

# Statistical Inference for Data Science

Dr. Anja Mühlemann

27. August 2025





# Questions from Day 1

# Parameter Estimation

## Day 2

### Today's Topics

- Point Estimates
- Least squares / Maximum likelihood
- Confidence intervals
- Regression
- p-values

# So far ...

- Descriptive Statistics gives insight on a sample
- However, often we are **not only** interested in the sample itself
- We would like to draw conclusions about the **entire population** from which the sample was drawn

## Example:

n volunteers received a vaccine. Now Novartis would like to predict the efficacy of the vaccine. More precisely, Novartis would like to predict the efficacy for the entire population and not only for the volunteers.

# Inferential Statistics

## Inferential Statistics

With a certain degree of certainty, one would like to draw conclusions from empirical data, even if the data are subject to error or incomplete.

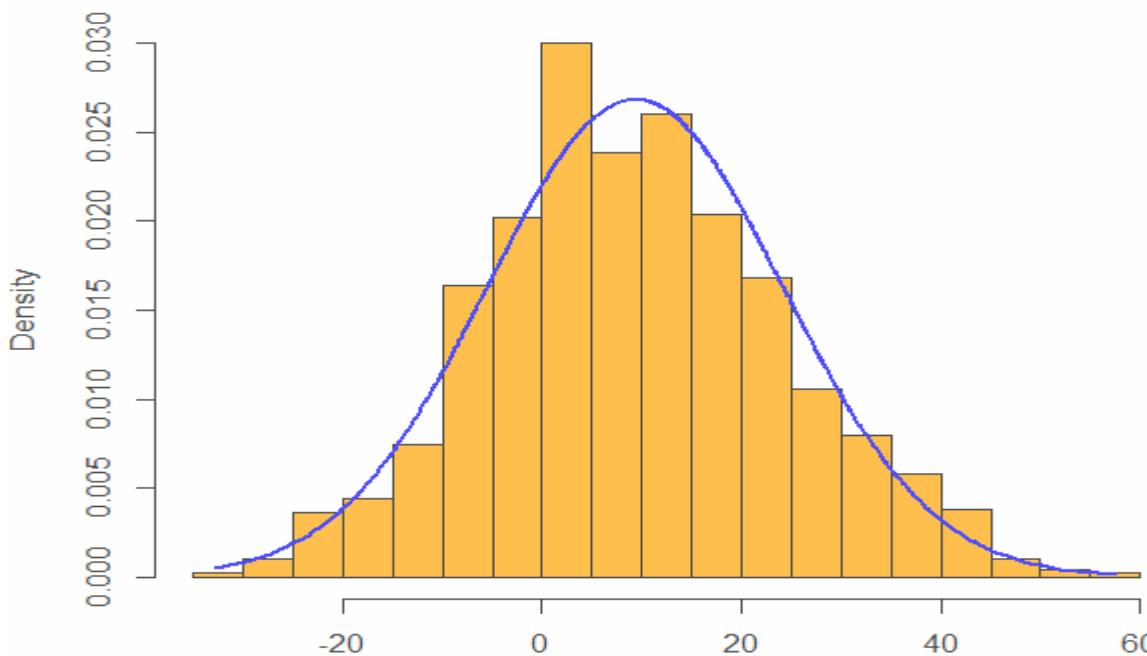
### 3 main techniques

- **Parameter estimates:** Calculation estimate for unknown parameter of underlying probability distribution
- **Confidence intervals:** Calculation of a region within which unknown parameter should lie with certain degree of certainty
- **Tests:** Tests are intended to prove that a certain effect, e.g. the effect of a vaccine, is indeed present.

