Data Analysis and Visualization

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Lesson 1: Basics of Data Analysis

What is a Random Variable?

A random variable (r.v.) X is a function $X: \Omega \rightarrow R$ where Ω is the state space and R is the set of values that the variable can take called Range.

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Intuitively, a r.v. is equivalent to a column of your dataset after applying zero or more filters.

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A random variable can be of different types: numerical or categorical.

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What is a Random Variable?

Numerical:

- **Continuous**: Can take on any value within a range, including decimals and fractions. E.g., the height of students in a school (150.2 cm, 165.8 cm …).
- **Discrete**: Can take on specific, separate values and is countable. E.g., the number of cars passing a toll booth in a day (0, 1, 2, 3 …).
    - **Finite Set**: The number of siblings a person has (e.g., 0, 1, 2, 3... up to a reasonable maximum).
    - **Infinite Set**: The number of times you need to roll a dice until you get a six (potentially infinite but countable).

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What is a Random Variable?

Categorical: Variables that represent distinct groups or categories.

- **Nominal:** no inherit order. E.g., eye color of individuals (Blue, Brown, Green).
- **Ordinal**: Variables with a meaningful order or ranking. E.g., rating of a restaurant on a scale from 1 to 5 (Poor, Fair, Good, Very Good, Excellent).

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What is a Random Variable? function X: Ω → R

Age	Height	Degree's level
25	172	Master
26	167	Master
22	170	Bachelor
23	160	Bachelor

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What is a Random Variable? function X: Ω → R

Columns

(Random Variables)

Age	Height	Degree's level
25	172	Master
26	167	Master
22	170	Bachelor
23	160	Bachelor

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What is a Random Variable? function X: Ω → R

Rows

(Elements of Ω)

Age	Height	Degree's level
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Set of values of a r.v.

(Range R)

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Set of values of a r.v.

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What is wrong in this dataset?

Age	Height	Degree's level
150	172	Master
26	167	University
22	170	Bachelor
23		Bachelor

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What is wrong in this dataset?

Outlier

Age	Height	Degree's level
80	172	Master
26	167	University
22	170	Bachelor
23		Bachelor

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What is wrong in this dataset?

Age	Height	Degree's level
80	172	Master
26	167	University
22	170	Bachelor
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Outlier

Missing value

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What is wrong in this dataset?

Age	Height	Degree's level
80	172	Master
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23		Bachelor

Outlier

Wrong value

Missing value

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Outlier

An **outlier** is a data point that differs significantly from other observations in a dataset. It can be much higher or lower than the expected range of values, making it stand out.

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An **outlier** is a data point that differs significantly from other observations in a dataset. It can be much higher or lower than the expected range of values, making it stand out.

It’s important to identify them!

- They can **distort statistical analyses**, such as averages and regression results.
- They might indicate **errors** in data collection or entry.
- They can reveal **insights** about rare or unexpected phenomena.

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How to identify outliers?

1. **Visual Methods**: Scatterplots, boxplots, or histograms.
2. **Statistical Methods**:
    1. Z-scores (values more than 3 standard deviations away from the mean).
    2. Interquartile Range (IQR): Points outside $1.5 \times \text{IQR}$ beyond the first and third quartiles.
3. **Model-Based Approaches**: Identifying outliers based on residuals in regression or clustering methods.

