Einführung in die Datenanalyse

Introduction to Data Science

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Course Overview

1. **What is Data Science?**

2. Data: An Overview.

3. Exploratory Data Analysis

What is Data Science? (I)

- *„The extraction of knowledge from data.“*
  -- Wikipedia

- *„A data scientist is someone who can obtain, scrub, explore, model and interpret data, blending hacking, statistics and machine learning.”*
  -- Daniel Tukelang (LinkedIn)

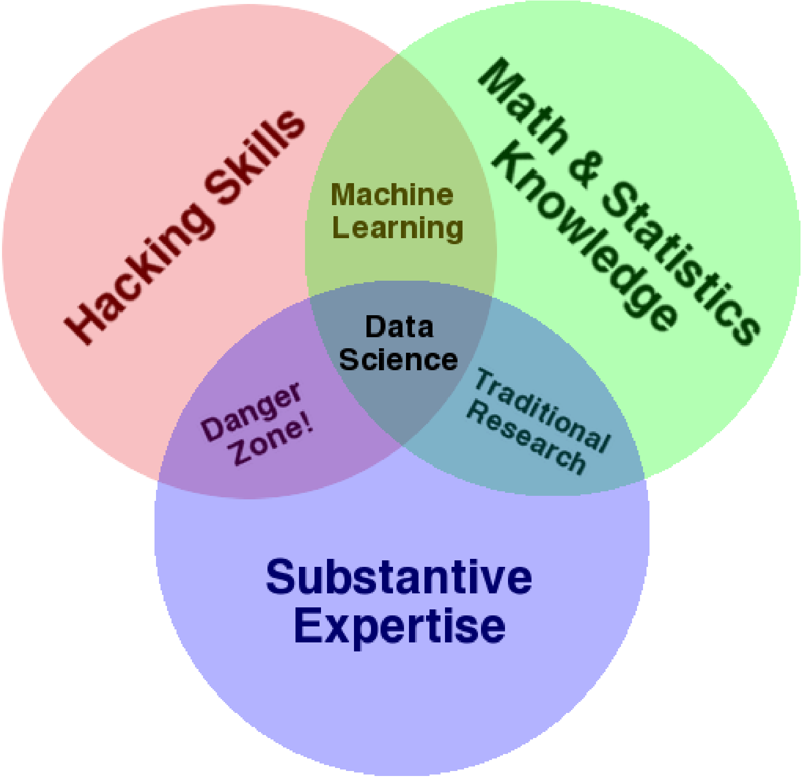
- *„The sexiest career of the 21st century.”*
  -- Harvard Business Review

- *„By 2018 the United States will experience a shortage of 190,000 skilled data scientists.”*
  -- McKinsey

- *„A buzzword without clear definition [that] has simply replaced Business Analytics in contexts such as graduate degree programs.“*
  -- Gil Press (Forbes)

- *„A sexed up term for a statistician.“*
  -- Nate Silver (FiveThirtyEight.com)

What is Data Science? (II)

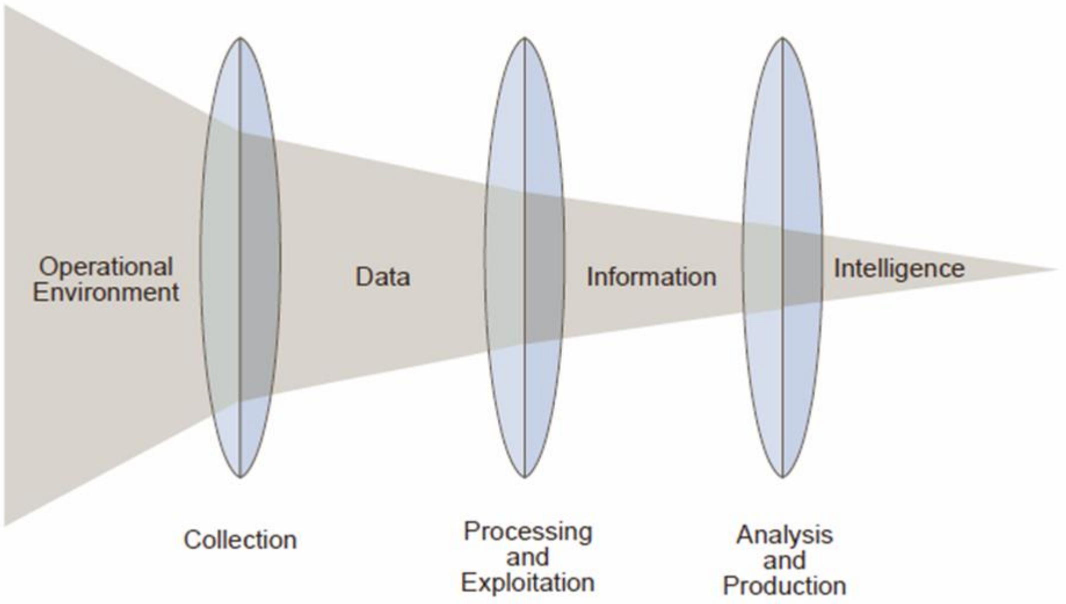


Source: http://www.niemanlab.org/images/drew-conway-data-science-venn-diagram.jpg

What is Data Science? (III)

How to get from here ....

Relationship of Data, Information and Intelligence



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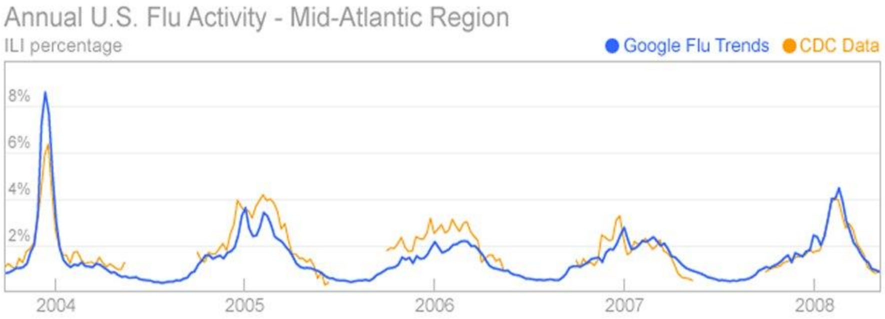
Source: Joint Intelligence / Joint Publication 2-0 (Joint Chiefs of Staff)