# Parameter Estimation

## Situation

- We have data
- We have (chosen) a model describing the data
- The model has parameters
- We want to estimate the parameters from the data



# Normal distribution

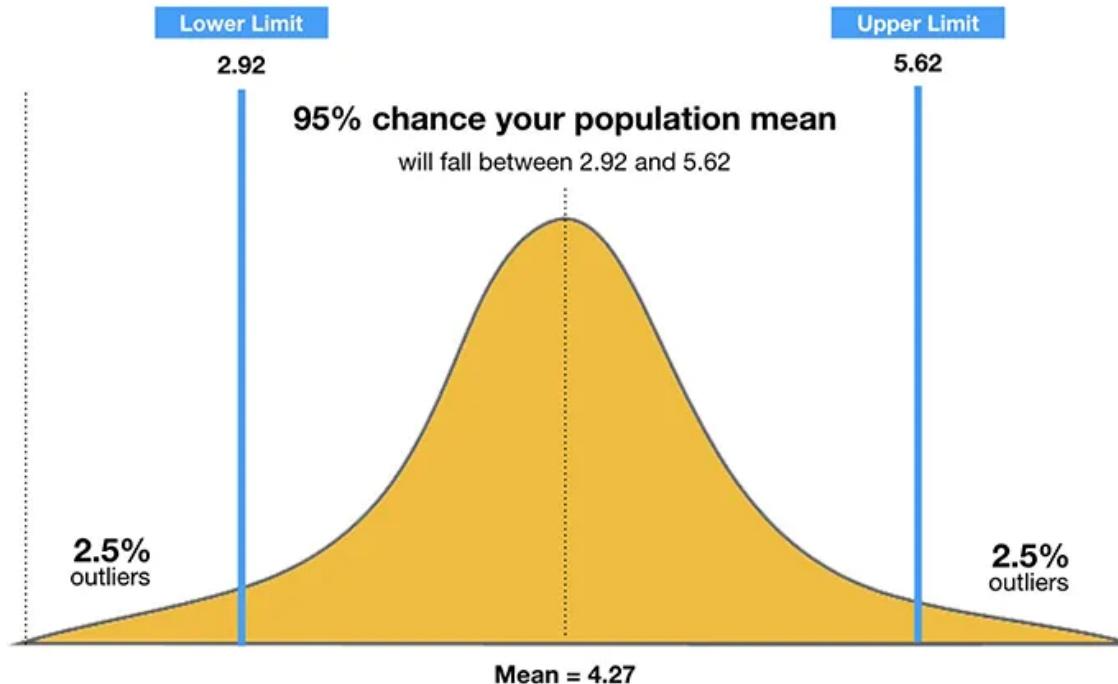
- The normal distribution is uniquely characterized by its mean  $\mu$  and variance  $\sigma^2$  (standard deviation $^2$ )
- We can estimate those parameters by the sample mean and the sample variance

$$\hat{\mu} = \frac{1}{n} \sum_{i=1}^n x_i, \quad \hat{\sigma}^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

- Estimators often denoted with ‘hat’ e.g.  $\hat{\theta}$  is an estimate for  $\theta$ .
- During this CAS you will fit many other model parameters from data.

