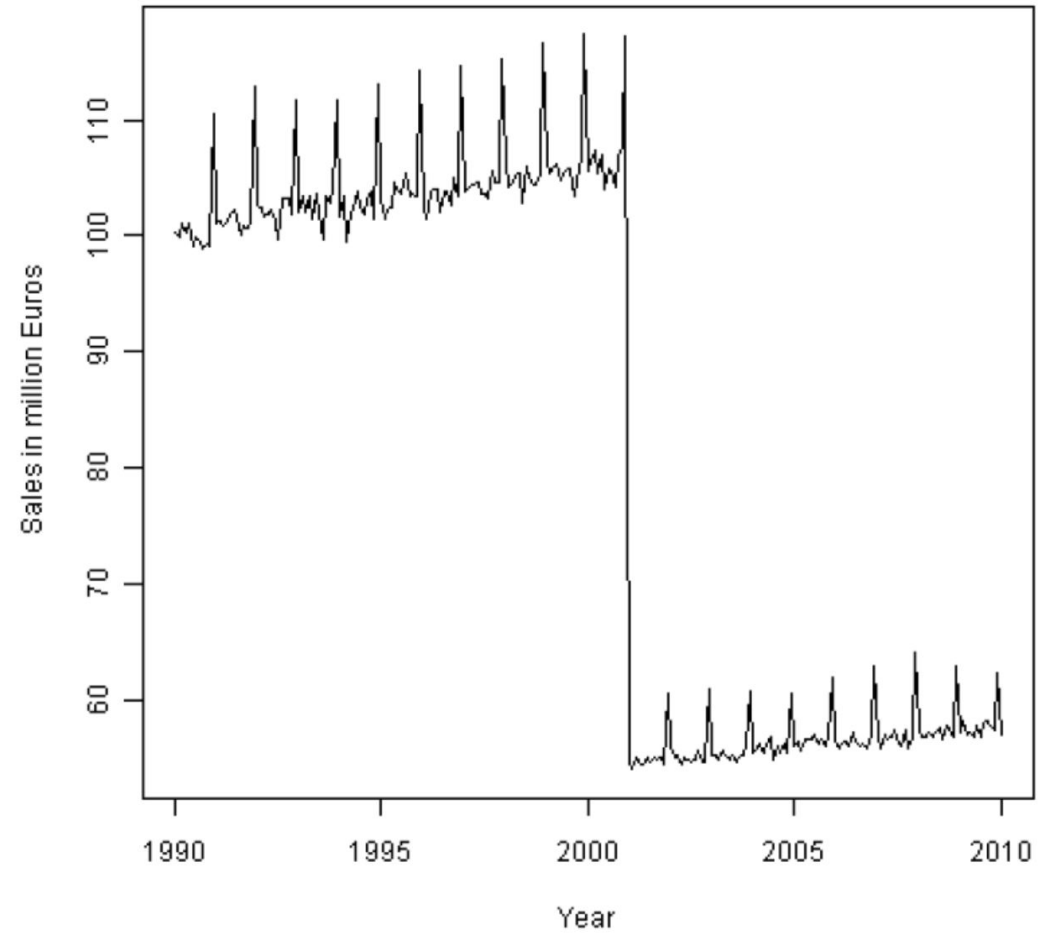
- Data set may include data objects that are duplicates, or almost duplicates of one another
 - Major issue when merging data from heterogeneous sources
- Examples:
 - Same person with multiple email addresses
- Data cleaning
 - Process of dealing with duplicate data issues

Statistics & Visualization

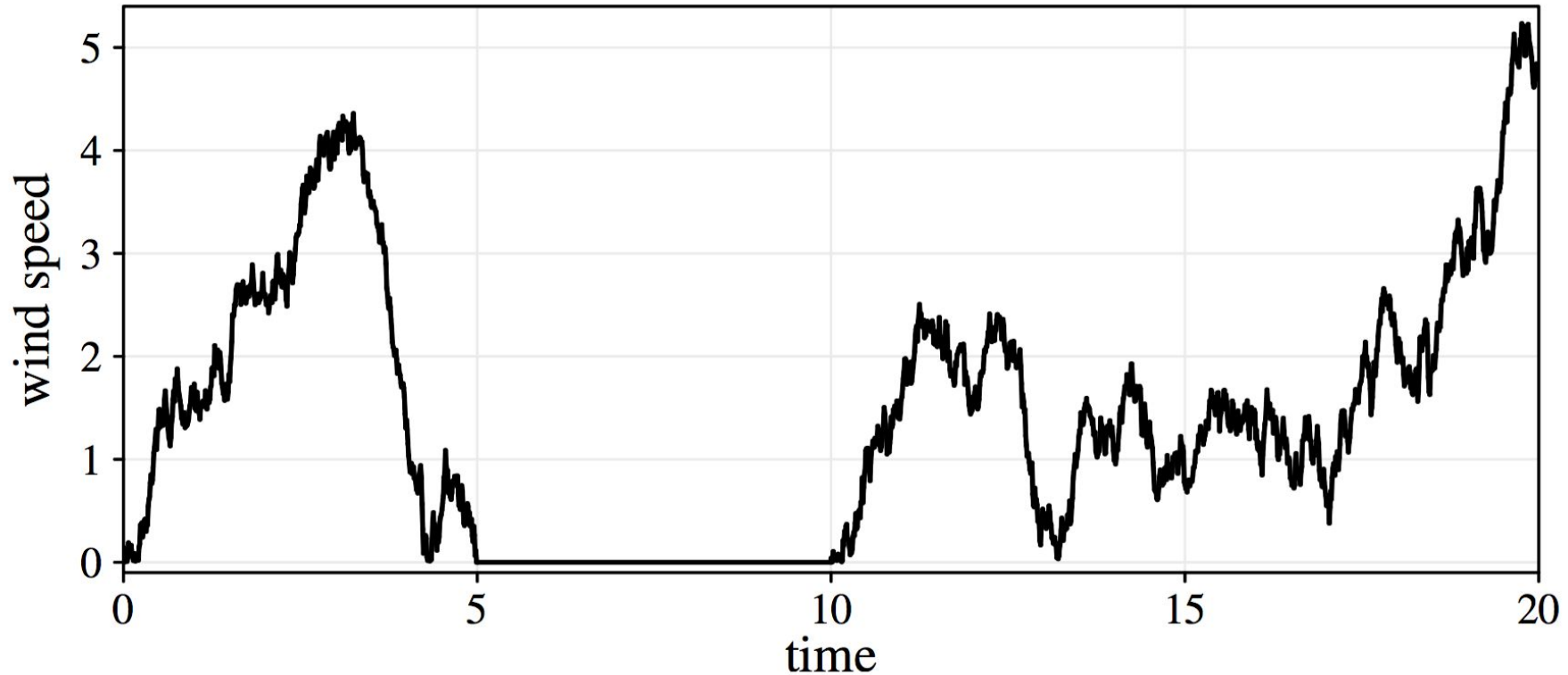
In order to know our data and discovery quality issues we need:

- 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

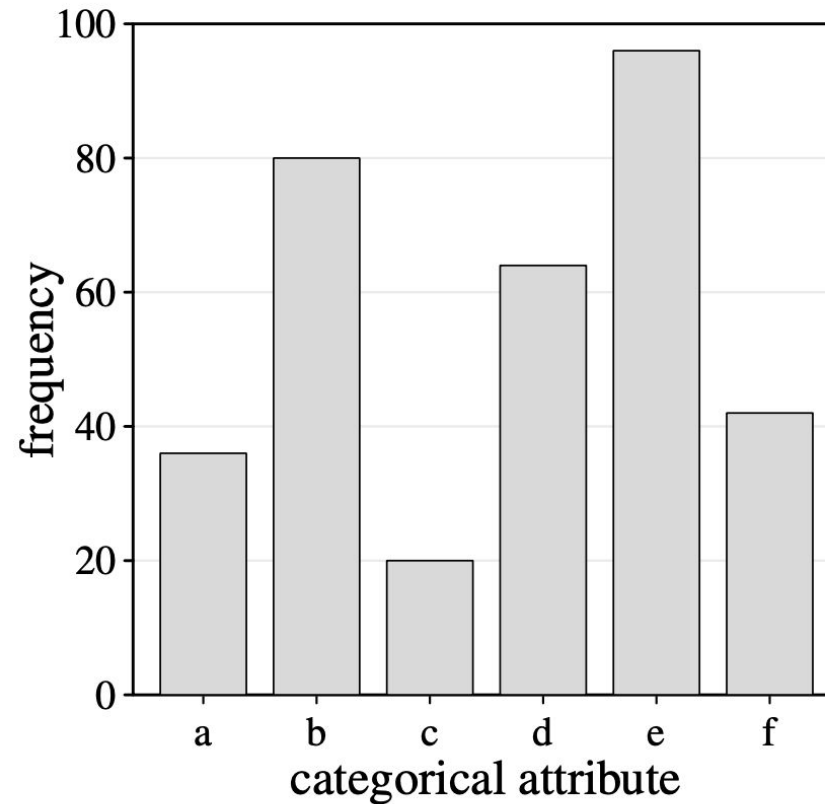


Data Visualization



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

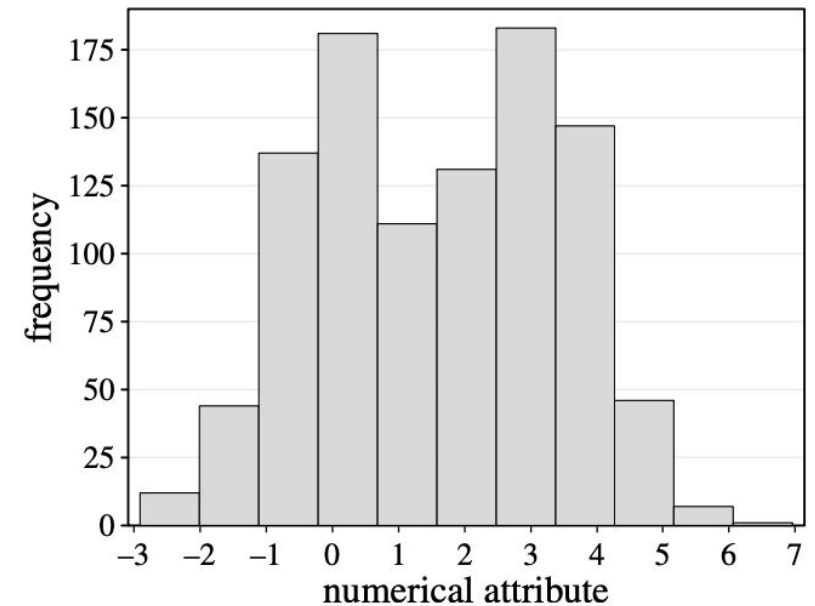
Bar Chart for Categorical Attributes



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

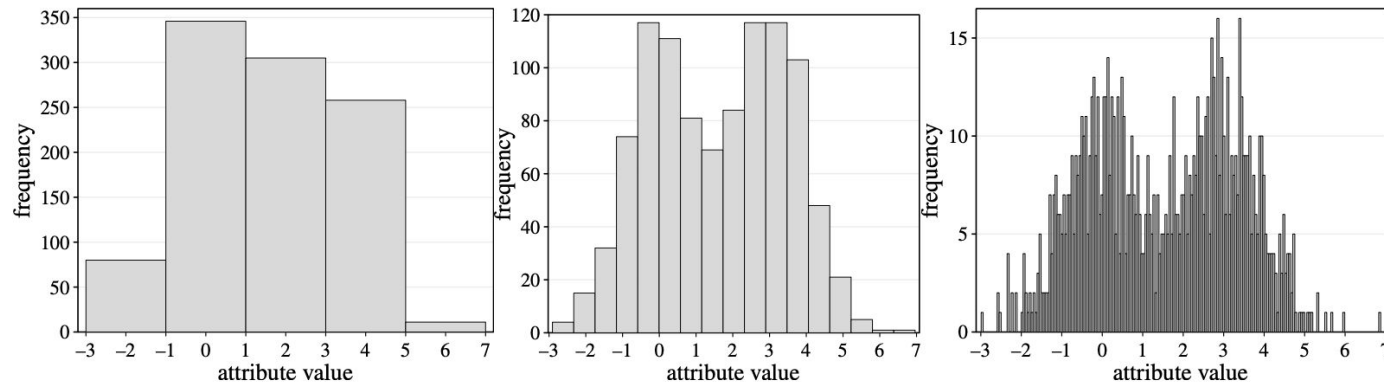
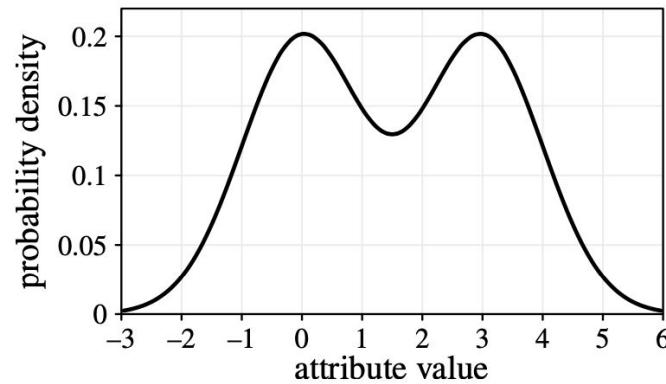
Histograms for Numerical Attributes

- 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**:

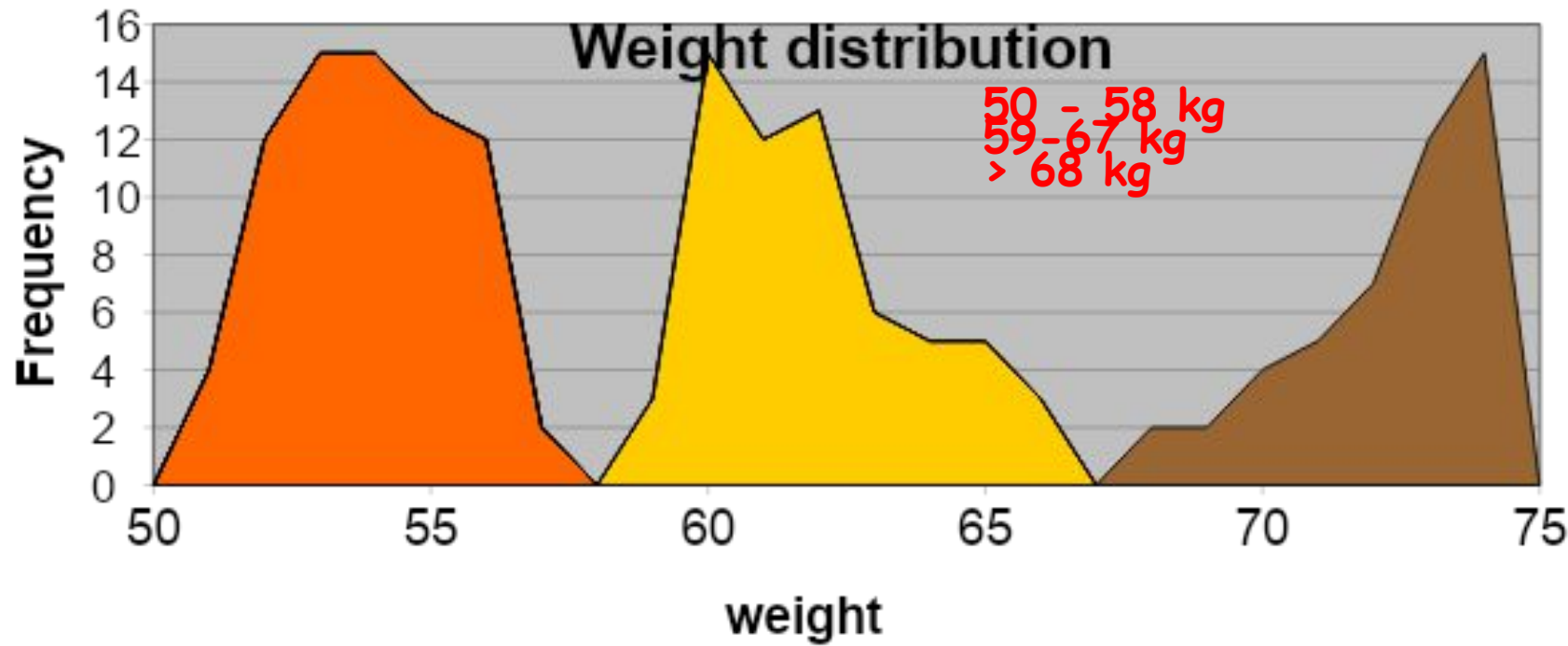
$$k = \lceil \log_2(n) + 1 \rceil$$

where n is the sample size

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

How to choose intervals?

1. Interval with a fixed “reasonable” granularity
Ex. intervals of 10 cm for height.
2. Interval size is defined by some domain dependent criterion
Ex.: 0-20ML, 21-22ML, 23-24ML, 25-26ML, >26ML
3. Interval size determined by analyzing data, studying the distribution and find breaks or using clustering



Natural Binning

- Simple
- Sort of values, subdivision of the range of values in k parts with the same size

$$\delta = \frac{x_{\max} - x_{\min}}{k}$$

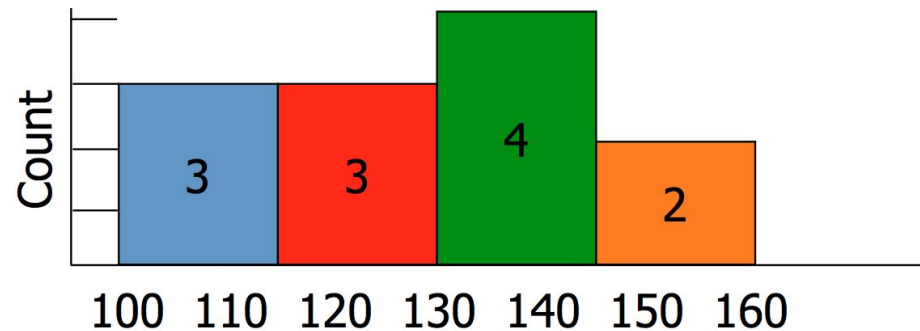
- Element x_j belongs to the class i if

$$x_j \in [x_{\min} + i\delta, x_{\min} + (i+1)\delta)$$

- It can generate distribution very unbalanced

Example

- Histogram for Price
- $\delta = (160-100)/4 = 15$
- bin 1: [100,115)
- bin 2: [115,130)
- bin 3: [130,145)
- bin 4: [145, 160]



Bar	Beer	Price
A	Bud	100
A	Becks	120
C	Bud	110
D	Bud	130
D	Becks	150
E	Becks	140
E	Bud	120
F	Bud	110
G	Bud	130
H	Bud	125
H	Becks	160
I	Bud	135

Equal Frequency Binning

- Sort and count the elements, definition of k intervals of f , where:

$$f = \frac{N}{k}$$

(N = number of elements of the sample)

