# Week 8 - Introduction to Regression and Correlation Models

## Introduction:

Welcome to this seminar on linear regression in the context of mathematical modeling. Linear regression and Correlation are related statistical techniques used to model the relationship between one or more independent variables and a dependent variable.

In this seminar, we will explore the principles of linear regression, correlation, and confidence intervals. We will also look at its applications, and how it fits into mathematical modeling.

## Understanding Correlations

We may be interested in seeing if there is a linear relationship between 2 (scale) variables.

We can plot the values on a scatter diagram and see how close the points are to a straight line

Consider the following plot, where each point is one data point. Each point represents the data for one person. The scatterplot displays two numerical variables, x (independent or predictor) and y (dependent)

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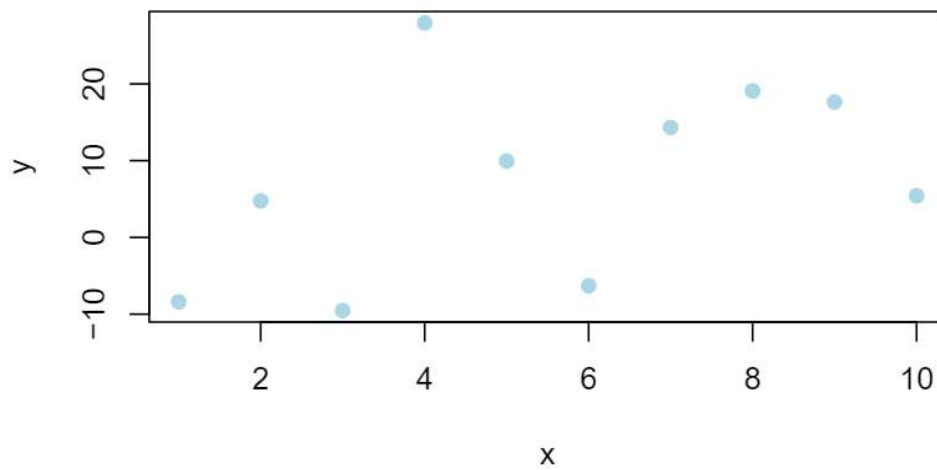
The relationship between the two variables is not exact – there is an unpredictable or random element: every person is different.

We can model the underlying relationship by a straight line of best fit (or trendline) We can measure how close those points are to that line (below, the trendline is in red)
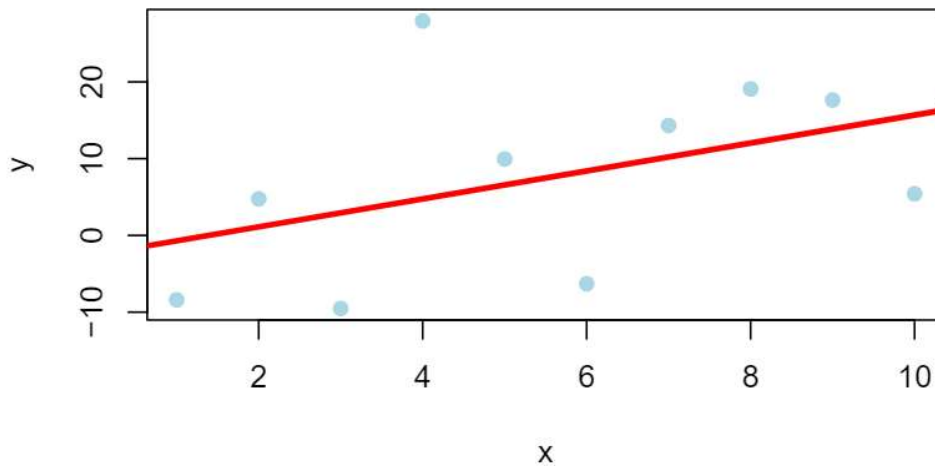
## Pearsons Product Moment Correlation, r

The correlation coefficient, r, measures how close the points are to the line ie. the strength of the linear relationship.

