Imputation Methods

Data Mining & Neural Networks

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Imputation Methods for Missing Data

- In data mining and neural networks, **handling missing data is crucial for building robust and accurate models**.
- This session will explore various imputation techniques, their advantages, limitations, and practical applications.

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Introduction to Missing Data

- Missing data occurs when no **value is stored for a variable** in an observation.
- It can arise from data **entry errors, equipment malfunctions, or non-responses in surveys**.
- Ignoring **missing data can lead to biased results** and reduced model performance.

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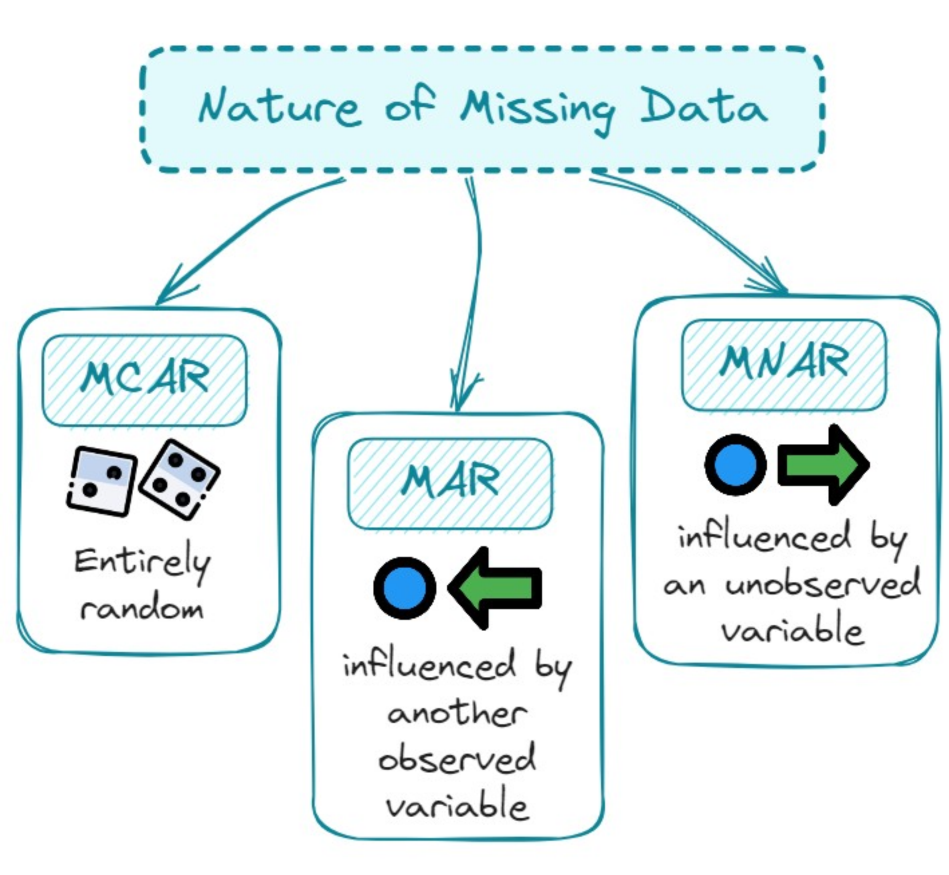
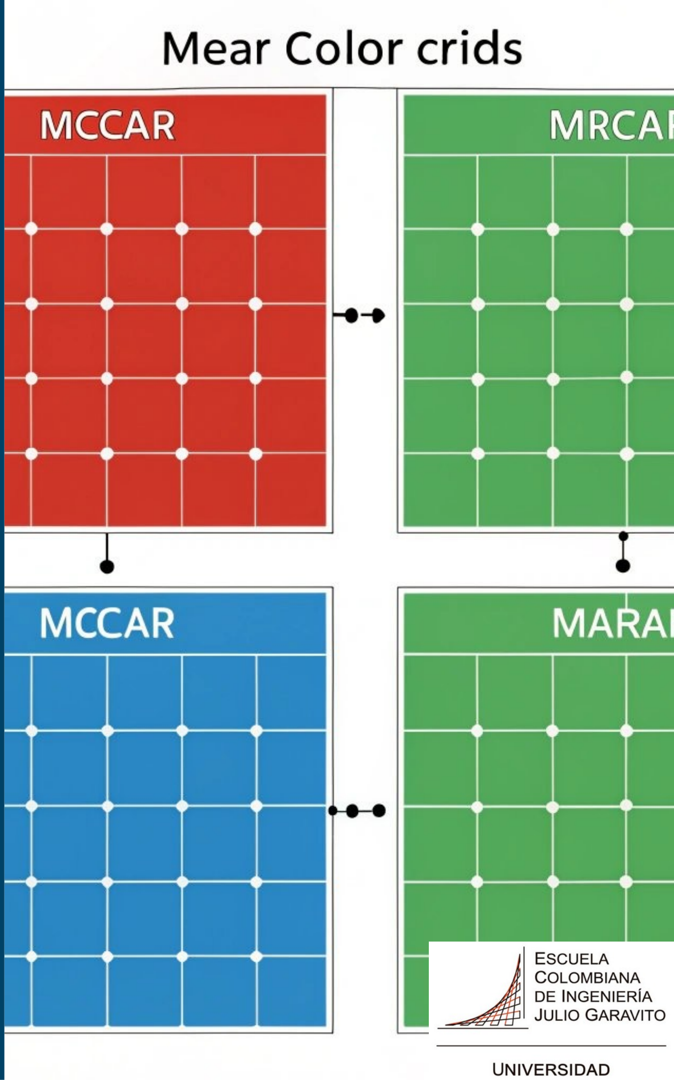
Types of Missing Data