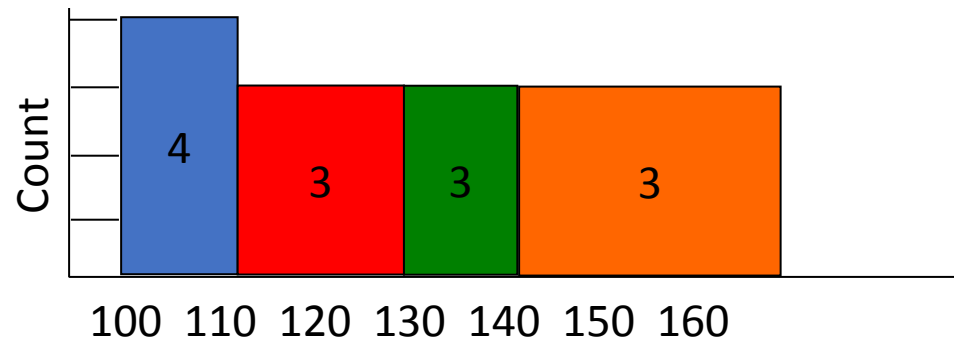
- The element x_i belongs to the class j if

$$j \times f \leq i < (j+1) \times f$$

- It is not useful for highlighting interesting distribution

Example

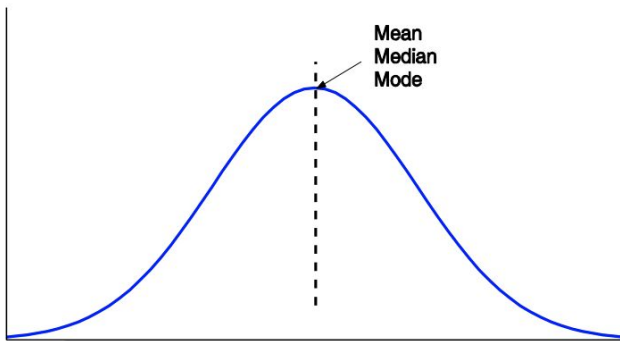
- Histogram for Price
- $f = 12/4 = 3$
- class 1: {100,110,110}
- class 2: {120,120,125}
- class 3: {130,130,135}
- class 4: {140,150,160}



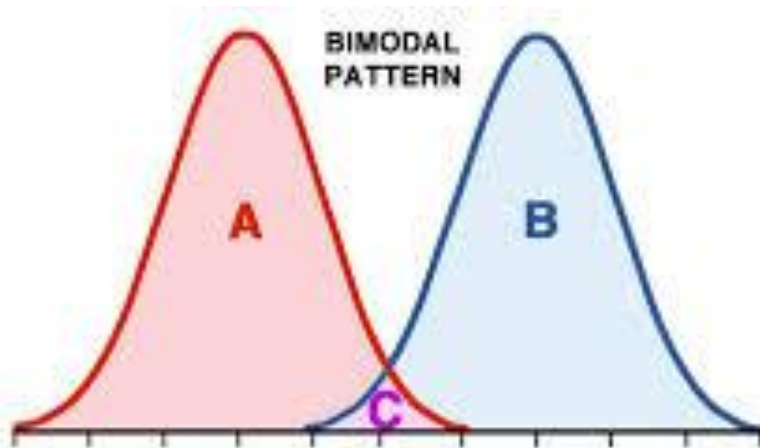
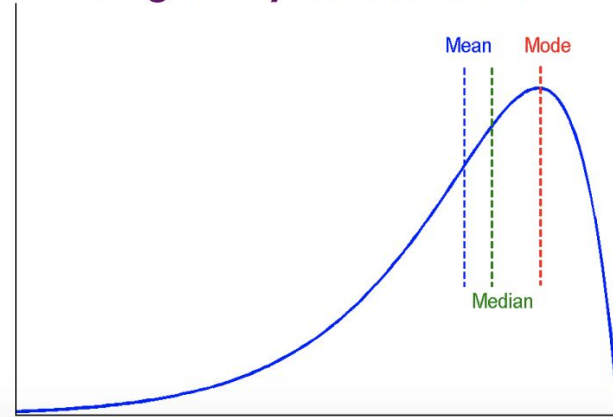
Bar	Beer	Price
A	Bud	100
A	Becks	120
C	Bud	110
D	Bud	130
D	Becks	150
E	Becks	140
E	Bud	120
F	Bud	110
G	Bud	130
H	Bud	125
H	Becks	160
I	Bud	135

Observing Data Distribution

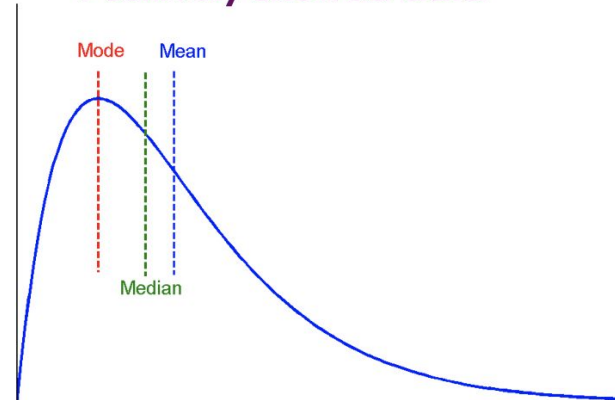
Symmetric data



Negatively skewed data



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.

Measuring the Central Tendency

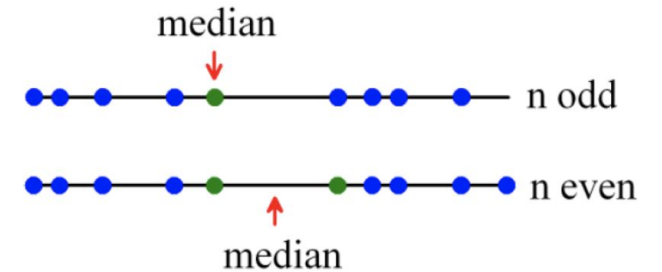
- Mean

- 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** σ is the square root of variance σ^2

- σ 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:

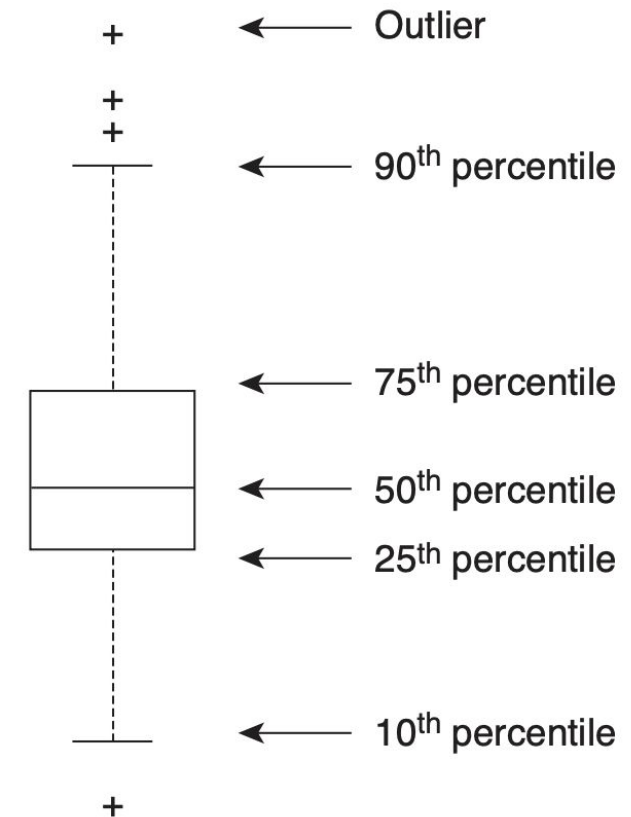
- **absolute average deviation (AAD)**
- **median average deviation (MAD)**

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

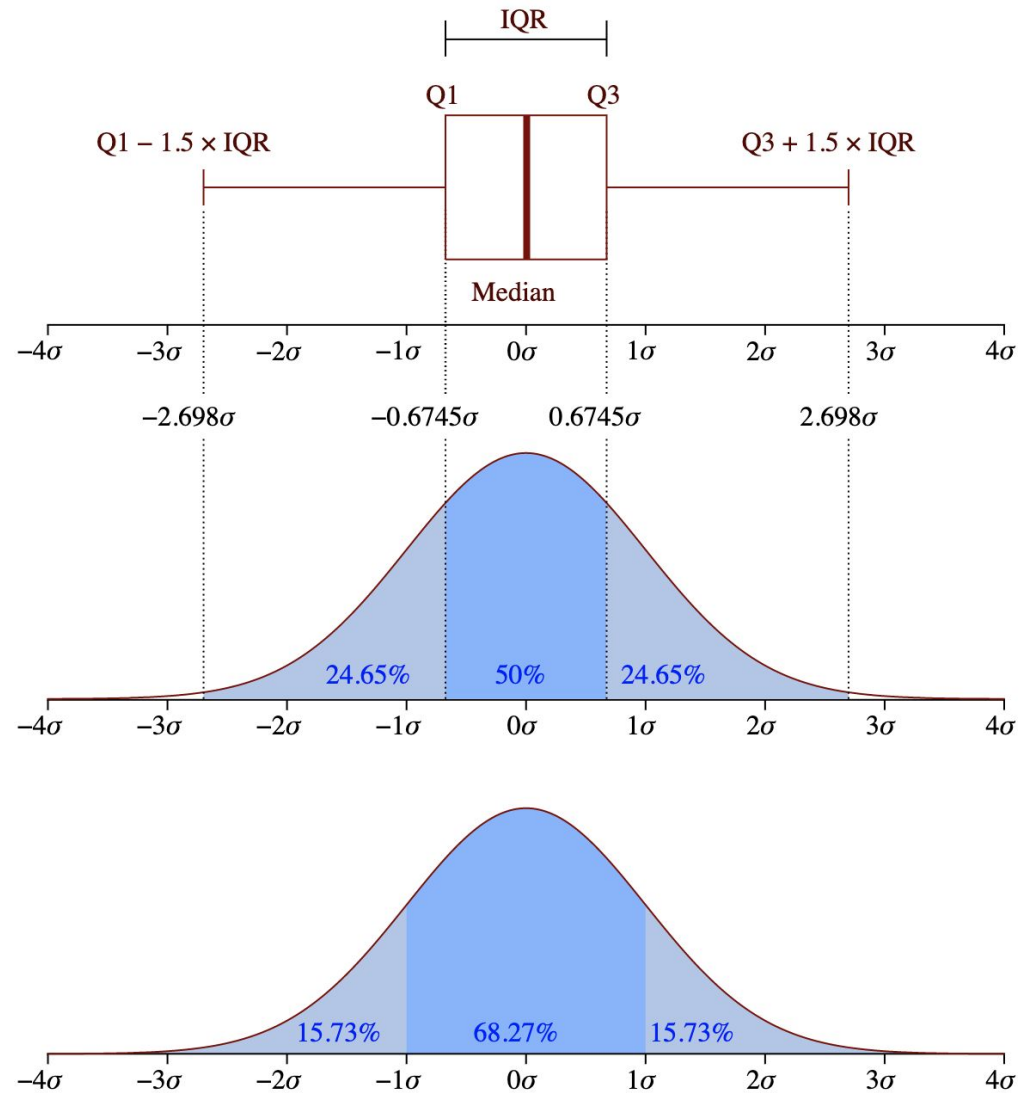
$$\text{MAD}(x) = \text{median}\left(\{|x_1 - \bar{x}|, \dots, |x_m - \bar{x}|\}\right)$$