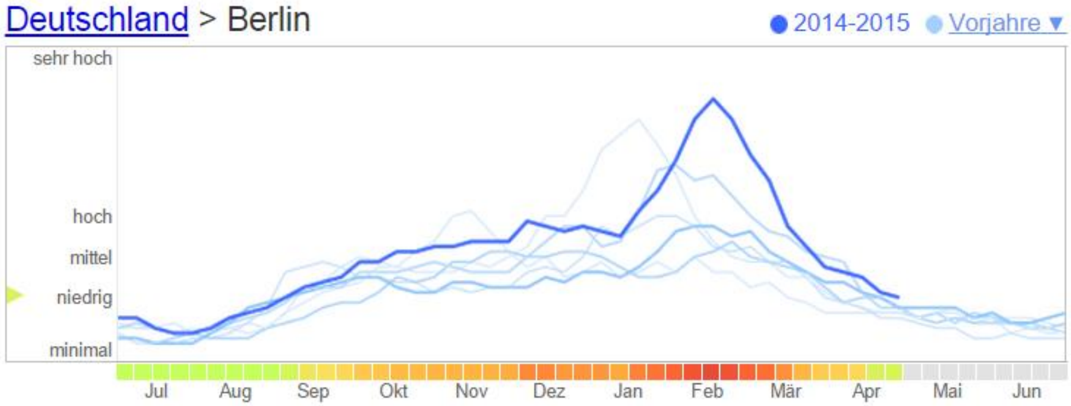
Data Science Success Stories: Google Flu Trends



- In 2008, Data Scientists at Google found that they can predict Flu seasons by monitoring the frequency of Flu-related search terms.
- Today, Google is able to predict an incoming Flu season about two weeks before it arrives!

Google offers its flu-related predictions and observations at:

www.google.org/flutrends/

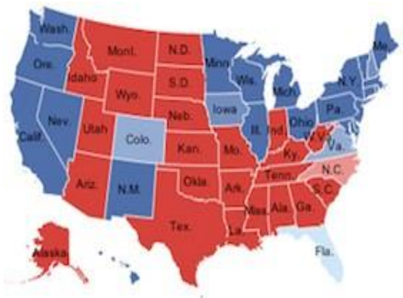


Data Science Success Stories: FiveThirtyEight.com

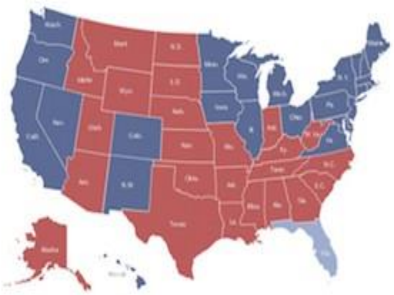
- A thorough statistical model based on polling data enabled Data Analyst & Blogger Nate Silver to accurately predict the outcome of the 2012 US presidential race with 96% accuracy.

- This came as a shock to the „traditional media", who previously called Nate a *„joke"* whose predictions were *„getting into silly land"*.

- Today, he offers statistical predictions for a variety of events from Economics, Sports & Politics at www.fivethirtyeight.com .



Nate Silver's Map



The Actual Map

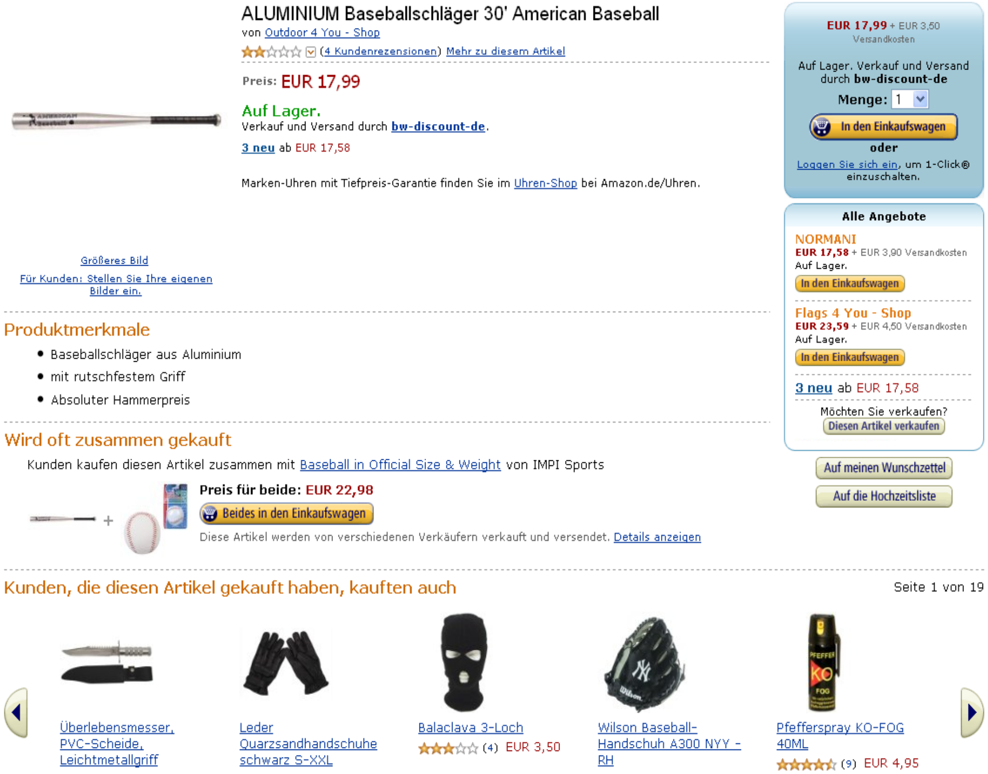
FiveThirtyEight

Data Science Success Stories: Amazon Recommendations

- Amazon is probably the best example for how data analysis can help a business to increase its revenue.

- By monitoring, and modelling the buying behavior of their users, Amazon was able to build a hugely successful product recommendation engine.

- Today, around 20-30% of Amazon‘s revenue can be traced back to product recommendations.



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Seite 1 von 19

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Data Science Success Stories: IBM Watson

- In 2011, IBM’s Big Data Knowledge System Watson managed to beat human competitors in Jeopardy.

- Watson’s core algorithm utilizes Natural Language Processing, Information Extraction & Statistics to infer knowledge from textual data.

- IBM expects Watson to generate around 100 million USD in revenue, primarily in Healthcare, strategic business consulting & Pharmaceutical Research.

So, is Data everything we need?

DILBERT
BY SCOTT ADAMS
CONSULTANTS SAY THREE QUINTILLION BYTES OF DATA ARE CREATED EVERY DAY.
DilbertCartoonist@gmail.com
IT COMES FROM EVERYWHERE. IT KNOWS ALL.
ACCORDING TO THE BOOK OF WIKIPEDIA, ITS NAME IS "BIG DATA."
BIG DATA
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BIG DATA LIVES IN THE CLOUD. IT KNOWS WHAT WE DO.
IN THE PAST, OUR COMPANY DID MANY EVIL THINGS.
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IS IT TOO LATE TO SIDE WITH EVIL?
SHHHH! IT HEARS YOU.