$$r = \frac{S_{xy}}{\sqrt{S_{xx}S_{yy}}}$$

where:

$$S_{xy} = \sum(x - \bar{x})(y - \bar{y}) = \sum xy - \frac{\sum x \sum y}{n})$$

$$s_{xx} = \sum(x - \bar{x})^2 = \sum x^2 - \frac{(\sum x)^2}{n}$$

$$s_{yy} = \sum(y - \bar{y})^2 = \sum y^2 - \frac{(\sum y)^2}{n}$$

- Its value is between -1 and 1 - A value close to 1 or -1 represents a strong linear relationship. -A positive value suggests a positive relationship ie. as one variable increases the other increases - A negative value suggests a negative relationship ie. as one variable increases the other decreases - A value close to 0 means a very weak or no linear relationship.

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(Note that even if there is no linear relationship, there still may be a relationship which is non-linear)

## Plots with strong positive, strong negative, no correlation, perfect negative correlation

Consider the following example. The number of vehicles, millions, and the number of accidents, thousands, in 15 different countries were:

| Country | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vehicles (x) millions | 8.6 | 13.4 | 12.8 | 9.3 | 1.3 | 9.4 | 13.1 | 4.9 | 13.5 | 9.6 | 7.5 | 9.8 | 23.3 | 21 | 19.4 |
| Accidents (y) thousands | 33 | 51 | 30 | 48 | 12 | 23 | 46 | 18 | 36 | 50 | 34 | 35 | 95 | 99 | 69 |

Calculate the product moment correlation coefficient for the number of vehicle and the number of accidents.

We will need the following

$$\sum x = 176.9 \quad \sum y = 679$$
$$\sum x^2 = 2576.47 \quad \sum y^2 = 39771$$
$$\sum xy = 9915.3$$

$$S_{xy} = \sum xy - \frac{\sum x \sum y}{n} = 9915.3 - \frac{176.9 * 679}{15} = 1907.62...$$

$$s_{xx} = \sum x^2 - \frac{(\sum x)^2}{n} = 257.47 - \frac{(176.9)^2}{15} = 490.22...$$

$$s_{yy} = \sum y^2 - \frac{(\sum y)^2}{n} = 39771 - \frac{(679)^2}{15} = 9034.93...$$

$$r = \frac{S_{xy}}{\sqrt{S_{xx}S_{yy}}} = \frac{1907.62...}{\sqrt{490.22... * 9034.93...}} = 0.906 (3.d.p)$$

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This suggests a very strong positive linear relationship between the number of vehicles and the number of accidents.

Consider the following example. The head circumference in cm (x) and gestation period (y) in weeks for new born babies at a certain clinic over a period of time is as follows.

| Baby | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Head circumference (x) | 31.1 | 33.3 | 30.0 | 31.5 | 35.0 | 30.2 |
| Gestation period (y) | 36 | 37 | 38 | 38 | 40 | 40 |

Find the correlation between head circumference and gestation period.

We will need the following

$$\sum x = 191.1 \sum y = 229$$
$$\sum x^2 = 6105.39 \sum y^2 = 8753$$
$$\sum xy = 7296.7$$

$$S_{xy} = \sum xy - \frac{\sum x \sum y}{n} = 7296.7 - \frac{191.1 * 229}{6} = 3.05$$

$$s_{xx} = \sum x^2 - \frac{(\sum x)^2}{n} = 6105.39 - \frac{(191.1)^2}{6} = 18.855$$

$$s_{yy} = \sum y^2 - \frac{(\sum y)^2}{n} = 8753 - \frac{(229)^2}{6} = 12.833$$

$$r = \frac{S_{xy}}{\sqrt{S_{xx}S_{yy}}} = \frac{3.05}{\sqrt{18.855 * 12.833}} = 0.196$$

This is a low correlation which suggests very little evidence of a linear relationship between head circumference and gestation period

## Some problems

A very strong correlation does not necessarily mean that a change in x causes a change in y

A very weak correlation does not necessarily mean that x and y are unrelated. The relationship could be non-linear.

High correlations can arise purely by chance, particularly if the sample size is small. The correlation may not be significantly different from zero.