Box Plot: Five-number summary of a distribution

- Data represented with a **box**
- The ends of the box are at the
 - **Q1: 1st quartiles** (25%-quantile or 25th percentile)
 - **Q3: 3rd quartiles** (75%-quantile or 75th percentile)
- **Median**: value in the middle is the **Q2: 2nd quartile** (50%-qua,, 50th perc.)
- The height of the box is **Interquartile range (IQR)**: $Q3 - Q1$
- **Whiskers**: two lines outside the box extended from:
 - 1st, or 5th, or 10th percentile, or $Q1 - k \text{ IQR}$ (with $k = 1.5$)
 - 99th, or 95th, or 90th percentile, or $Q3 + k \text{ IQR}$ (with $k = 1.5$)
- **Outliers**: are points beyond whiskers
- In general, $p\%$ -quantile ($0 < p < 100$): Is the value x s.t. $p\%$ of the values are smaller and $100-p\%$ are larger.



Relationship Between Box-Plot and Histogram



Example Data Set: Iris data



iris setosa



iris versicolor



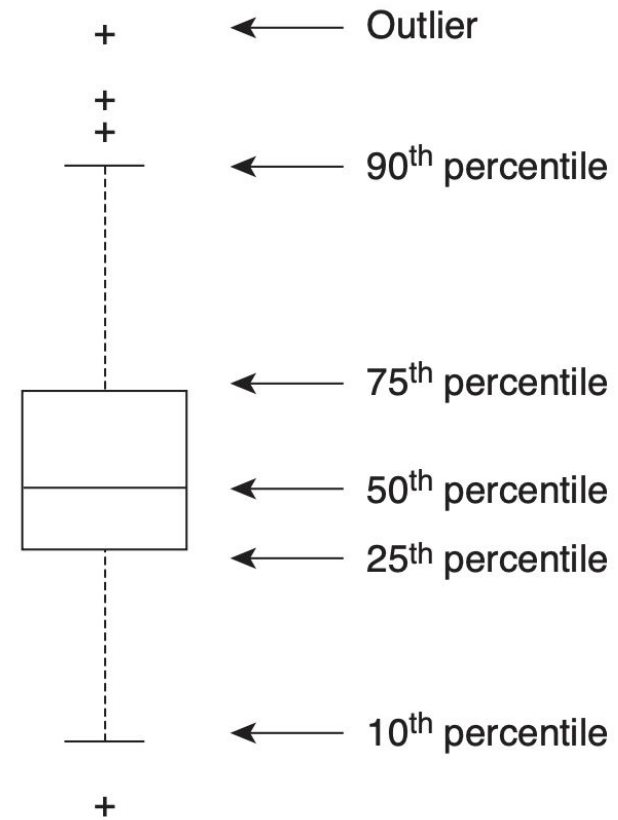
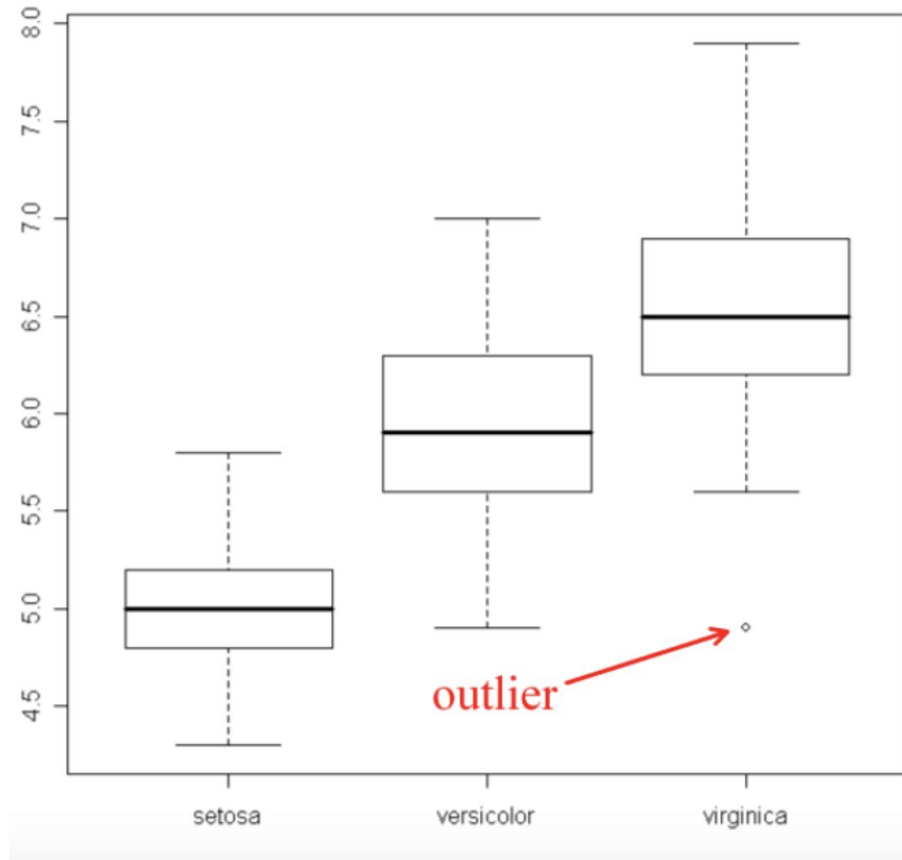
iris virginica

- 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

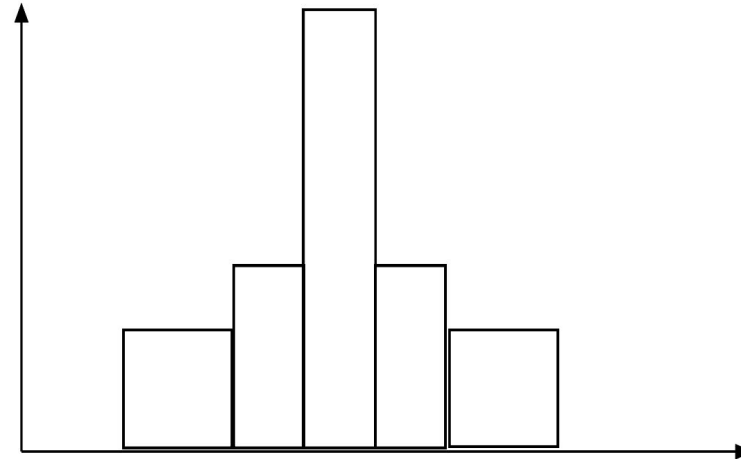
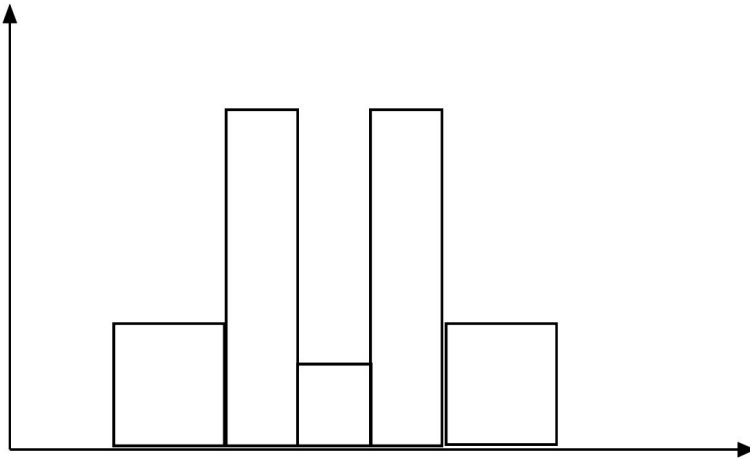
Sepal Length	Sepal Width	Petal Length	Petal Width	Species
5.1	3.5	1.4	0.2	Iris-setosa
...				
...				
5.0	3.3	1.4	0.2	Iris-setosa
7.0	3.2	4.7	1.4	Iris-versicolor
...				
...				
5.1	2.5	3.0	1.1	Iris-versicolor
5.7	2.8	4.1	1.3	Iris-versicolor
...				
...				
5.9	3.0	5.1	1.8	Iris-virginica