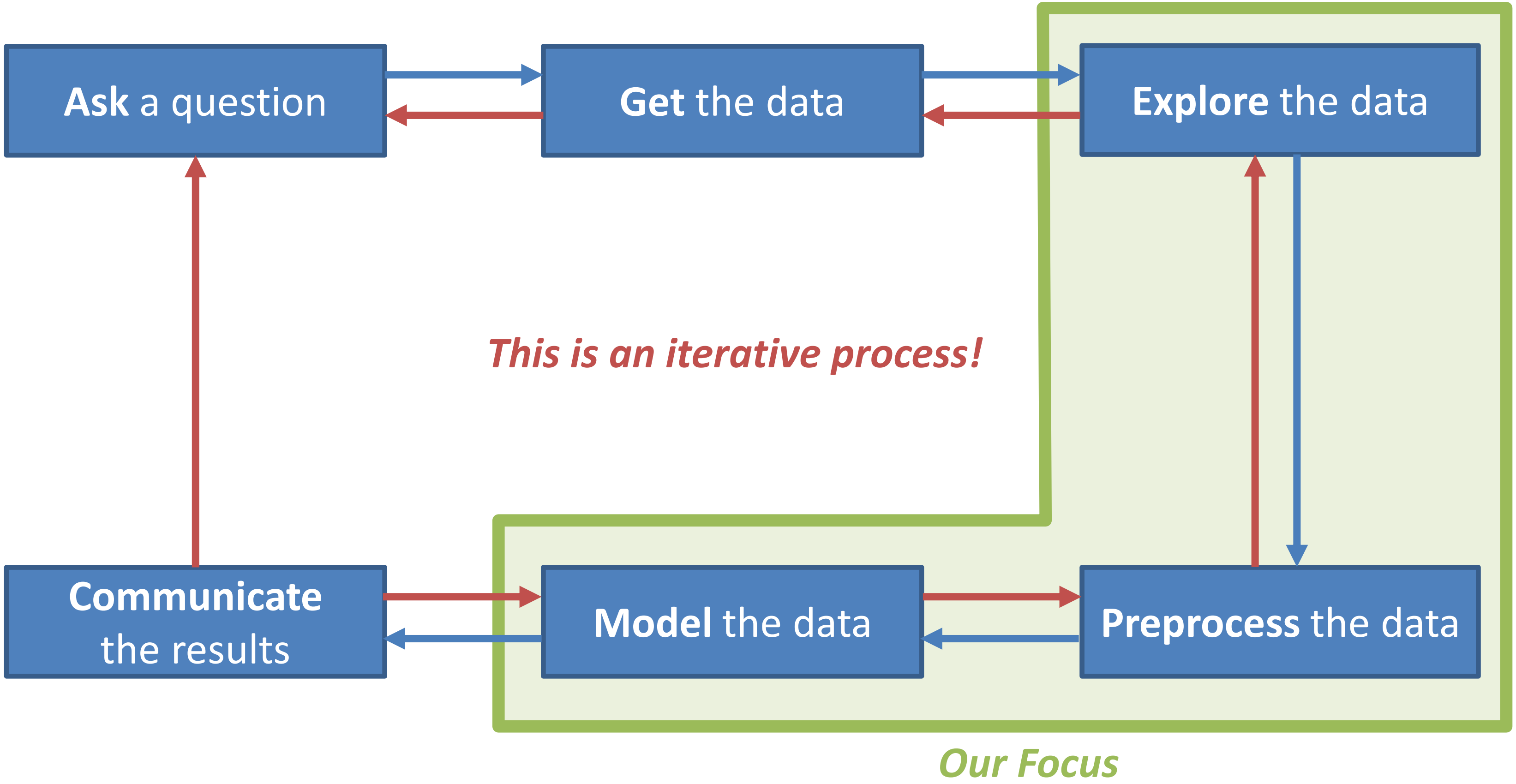
Avoiding Big Data Hubris

- At the moment, Data Science & Big Data are very hip topics.
  - □ Several big companies, research labs & government agencies are successfully applying it.
  - □ **However:** This success has also led to the topics becoming somewhat over-hyped.
  - □ ➔ People often put a lot of trust into results obtained from data analysis ("Big Data Hubris").

- However, always remember: **Above all, data analysis is a tool!**
  - □ It can help to prove assumptions, find new insights, understand problems.
  - □ But it cannot (and should not) replace experimentation, scientific modelling, applied domain knowledge, and (above all) human insight.

- Furthermore: Lying with data & misinterpreting results is incredibly easy!
  - □ Biased data sources, incorrect analysis methods, wrong model assumptions, implementation errors, misunderstood theory, deceiving representations, …
  - □ ➔ Always double-check results & insights coming from data analysis!
    - *"The only statistics you can trust are those you falsified yourself."*

The Data Analysis Process


Ask a question

Get the data

Explore the data

This is an iterative process!

Communicate the results

Model the data

Preprocess the data

Our Focus

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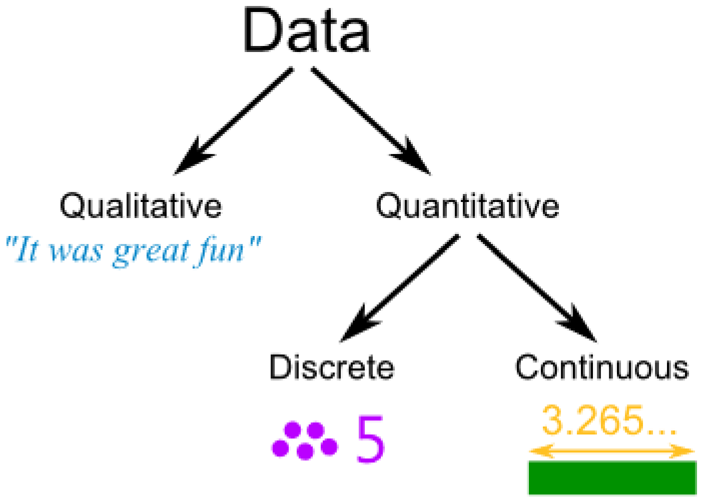
1. What is Data Science?
2. **Data: An Overview**
3. Exploratory Data Analysis