# Confidence Intervals

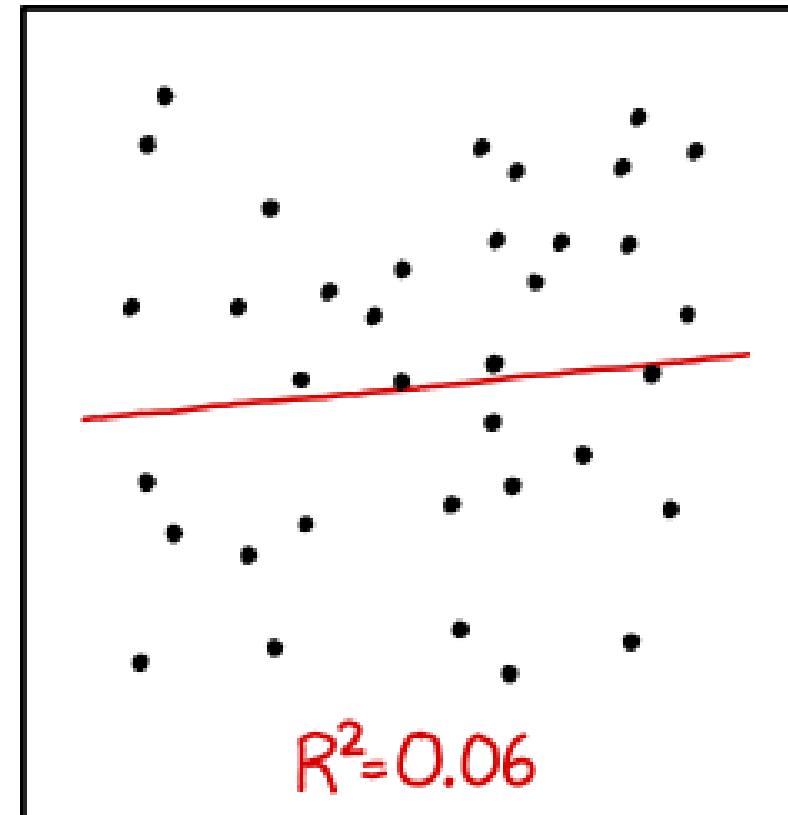
- is an interval that contains a certain parameter with a predetermined certainty (usually 95%)
- In contrast to point estimators, confidence intervals also reveal the uncertainty that arises due to the sample itself and the sample size.



$$\bar{x} \pm t \cdot \frac{s}{\sqrt{n}}$$

# Regression

- Estimate the relationship between variables



I DON'T TRUST LINEAR REGRESSIONS WHEN IT'S HARDER  
TO GUESS THE DIRECTION OF THE CORRELATION FROM THE  
SCATTER PLOT THAN TO FIND NEW CONSTELLATIONS ON IT.

# Different types

## Linear

- Linear refers to the relationships between the  $x_i$  and  $y$

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n$$

- e.g. straight line  $y = \beta_0 + \beta_1 x_1$
- Inter- and extrapolation allows prediction