Example of Conditional Box Plot



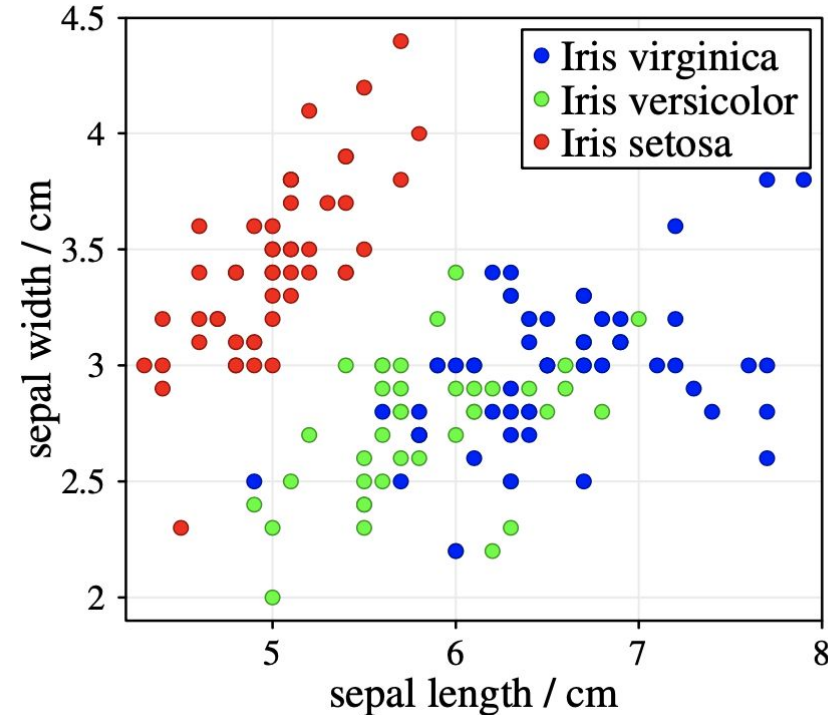
Histograms Often Tell More than Boxplots

- 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**



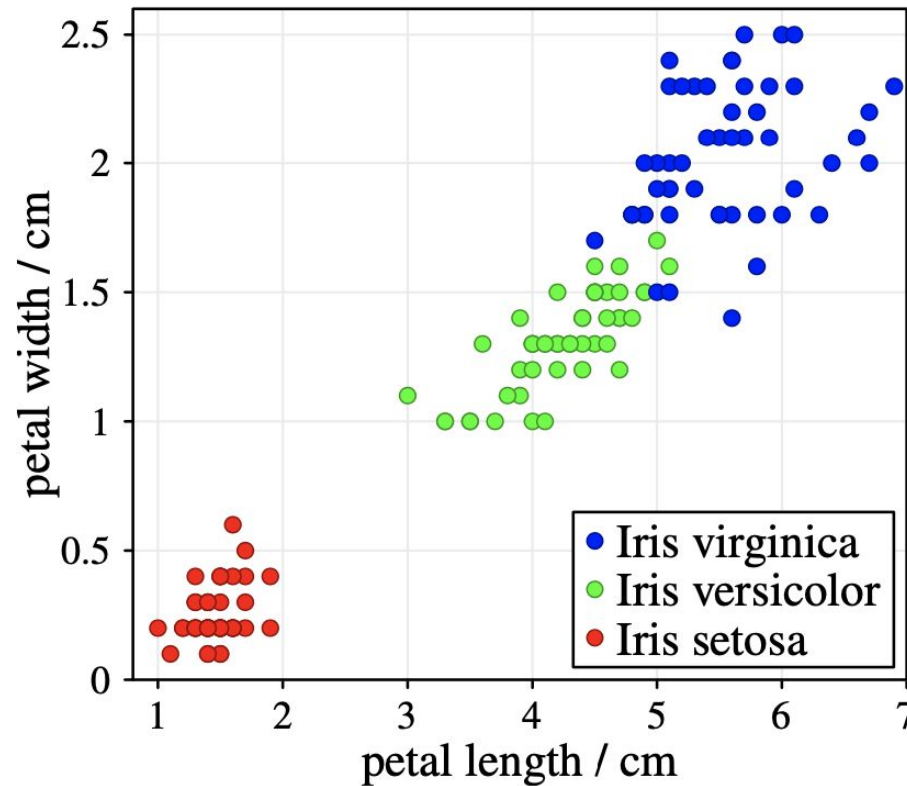
Scatter Plot

- 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



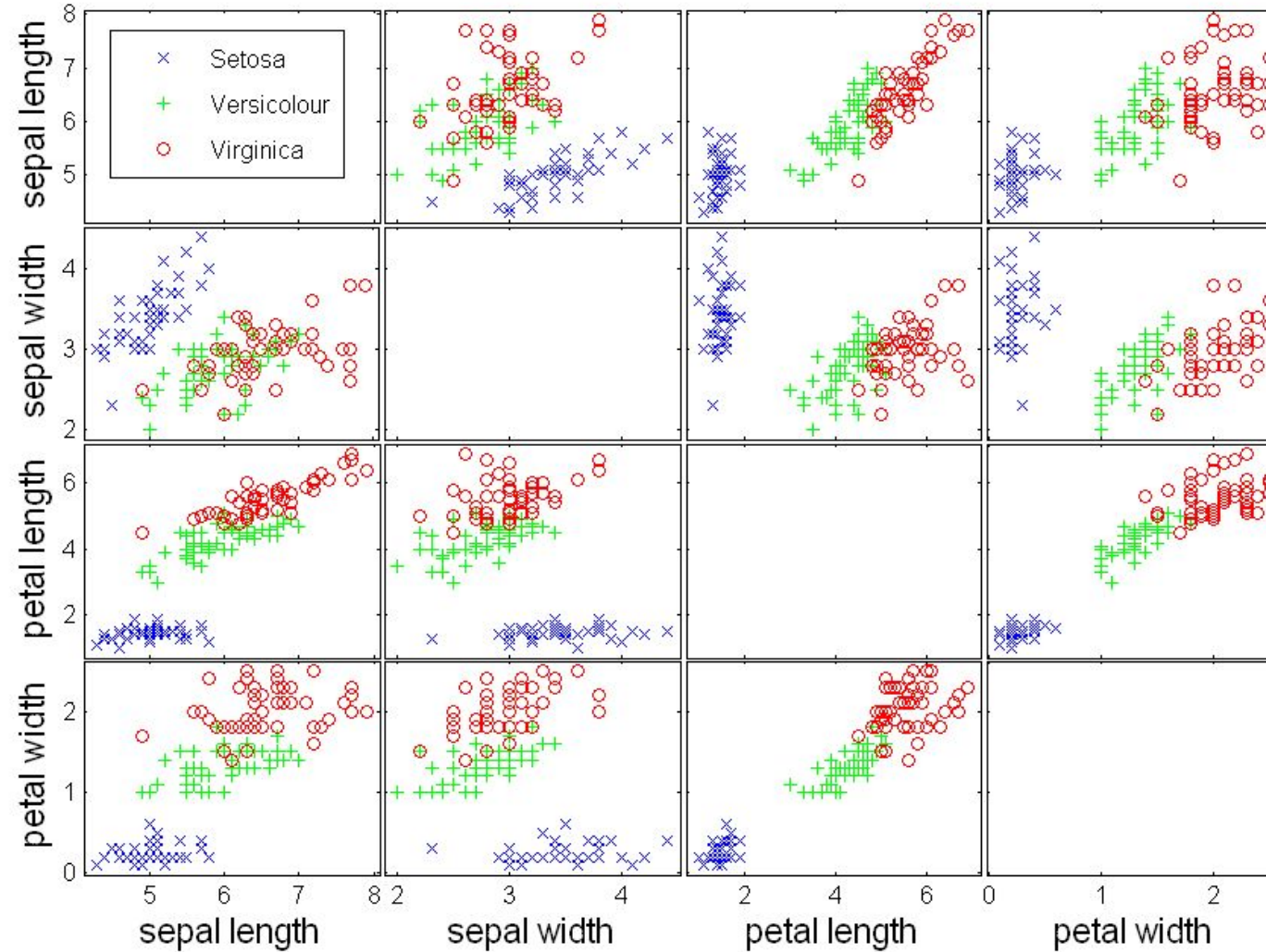
Scatter plots can be enriched with additional information: **Colour** or **different symbols** to **incorporate a third attribute** in the scatter plot.