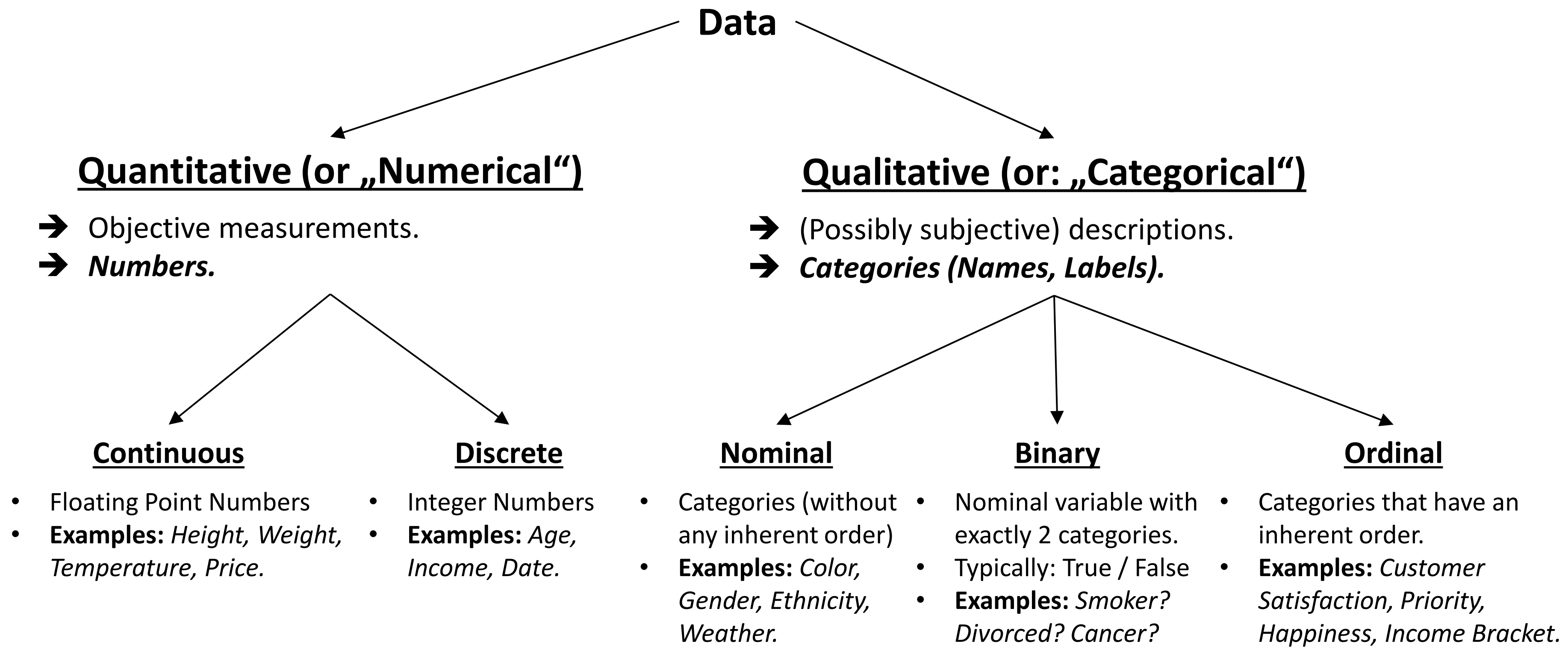
What is Data?

- Wikipedia: *„A set of values of qualitative or quantiative variables“.*



https://www.mathsisfun.com/data/images/data-types.gif

Classifying Variables



Data

Quantitative (or „Numerical“)

➔ Objective measurements.

➔ ***Numbers.***

Continuous

- Floating Point Numbers
- **Examples:** *Height, Weight, Temperature, Price.*

Discrete

- Integer Numbers
- **Examples:** *Age, Income, Date.*

Qualitative (or: „Categorical“)

➔ (Possibly subjective) descriptions.

➔ ***Categories (Names, Labels).***

Nominal

- Categories (without any inherent order)
- **Examples:** *Color, Gender, Ethnicity, Weather.*

Binary

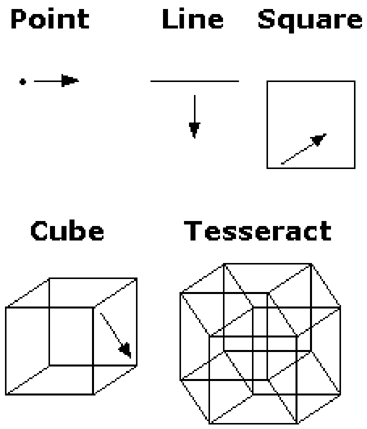
- Nominal variable with exactly 2 categories.
- Typically: True / False
- **Examples:** *Smoker? Divorced? Cancer?*

Ordinal

- Categories that have an inherent order.
- **Examples:** *Customer Satisfaction, Priority, Happiness, Income Bracket.*

Dimensionality

- The number of attributes (columns) in the dataset is called its **dimensionality**.
  - *Univariate data:* One dimension.
  - *Bivariate data:* Two dimensions.
  - *Multivariate data:* More than two dimensions.
    - ➔ This is the typical case!



- Data Analysis often gets very complicated for higher dimensions.
  - “Curse of Dimensionality”
  - Typical approaches: Visualize subspaces, Find structures (clustering), Project data into lower dimensional space (Dimensionality Reduction).

Structured, Unstructured, Semi-Structured

- We distinguish three primary data categories:

1. **Structured** data:
   - Follows a rigid pre-defined schema, consisting of multiple, well-defined variables.
   - **Examples:** *Relational databases (and everything that can be directly mapped to one).*

2. **Unstructured** data:
   - Does not follow any (apparent!) schema.
   - **Examples:** *Text, Images, Videos, Sound, CSV Files without metadata.*

3. **Semi-Structured** data:
   - Schema is encoded within the data (self-describing schema).
   - **Examples:** *JSON, XML.*

Metadata

- Metadata is „data about data“ (Wikipedia).
  - Essentially, all information that describe the dataset.

- Some examples:
  - Name & Data type of the columns.
  - Length of the Dataset (# Tuples, Bytecount, …).
  - Lineage information (Author, Data Sources, Experimental Configuration, …).
  - Purpose of the dataset.
  - Statistical information (e.g. Measurement error).
  - Date of Creation / Modification / Last Access.
  - Encoding (Video Codec, UTF-8, …).
  - Access restrictions.
  - …