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## Understanding Linear Regression:

Linear regression aims to establish a linear relationship between independent variables (predictors) and a dependent variable (response). It assumes that this relationship can be expressed as a linear equation: $Y = \ + \ X + \ X + ... + \ X + $ , where: Y is the dependent variable. $X$ , $X$ , ..., $X$ are the independent variables. $, , , ...,$ are the coefficients. represents the error term, accounting for unexplained variability.

## Simple Linear Regression:

In simple linear regression, there is only one independent variable (X) and one dependent variable (Y). The relationship is expressed as $y = a + bx$. The goal is to find the best-fitting line that minimizes the sum of squared errors (residuals) between the predicted and actual values of Y.

a is the intercept of the line.
b is the slope of the line.

In order to calculate a and b, you need the following

$$a = \bar{y} - b\bar{x}$$

and

$$b = \frac{S_{xy}}{S_{xx}}$$

Wait, we've seen the terms $ S\_{xy}$ and $S_{xx}$ before when working out correlation!

Example: The results from an experiment in which different masses were placed on a spring and the resulting length of the spring measured, are shown below

| Mass, x (kg) | 20 | 40 | 60 | 80 | 100 |
|---|---|---|---|---|---|
| Length, y (cm) | 48 | 55.1 | 56.3 | 61.2 | 68 |

We will need the following

$$\sum x = 300, \sum y = 288.6$$
$$\sum x^2 = 22000$$
$$\bar{x} = 60, \bar{y} = 57.72$$

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$$\sum xy = 18238$$

$$S_{xy} = \sum xy - \frac{\sum x \sum y}{n} = 18238 - \frac{300 * 288.6}{5} = 922$$

$$s_{xx} = \sum x^2 - \frac{(\sum x)^2}{n} = 22000 - \frac{(300)^2}{5} = 4000$$

$$b = \frac{S_{xy}}{S_{xx}} = \frac{922}{4000}$$

$$a = \bar{y} - b\bar{x} = 57.72 - 0.2305 * 60 = 43.89$$

$$y = 43.89 + 0.2305x$$

Predict and interpret:

  a. the value of y when the mass x $= 35$ kg
  b. the value of y when the mass x $= 120$ kg

a)

$$y = 43.89 + 0.2305 * 35 = 52.0cm$$

If the mass is 35 kg, then the length of the spring will be 52 cm on average

b)

$$y = 43.89 + 0.2305 * 120 = 71.55cm$$

If the mass is 120 kg, then the length of the spring will be 71.6 cm on average

In terms of predicting new values for the above example. The range of observed values of x was from 20 to 100. If we predict the value of Y for 20   100, this is called INTERPOLATION If the prediction is made outside this range, this is called EXTRAPOLATION

Extrapolation is generally unreliable since we have no way of knowing whether model assumptions remain valid outside the range of our observations

Hence the earlier prediction 'If the mass is 120 kg, then the length of the spring will be 71.6 cm on average' should be treated with caution

## Applications of Linear Regression:

  - Linear regression is widely used in various fields, including:
  - Economics: Modeling economic factors and predicting outcomes.
  - Finance: Predicting stock prices and risk assessment.
  - Medicine: Predicting patient outcomes based on medical variables.
  - Engineering: Predicting performance and optimizing processes.
  - Social Sciences: Analyzing social and behavioral data.

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## Model Evaluation:

Evaluating a linear regression model is essential to assess its quality and predictive power. Common evaluation metrics include:

- R-squared ($R^2$): Measures the proportion of variance explained by the model.
- Mean Squared Error (MSE) and Root Mean Squared Error (RMSE): Measure the average squared error of predictions.
- Residual plots: Visualize the distribution of residuals to check for patterns or anomalies.

## Conclusion

Linear regression is a powerful mathematical modeling technique that models relationships between independent and dependent variables using linear equations. It is widely applicable in various fields for prediction, analysis, and decision-making. Understanding the assumptions and techniques of linear regression is crucial for effective modeling and interpretation.

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