Scatter Plot



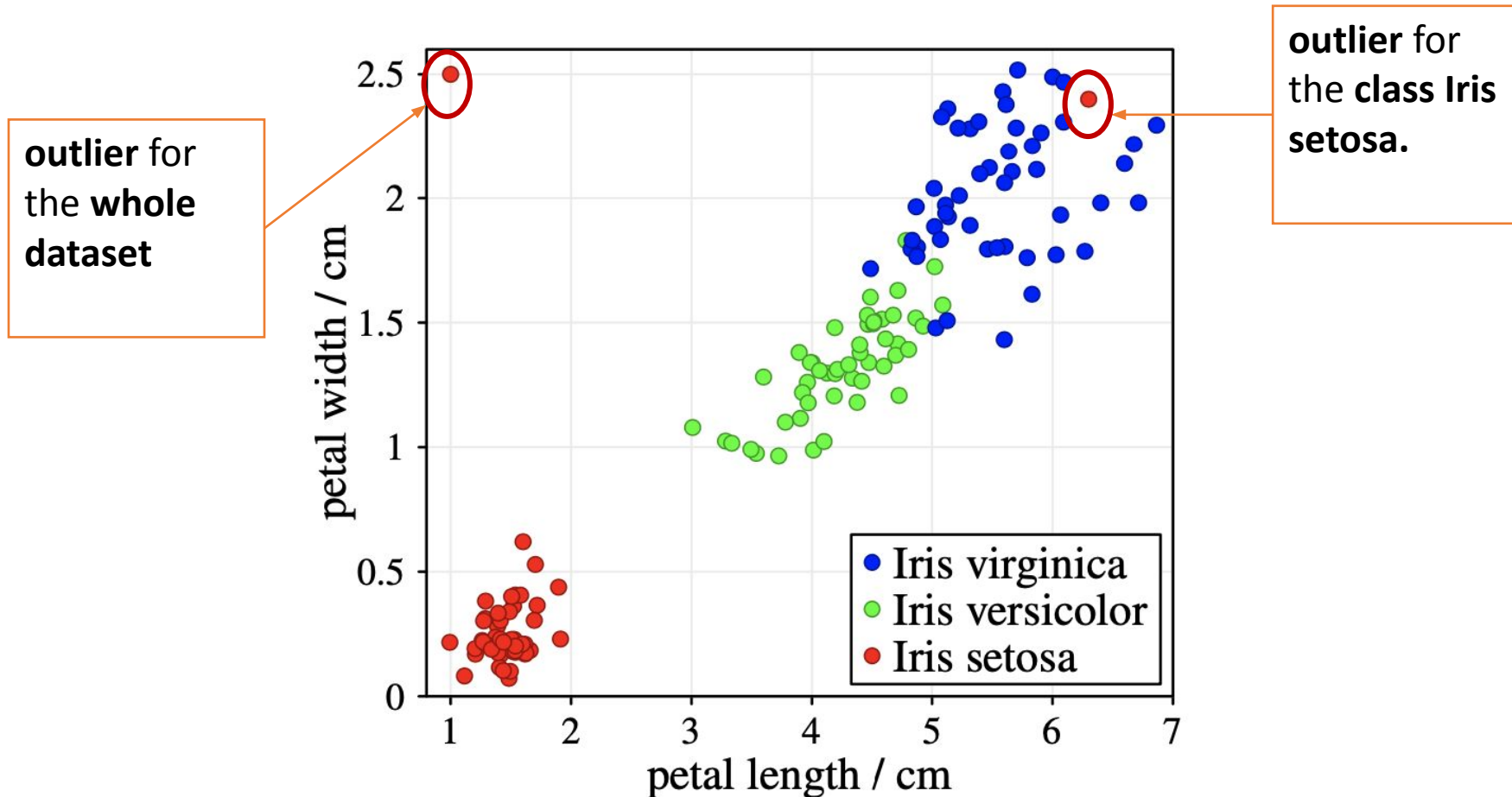
The two attributes petal length and width provide a **better separation of the classes** Iris versicolor and Iris virginica than the sepal length and width.

Scatter Matrix of Iris Attributes



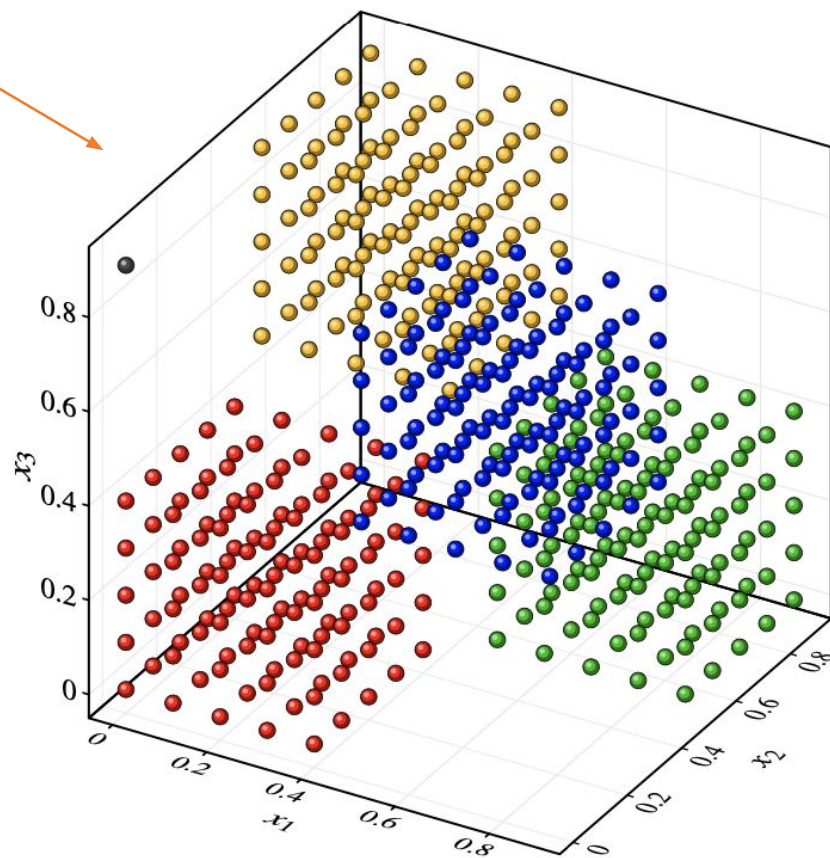
Scatter Plot & Outliers

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.

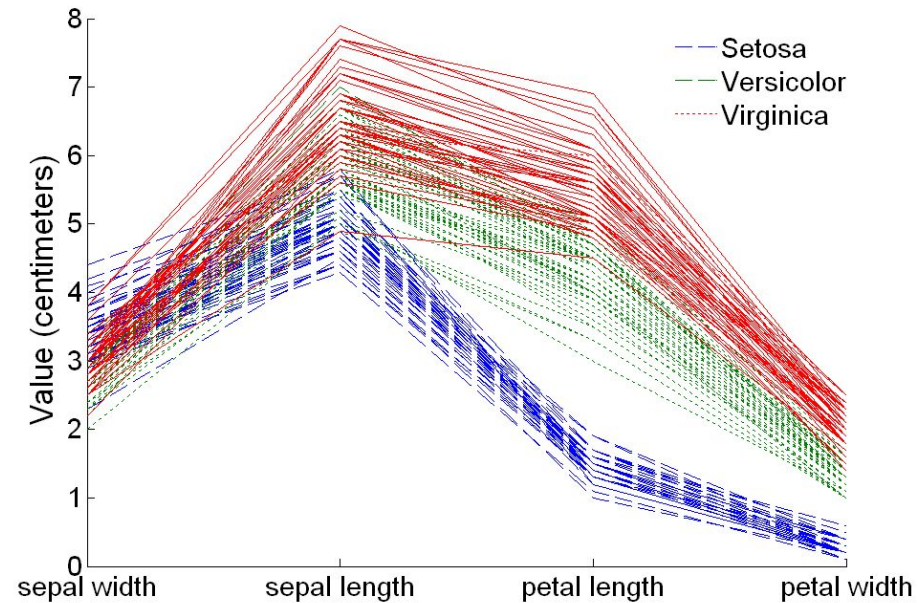
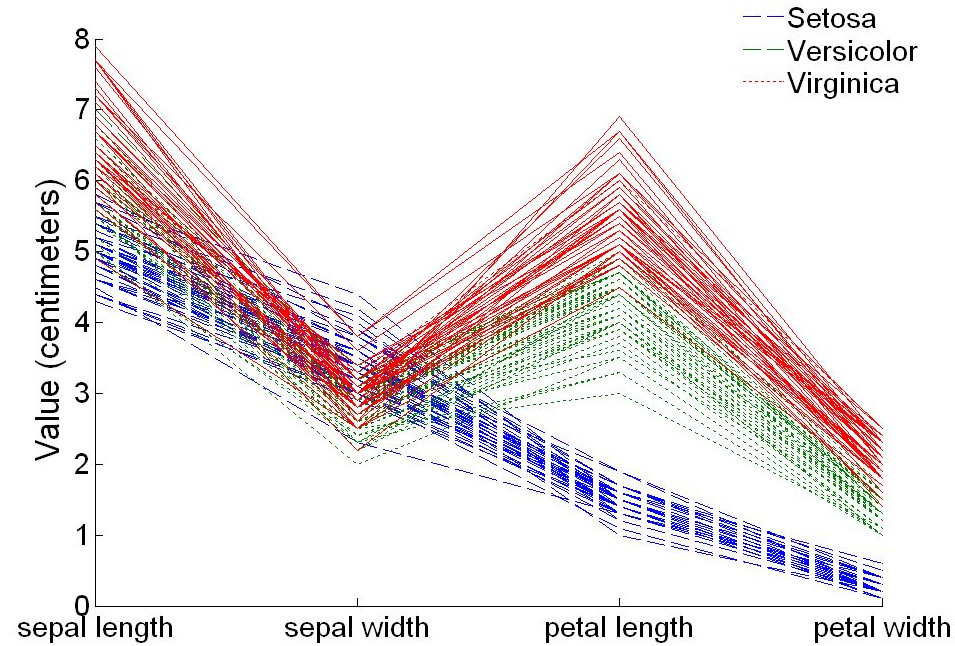
Parallel Coordinates