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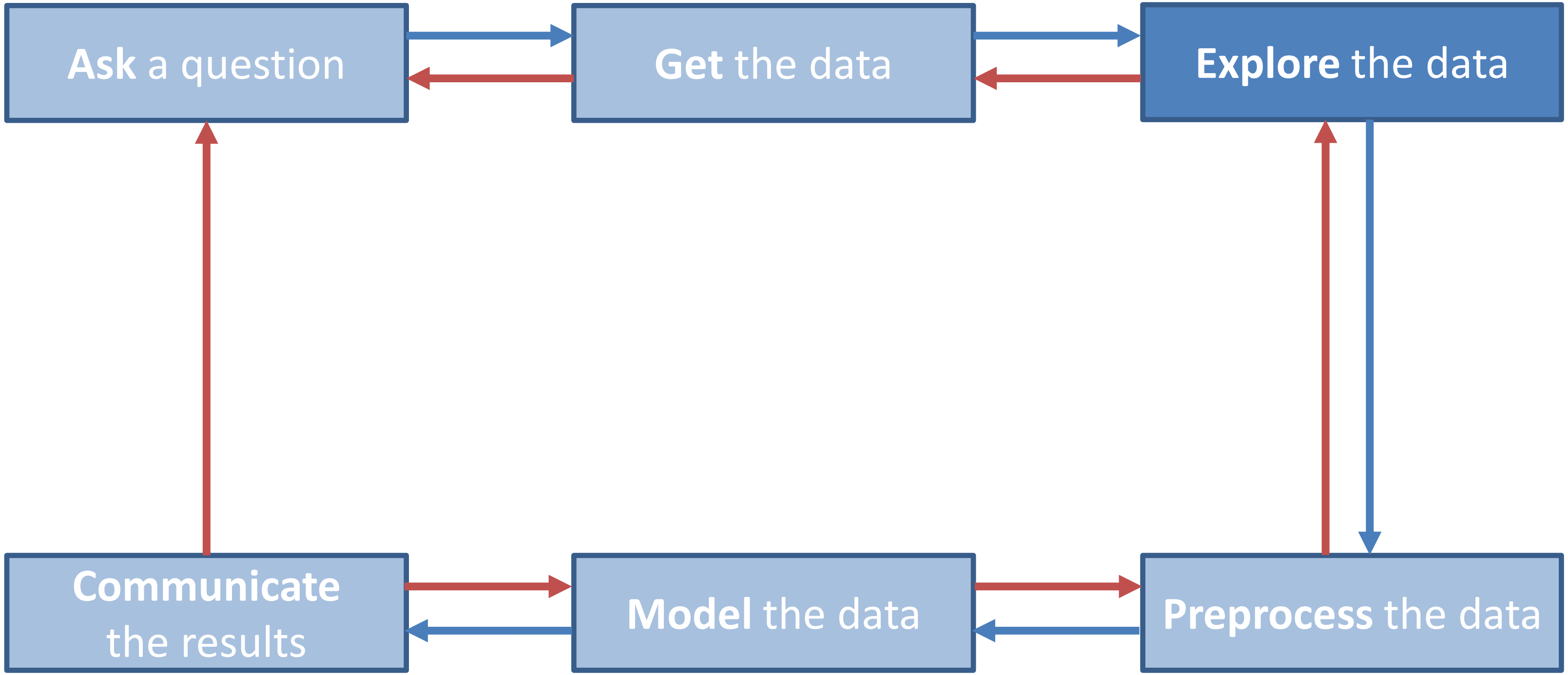
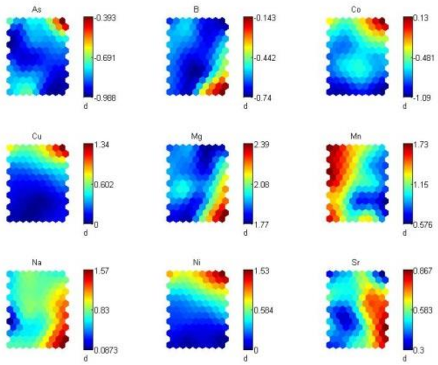
3. **Exploratory Data Analysis**

Reminder: The Data Analysis Process

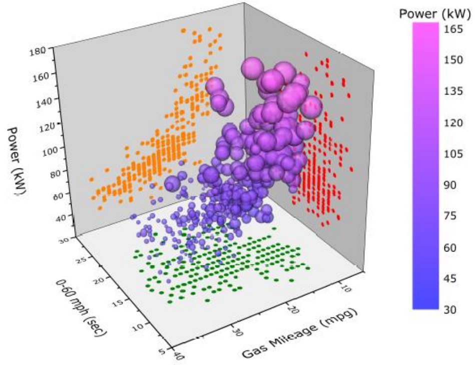


Exploratory Data Analysis

- Before we can perform any serious analysis tasks, we have to understand the data:
  - □ *“Listen”* to the data!
  - □ Investigate what is in the data / how it is structured / what are the interesting parts / are there anomalies / etc.
  - □ ➔ Helps to pick the right analysis methods & avoid costly mistakes.



- Exploratory Data Analysis (EDA):
  - □ „An approach of analyzing data to summarize their main characteristics without using a statistical model or having formulated a prior hypothesis.“
  - □ Done by inspecting & visualizing interesting data aspects.



The Exploratory Data Analysis Process

1. Look at the metadata!
   - □ Is the data structured or unstructured?
   - □ Which attributes are in the data? What are their datatypes?
     Are the attributes quantitative or qualitative?

2. Compute and inspect descriptive statistics for the attributes:
   - □ *Central tendency:* “What is a typical value for the attribute?”
   - □ *Variability measure:* “How are the values spread around the center?”
   - □ *Correlations:* “Do attributes influence each other?”

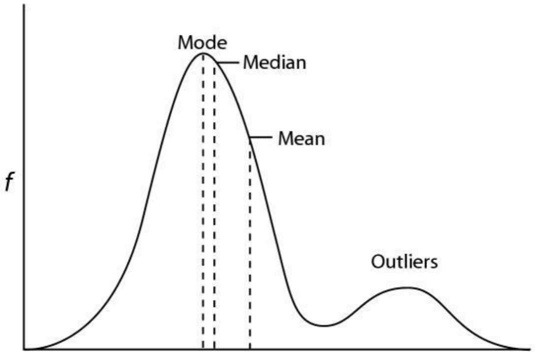
3. Plot data to visualize trends:
   - □ How is the data distributed? Can we see any relationships between attributes?
     Are there outliers or anomalies?

4. Rinse and Repeat:
   - □ While exploring the data, you will gain new insight that can
     be used to refine the process.

Central Tendencies

- Central Tendencies are descriptive statistics to describe the *typical values* of an attribute.

- The three most important tendencies are:
  - □ *Mean:* The *average value* in the attribute.
    - – Typically: Arithmetic Mean.
      - » $\mu_{ari} = \frac{1}{n} \sum_{i=1}^{n} x_i$
    - – Other means are: Weighted, Geometric, Harmonic.

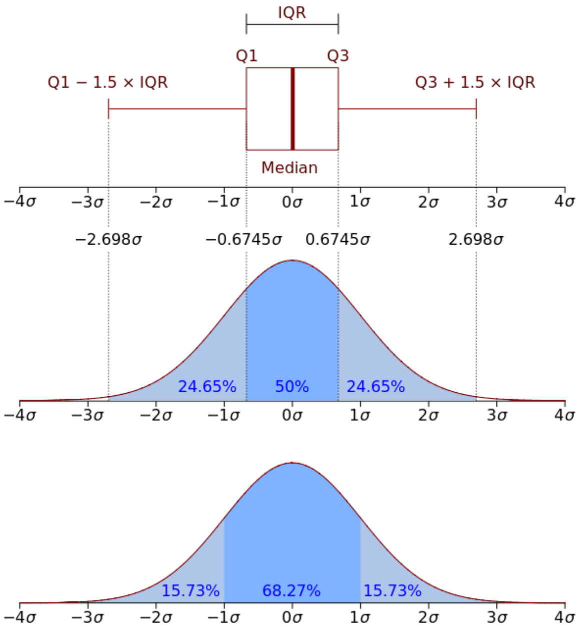


  - □ *Median:* The *middle value* in the attribute (half of all values are larger / smaller).
  - □ *Mode:* The *most common value* in the attribute.
    - – The mode is the only central tendency that is well-defined for qualitative variables.