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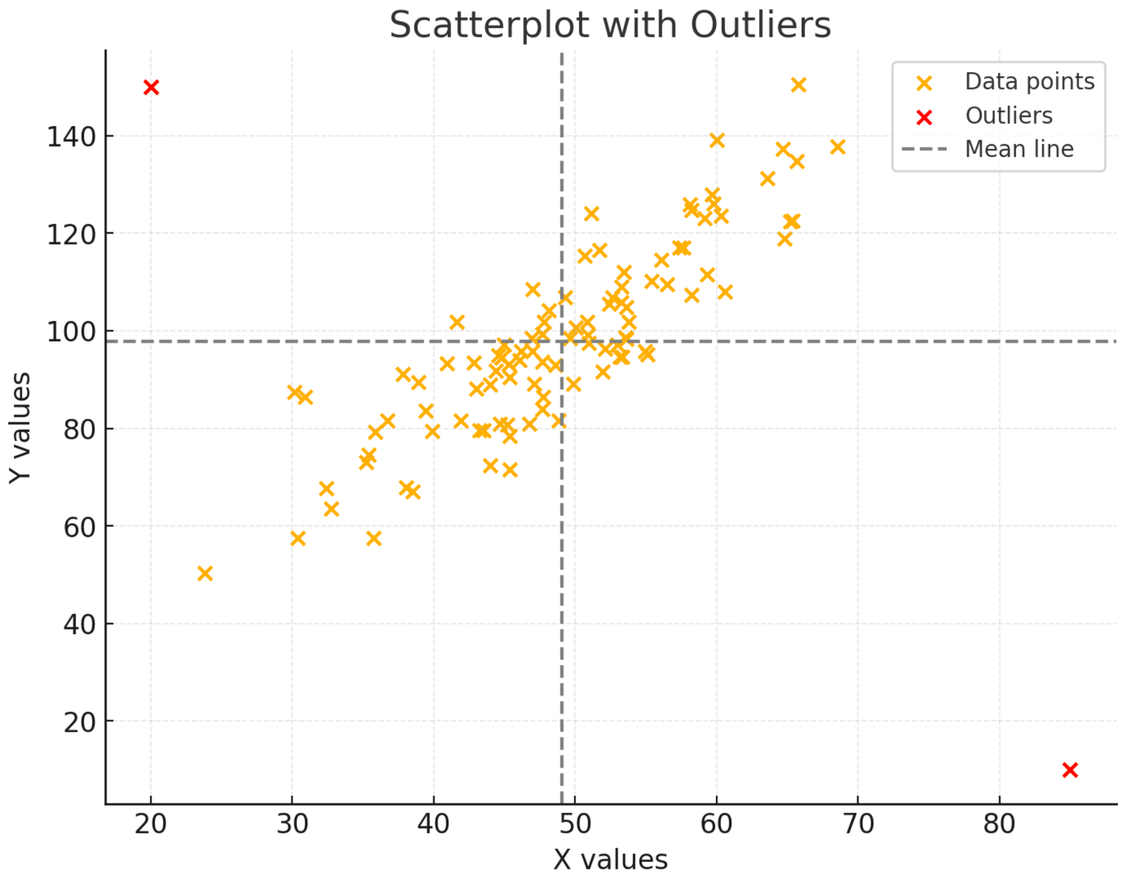
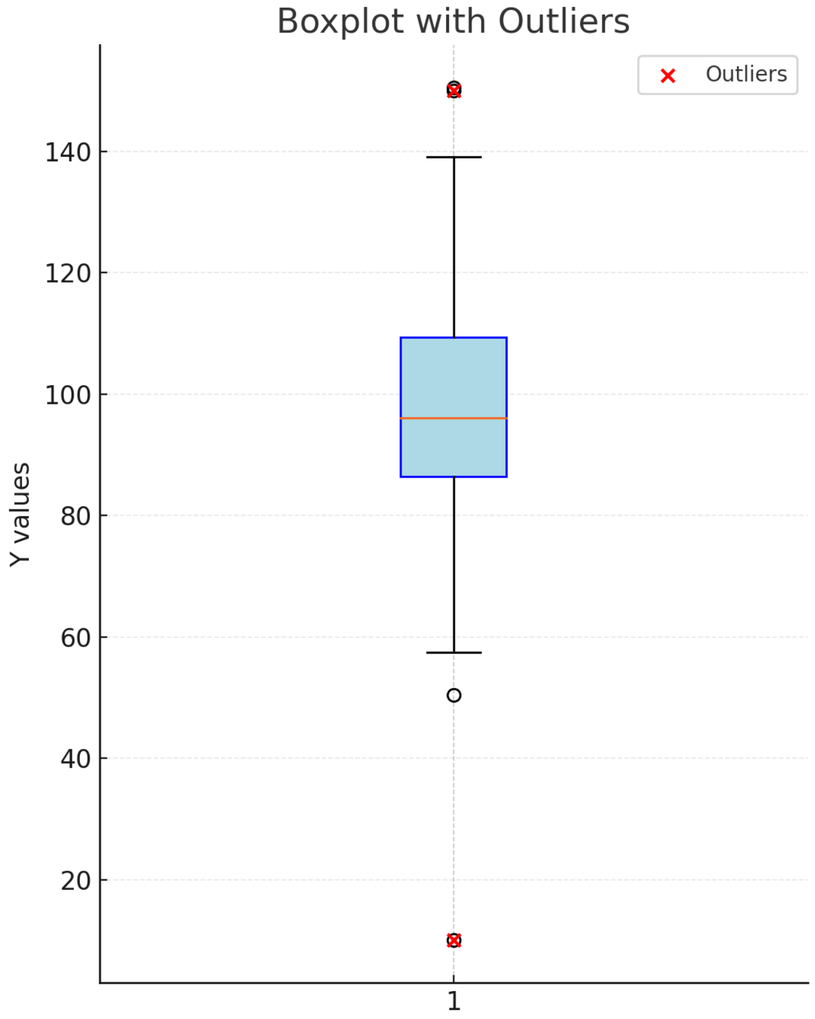
Example