- 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

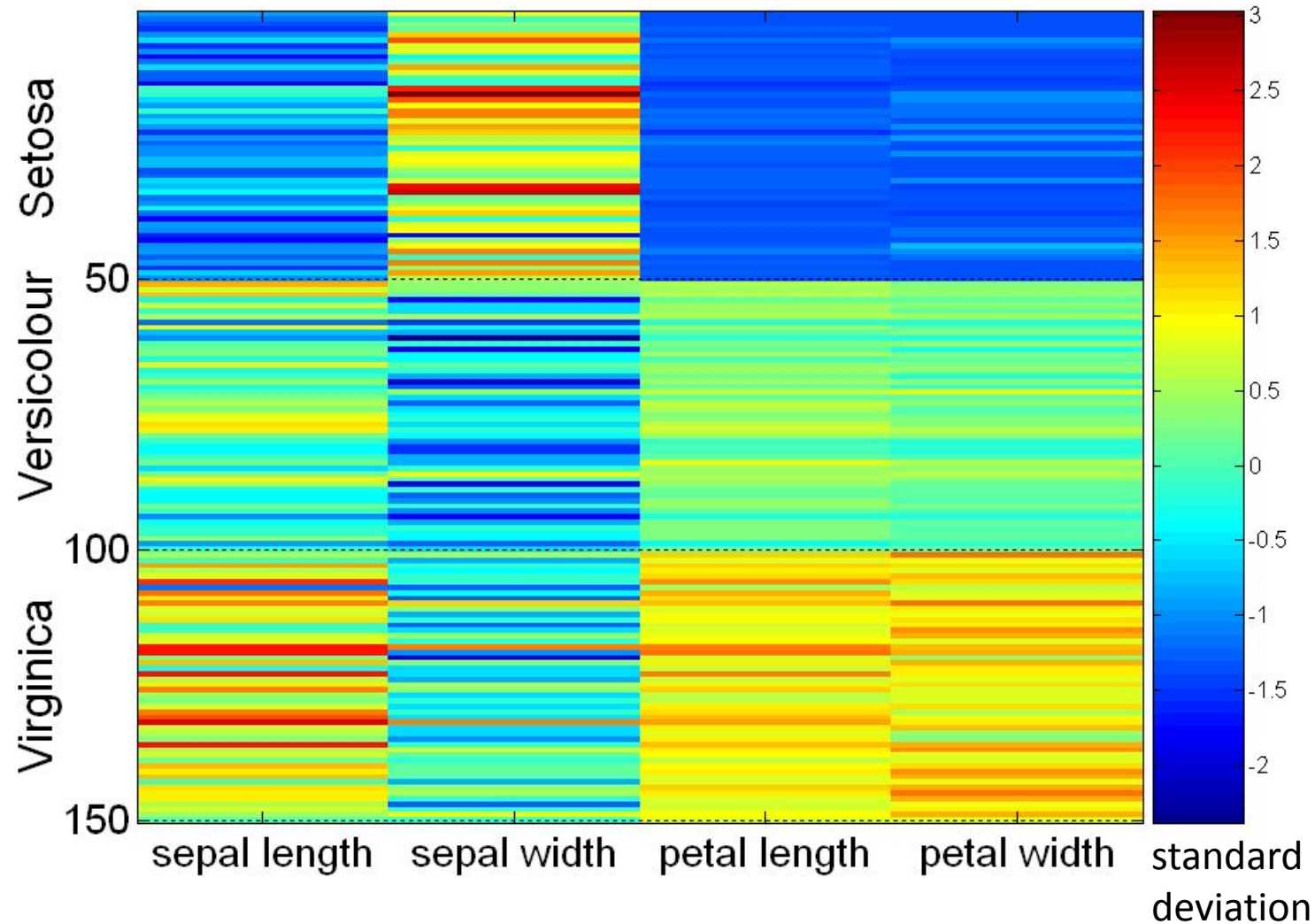
Parallel Coordinates Plots for Iris Data



Matrix Plots

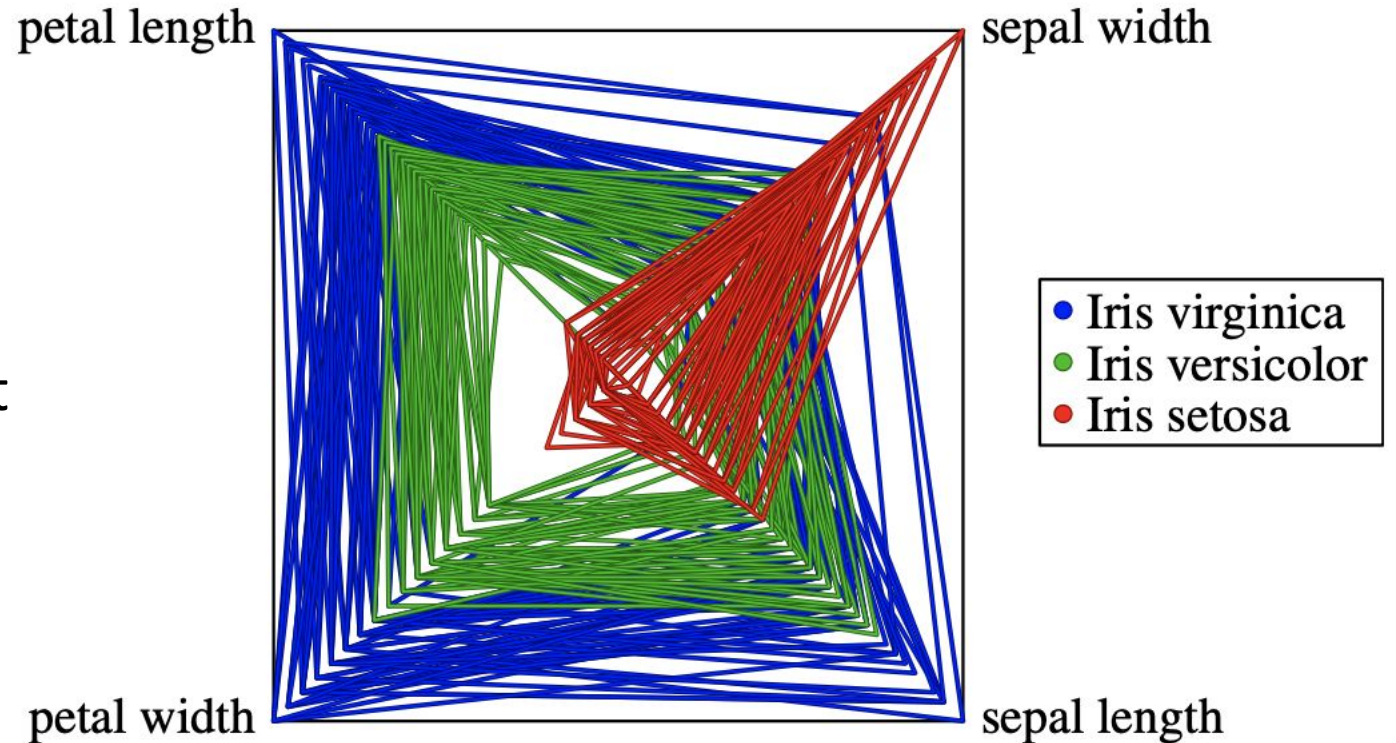
- Can plot the data matrix
- This can be useful when objects are sorted according to class
- Typically, the attributes are normalized to prevent one attribute from dominating the plot
- **Plots of similarity or distance matrices** can also be useful for visualizing the relationships between objects