Variability Measures

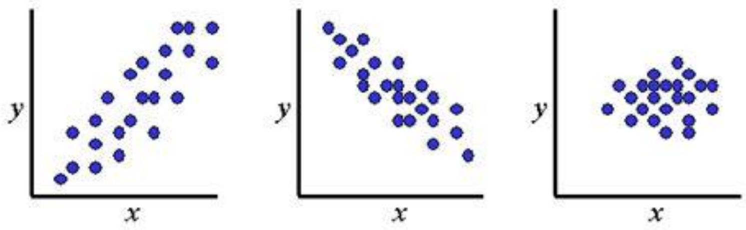
- Variability Measures are descriptive statistics to describe how the data is distributed around the central value.

- The most important variability measures are:
  - □ Range:
    - Difference between largest and smallest values.
  - □ Interquartile Range:
    - Difference between third and first quartile.
    - The three quartiles (Q1, median, Q3) divide the data set into four sets of equal magnitude.
  - □ Standard Deviation :
    - Average distance from the mean.
    - $\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\mu - x_i)^2}$



Correlation

- Correlation is the (statistical) dependence between two attributes.
  - □ Roughly: Changes in attribute A also appear in attribute B.

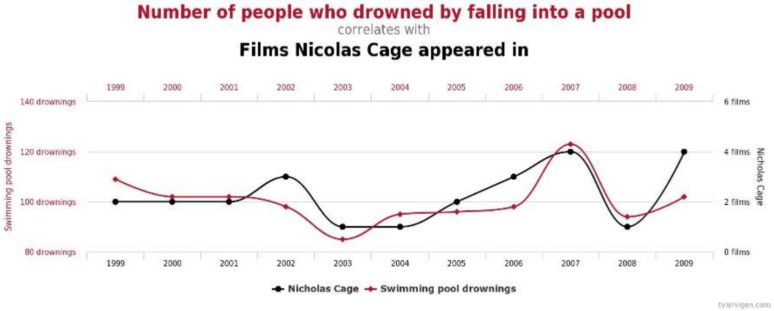


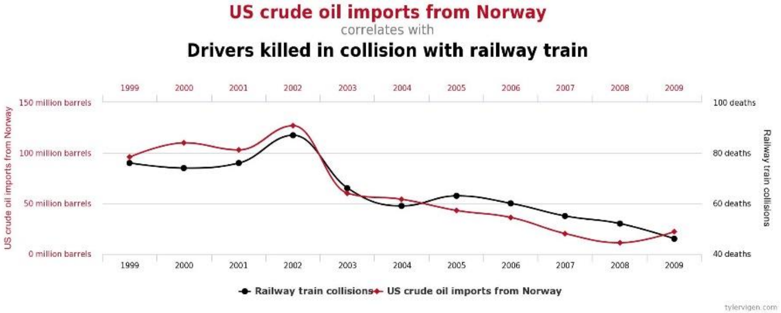
Positive correlation Negative correlation No correlation

- Correlation is typically measured via the Pearson coefficient:
  - □ $Cor(x,y) = \frac{\sum_{i=1}^{n}(x_i-\mu_x)\cdot(y_i-\mu_y)}{\sqrt{\sum_{n}^{i=1}(x_i-\mu_x)^2\cdot(y_i-\mu_y)^2}}$
  - □ Captures linear dependence between the two attributes x and y.

Correlation vs. Causation

- Always remember: **Correlation does not imply causation!**
  - □ Correlation may hint at causation, but you should always verify this externally.
  - □ There are several potential reasons why two variables A and B are correlated:
    - A causes B; B causes A; A causes B and B causes A.
    - A and B are both caused by a different variable C.
    - A causes C, which causes B.
    - Pure coincidence.



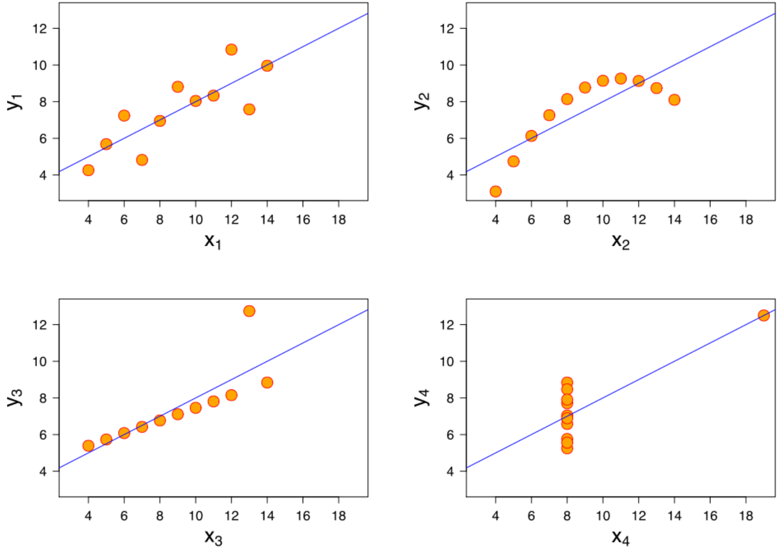


Source: http://www.tylervigen.com/spurious-correlations

Visualization is key!

- Descriptive statistics can give an important first look at the data.
  - □ However, they can be deceiving (and don’t tell the whole picture).

- Example: Anscombe’s quartet.
  - □ Four different, bivariate datasets that have the same:
    - – Average value.
    - – Standard deviation.
    - – Correlation coefficient.
  - □ ➔ We can see the differences only by visualizing the datasets!



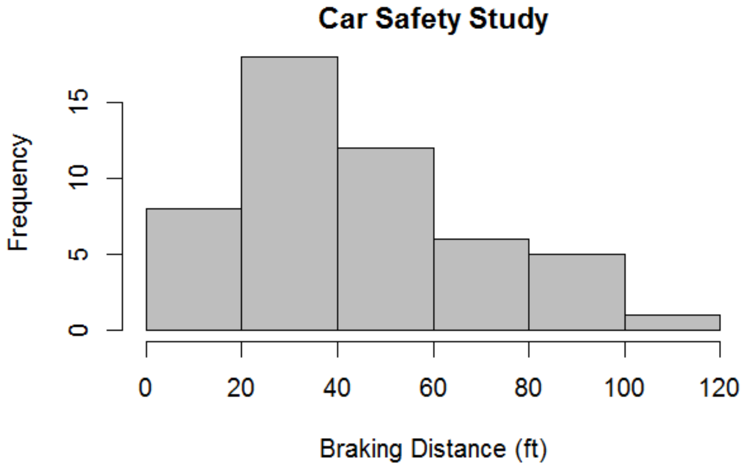
- “A picture is worth a 1000 words!”