## Non-linear

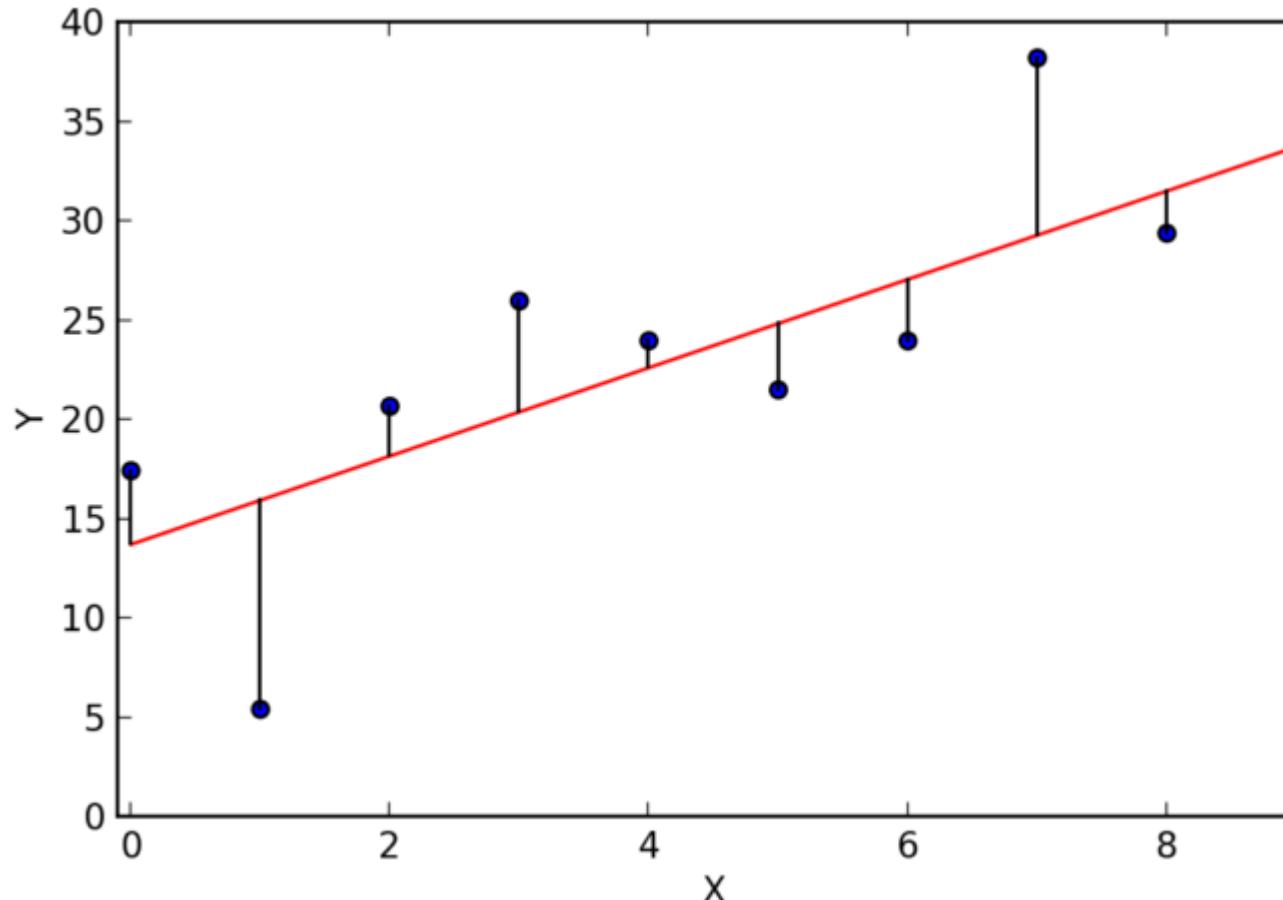
- When dependent variable ( $y$ ) not linear in the parameters

## Non-parametric

- Parametric models have parametric form
- If we have no clue about the exact relationship, we may use non-parametric estimation (e.g. isotone regression) 
- These normally need more data, because also the model structure must be somehow estimated

# Least Squares

- Minimize distance between data points and the regression line
- Under certain conditions same as Maximum Likelihood Estimator



# Maximum Likelihood

- Estimate parameters of probability distribution, so that under the assumed statistical model the observed data is most probable.
- Family of parametric models (pdf)  
 $\{f(x; \theta) : \theta \in \Theta\}$
- Find  $\theta \in \Theta$  that maximizes the Likelihood function

$$L(x; \theta) = \prod_{i=1}^n f(x_i; \theta)$$

- For computational reasons, mostly the log-likelihood

$$\log(L(x; \theta)) = \sum_{i=1}^n \log(f(x_i; \theta))$$

# Typical ML- Methods

- **Linear regression** (with logistic regression for classification)
- Decision trees (and random forest)
- Principal Component Analysis (dimension reduction)
- Nearest neighbor methods (k-means)
- **Neural Networks**
- In this CAS you will practice linear regression and neural networks (Module 3)

# Typical ML- Methods

- Most methods typically use either Least Squares or Maximum Likelihood to fit the optimal parameters.
- When the model is fitted, it can be used for hypothesis testing or classification.
- The simplest model is fitting a straight line to some data points. This model has 2 parameters.
- According to some sources, it is true that GPT-4 has 1.7 trillion parameters