Visualization of the Iris Data Matrix

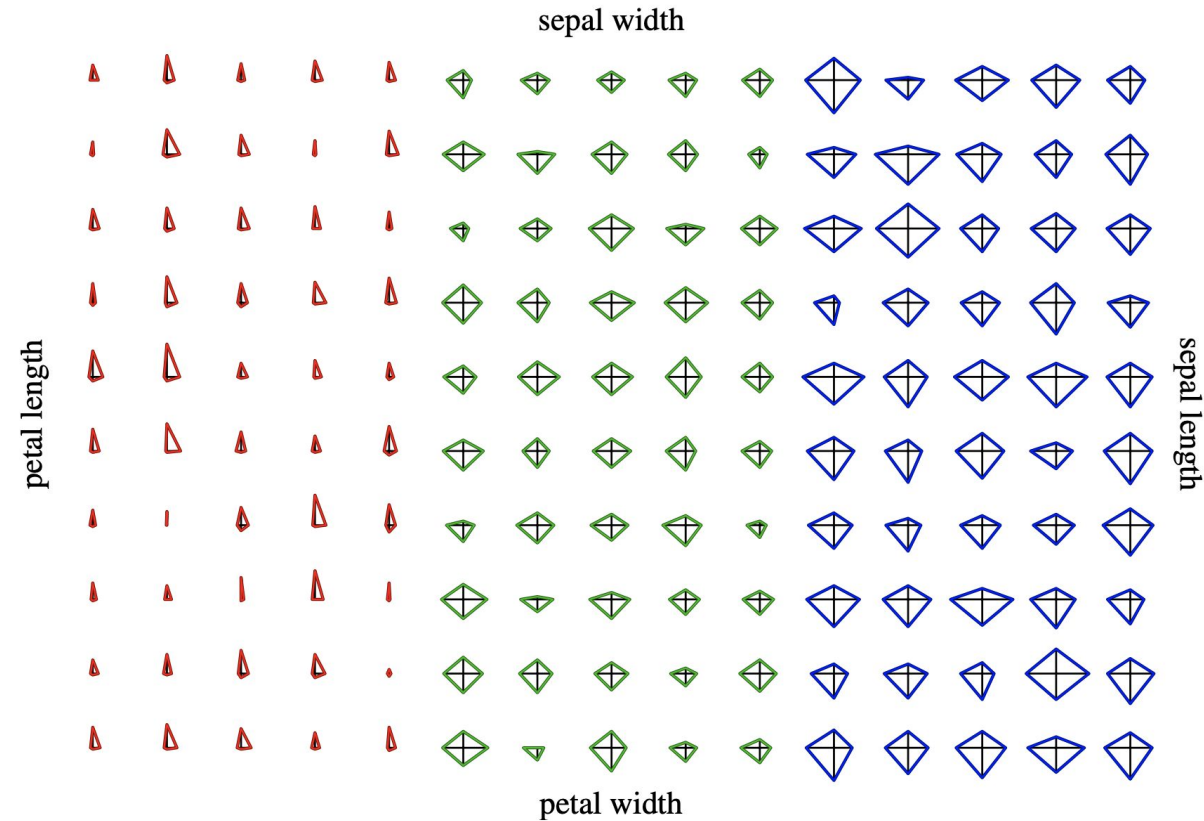


Radar Plot for Iris Data

- 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

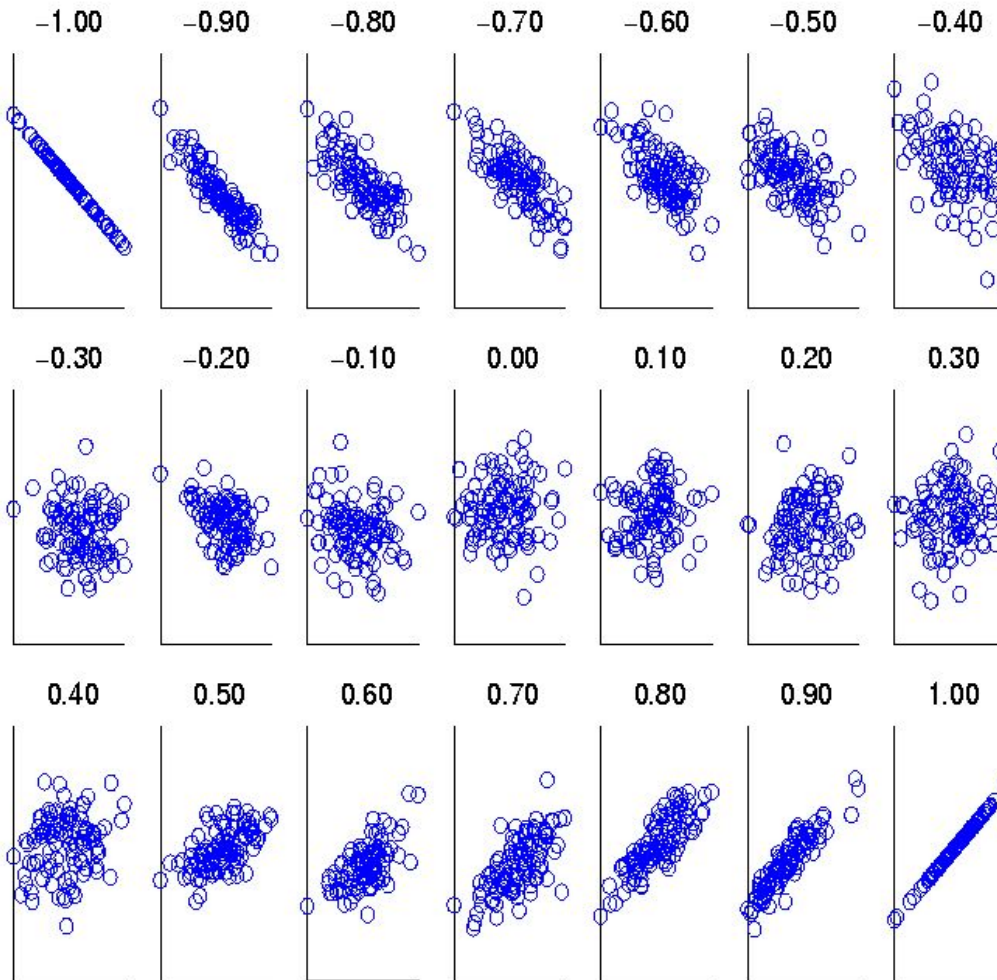
Pearson's Correlation Coefficient

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

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

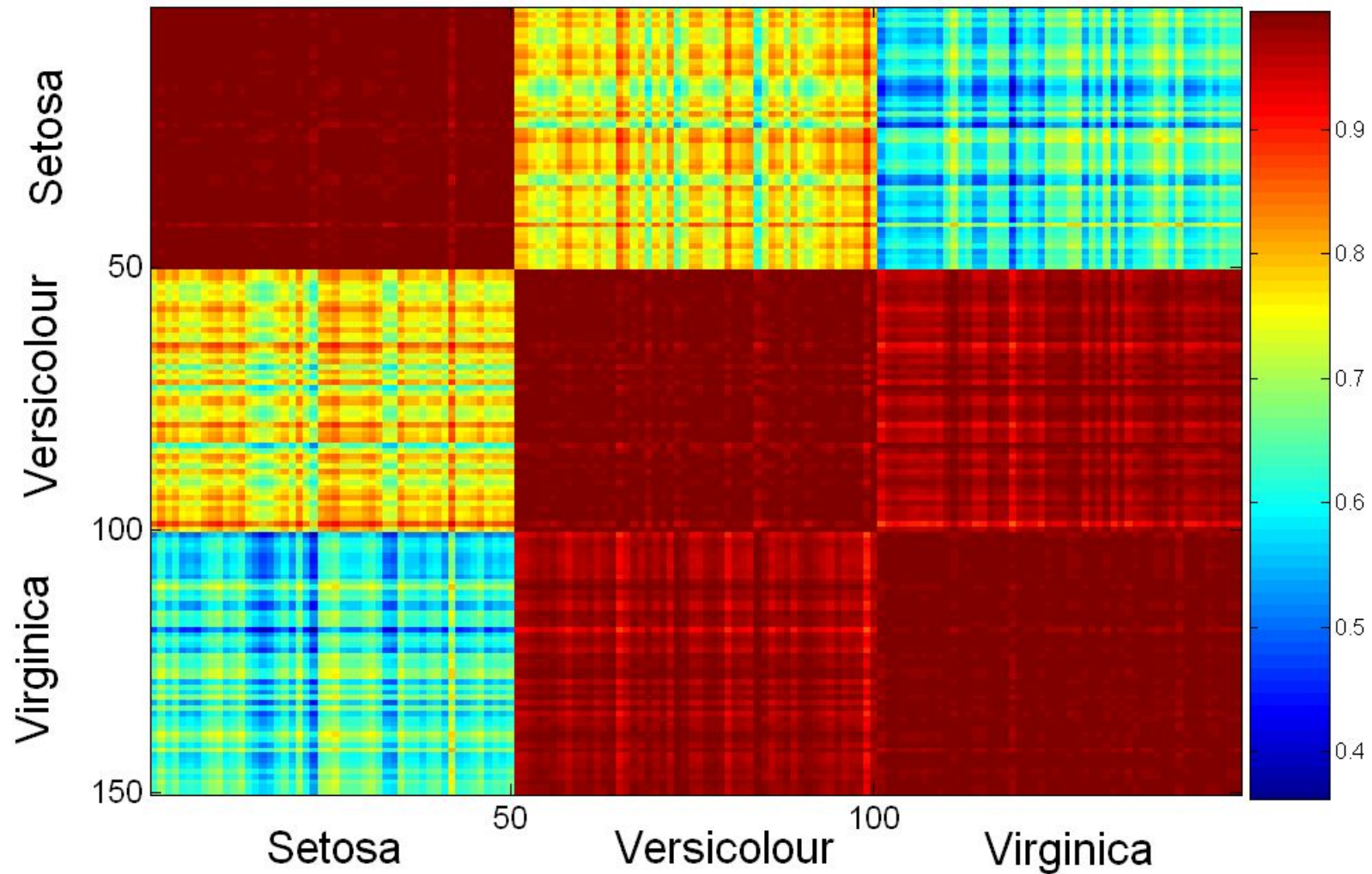
- where $\bar{x}$ and $\bar{y}$ are the mean values of the attributes X and Y, respectively. s_x and s_y are the corresponding (sample) standard deviations.
- The larger the absolute value of the Pearson correlation coefficient, the stronger the linear relationship between the two attributes.
- For $|r_{xy}|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

Visually Evaluating Correlation



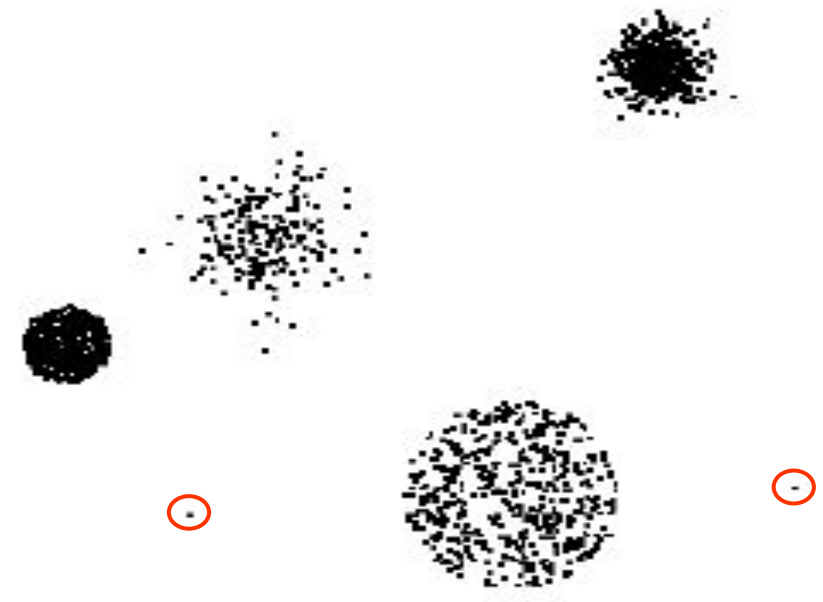
**Scatter plots
showing the
similarity
from -1 to 1 .**

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 (points outside whiskers)

- **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.