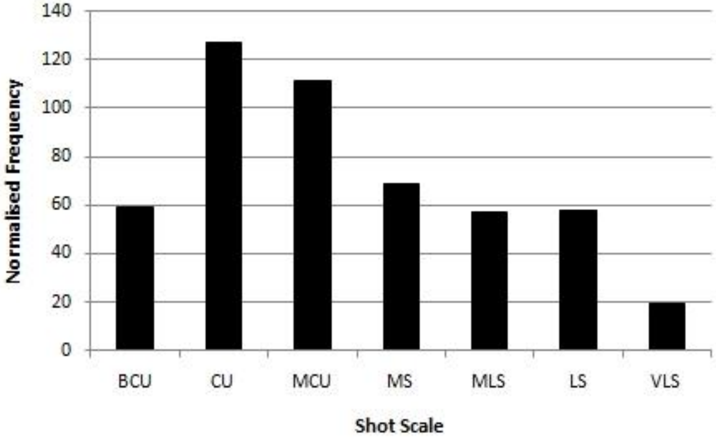
Visualization methods

- The choice of visualization method depends on the dimensionality.
- Univariate (Single Attributes):
  - Histograms.
  - Boxplots.
- Bivariate (Two Attributes):
  - Scatterplots.
- Multivariate (Multiple Attributes):
  - Scatterplots for 3D-data.
  - Scattermatrix.
  - Parallel Coordinate Plots.

Histograms

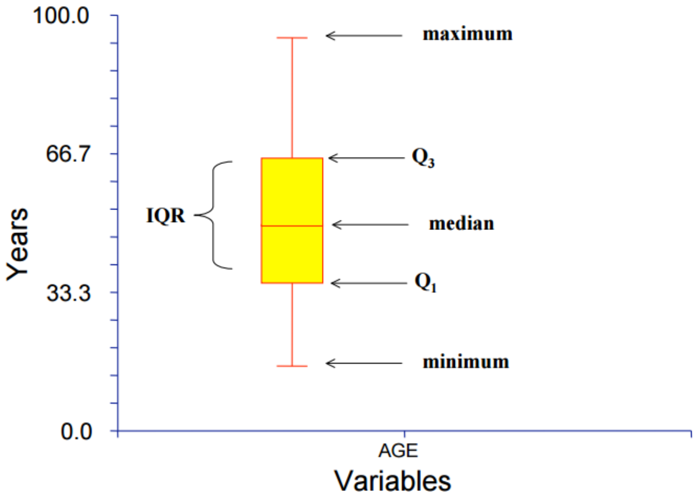
- Histograms are a quick way to visualize the data distribution of univariate qualitative and quantitative attributes:
  - □ *Qualitative attributes:* Count (or frequency) per distinct value.
  - □ *Quantitative attributes:* Discretization (binning) of neighboring values, then count the frequency count per bin.

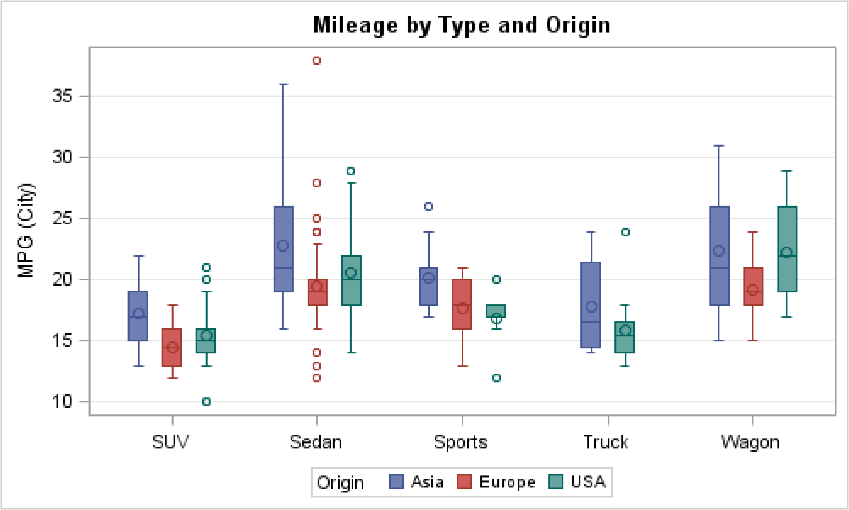




Boxplots

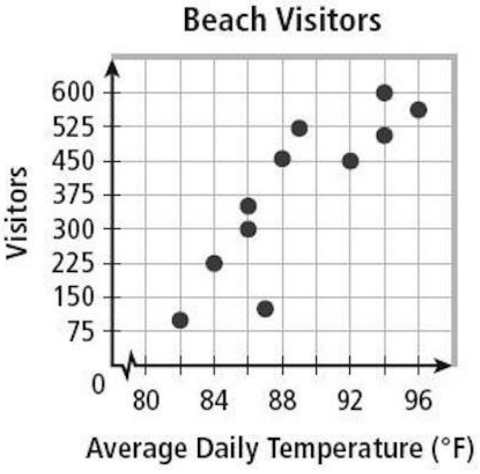
- Boxplots are a compact representation of important descriptive statistics for univariate quantitative attributes.
  - Typically: Median, first & third quartile, minimum & maximum, (outliers).
  - Boxplots can also visualize dependencies between a quantitative variable and one or two qualitative ones by grouping the data according to their labels.