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Outlier

Wrong value

Missing value

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How to correct outliers, wrong values and missing values?

1. **Outliers:**
    1. Leave them as they are (if they don’t affect too much the statistics)
    2. Apply transformations to reduce their impact (es. Log)
    3. Replace with an estimate (mean/median/mode/predict with ML models)
    4. Remove whole row (only if the dataset is sufficiently big)
2. **Wrong values:**
    1. Check the source of the data for corrections
    2. Replace with an estimate (mean/median/mode/predict with ML models)
    3. Remove whole row (only if the dataset is sufficiently big)
3. **Missing values:**
    1. Replace with an estimate (mean/median/mode/predict with ML models)
    2. Remove whole row (only if the dataset is sufficiently big)

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How to correct outliers, wrong values and missing values?

	Leave them as they are	Apply transformations	Replace with estimate	Remove row	Check the source
Outliers	✅	✅	✅	✅	✅
Wrong Values			✅	✅	✅
Missing Values			✅	✅	

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Replace with an estimate

1. **Mean & Median (only numeric variables):**
    1. **Mean:** $\frac{\sum_{i=1}^{n} x_i}{n}$ where x_i is each element in the column and n in the total number of elements
    2. **Median:** the middle value when the column is sorted in ascending order.
2. **Mode (both):**
    1. The most frequently occurring value in the column.
3. **Machine Learning model prediction (both):**
    1. **KNN Estimation**: Predict missing values based on the closest similar data points (neighbors).
    2. **Regression Imputation**: Use a regression model to predict missing values based on relationships in the data.

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Categorical Variable Encoding

Categorical: Variables that represent distinct groups or categories.

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Why Encode Them?

- Many machine learning models require numerical input.
- Proper encoding improves model performance and interpretability.

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Encoding Techniques

One Hot Encoding: converts categories into binary columns.

- [“Red," "Green," “Blue"] → [100, 010, 001].
- **Pros:** No ordinal assumptions; widely supported.
- **Cons:** Can lead to high-dimensional data.

Red	Green	Blue
1	0	0
0	1	0
0	0	1

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Label Encoding: Assigns unique integer values to each category.

- ["Red," "Green," "Blue"] → [0, 1, 2].
- **Pros**: Simple and memory-efficient.
- **Cons:** Assumes ordinal relationship, which might mislead models.

Red	0
Green	1
Blue	2

Demo with notebook

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Summary

- A random variable (r.v.) X is a function X: Ω → R where Ω is the state space and R is the set of values that the variable can take called Range.
  - A r.v. can be numerical (continuous/discrete) or categorical (nominal/ordinal)
- Outliers and missing values are important to detect: different ways to detect them!
- Computers only understand numbers: convert categorical variables into numerical!