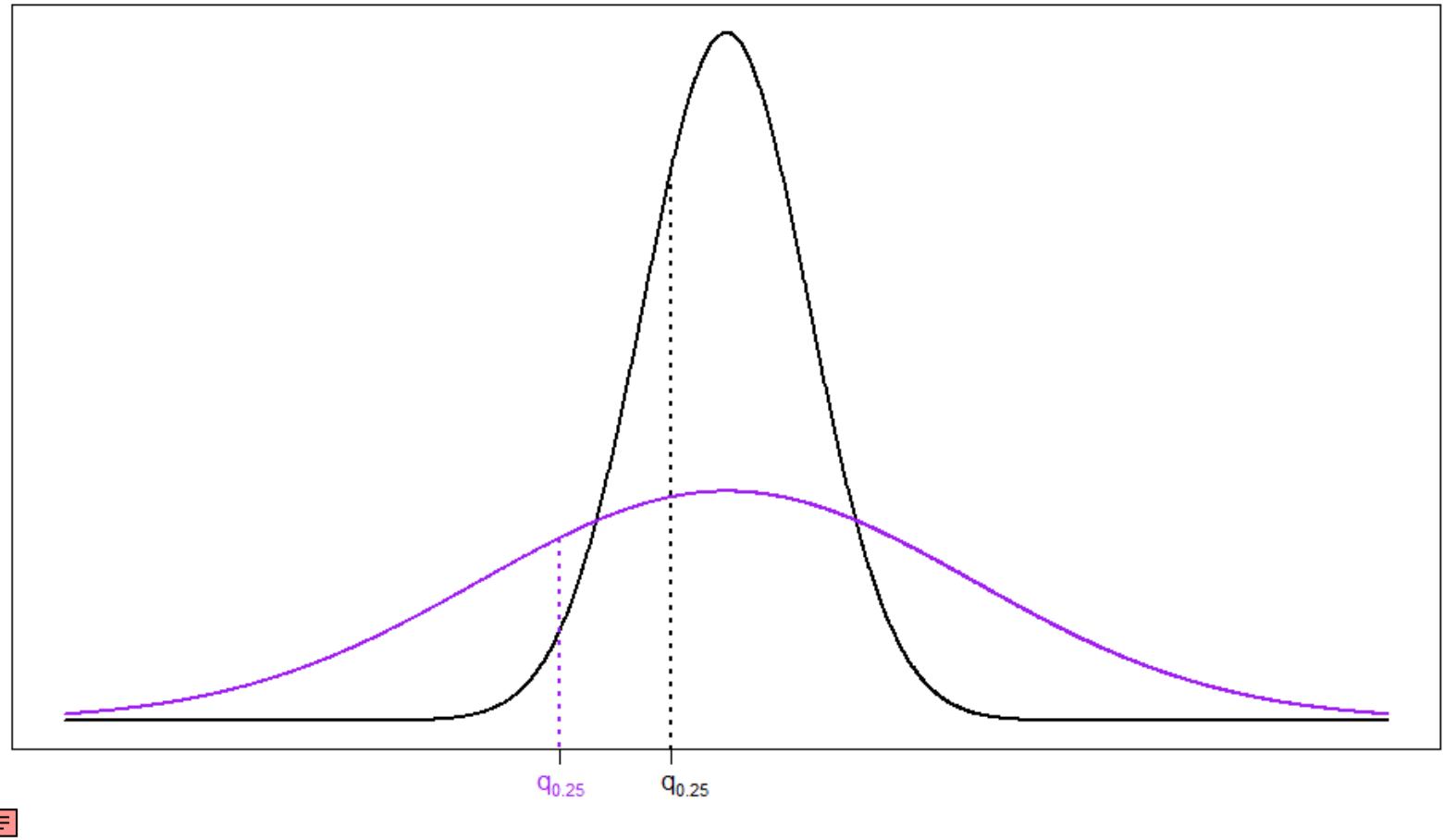


# Linear Regression

- (Least Squares) Linear regression is very widely used but we should not neglect the assumptions on which it relies
  - Normality
  - Linearity
  - Homoscedasticity (errors have equal variances)

*In the notebook there are plots to help you decide on all three assumptions*

# Normality assumption (Q-Q-Plot)



# Normality assumption (Q-Q-Plot)