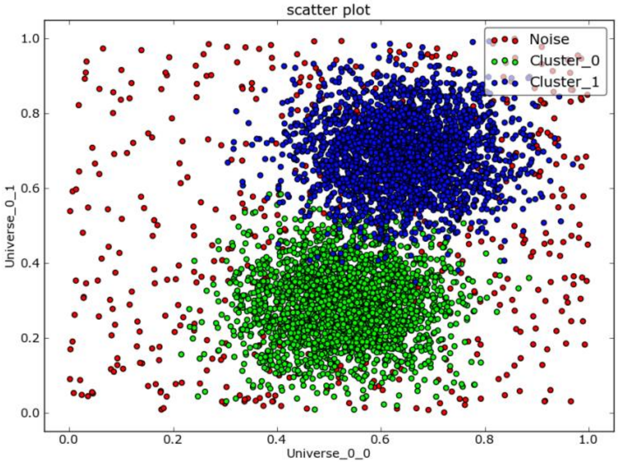


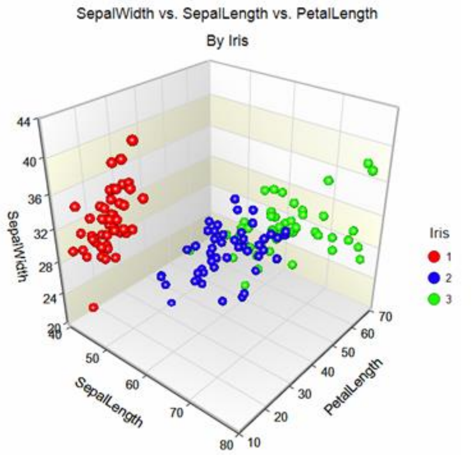


Scatterplots

- Scatterplots can be used to visualize the correlation & relationship between two (or three) quantitative attributes:
  - □ The attribute values are interpreted as (x,y)-coordinates and then drawn as points in a Cartesian coordinate system.
  - □ Additional coloring based on the label can be used to visualize dependencies on a qualitative attribute.

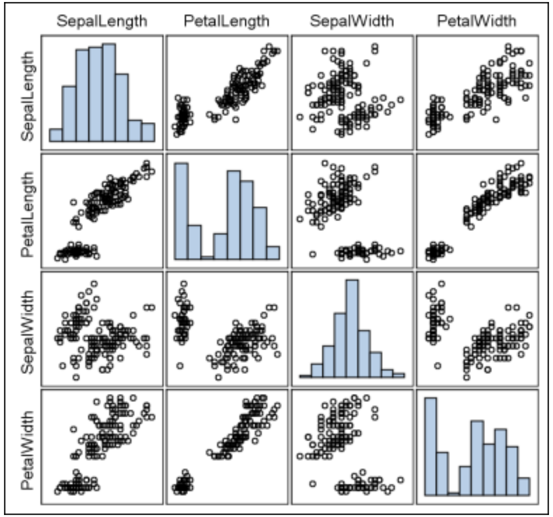


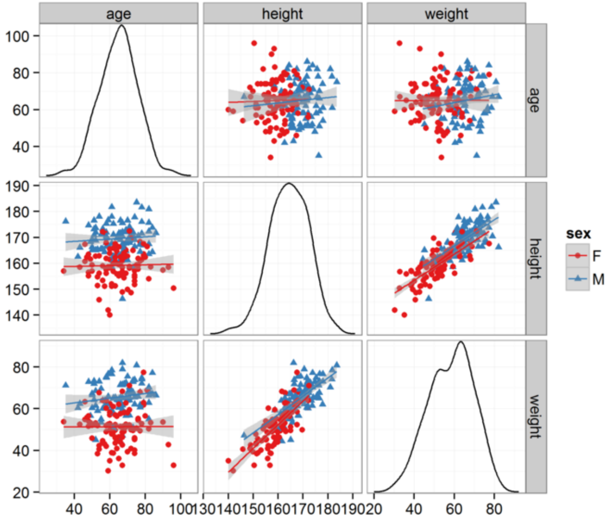




Scattermatrix

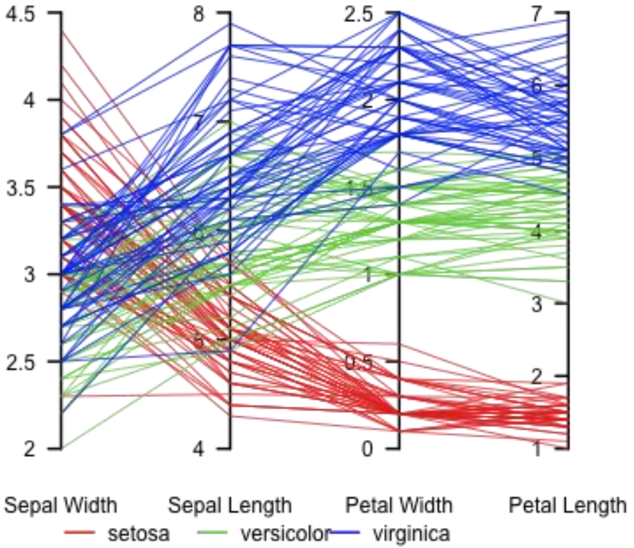
- For multivariate data (> three dimensions) a Scattermatrix can be used to visualize all pairwise correlations (relationships):
  - □ Draw all pairwise Scatterplots, align them in a grid according to the attributes.
  - □ Diagonal typically features Histograms or Density Plots for the single attributes.
  - □ Coloring based on label visualize dependence on qualitative attribute.

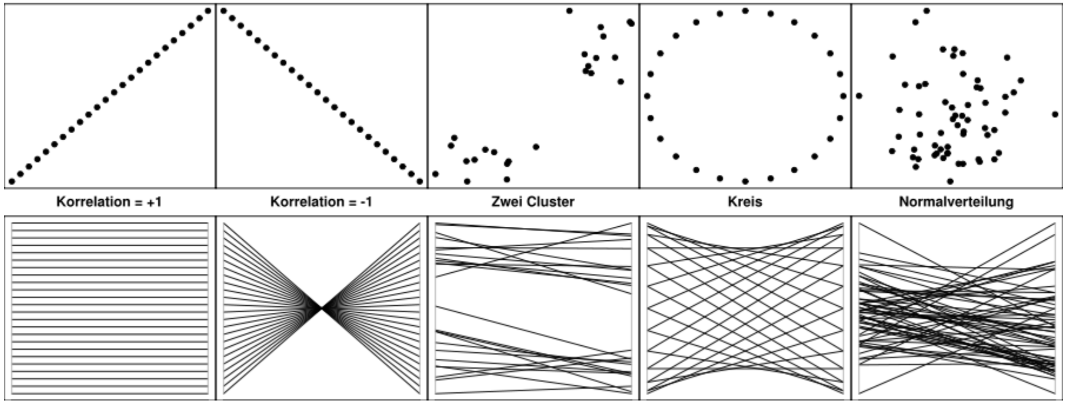




Parallel Coordinate Plots

- Visualizes multivariate data (both continuous and discrete) by aligning the attribute axes in parallel (rather than perpendicular in the scatter plot).
  - □ Points are interpreted as coordinates and illustrated as lines between the axes.
  - □ Can visualize very high-dimensional data. However: Ordering of the axes is important!





Outlook & Overview

- Today we discussed:
  - □ What is Data Science?
  - □ What is the Data Analysis Process?
  - □ How can we classify Data?
  - □ What is Exploratory Data Analysis?
  - □ What are the important statistical measures?
  - □ How can we visualize interesting data aspects?

- Next week:
  - □ Introduction to Machine Learning.
  - □ Machine Learning Methods for Data Analysis.