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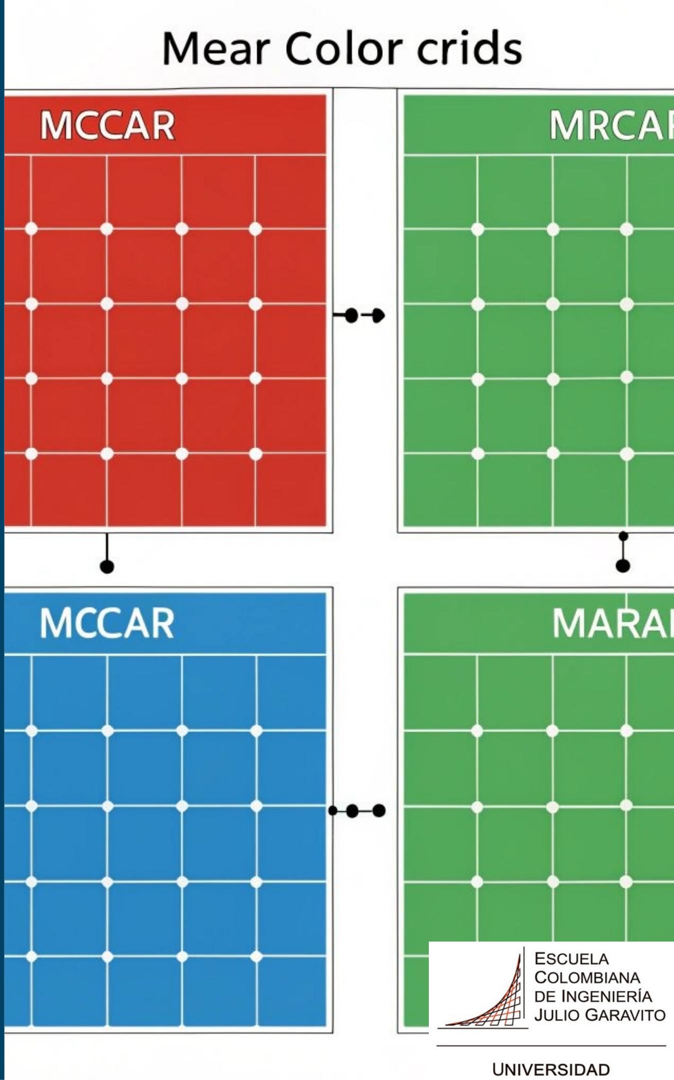
Types of Missing Data (1)

- **1: MCAR (Missing Completely at Random)**:
    - The missingness occurs **entirely at random** and is **unrelated to any values in the dataset**.
    - The missingness does **not depend on any variable**, neither the ones measured nor the ones missing.

- **Example**: Imagine a survey where **some questionnaires were lost in the mail randomly, with no connection to the respondents' answers** or characteristics.



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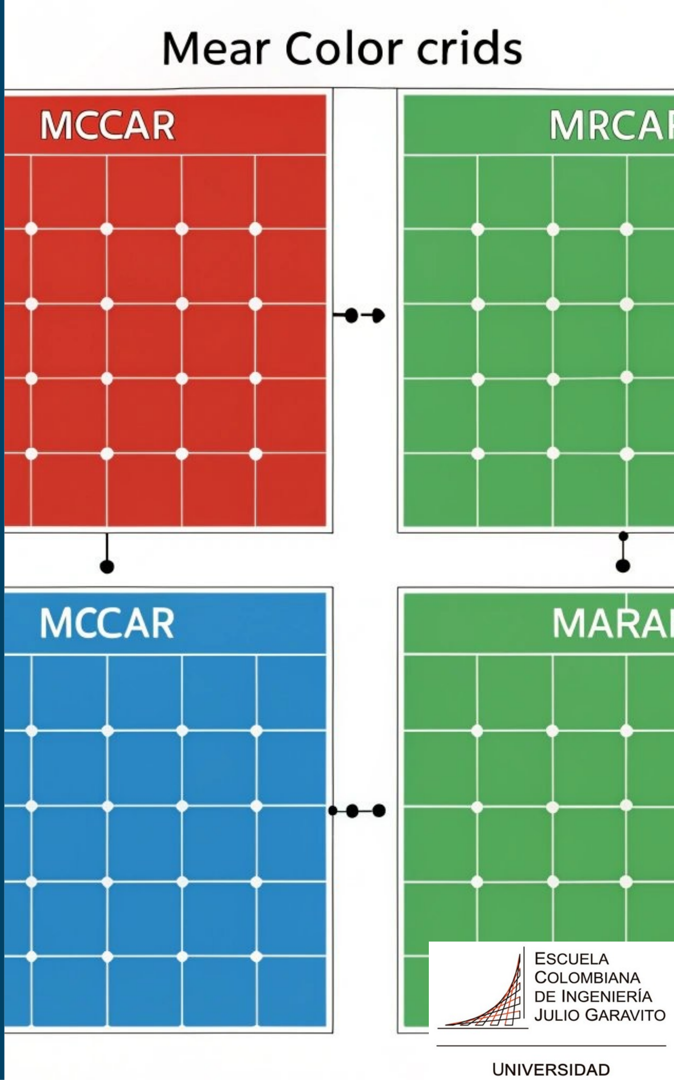
Types of Missing Data (2)

- **2: MAR (Missing at Random)**:
  - The **missingness is related to observed data**.
  - The probability of **a value being missing depends only on observed data**.
  - The missingness can be related to other variables that are observed in the dataset.

- **Example**: In a medical study, **older patients may be less likely to answer income questions**.
  - Here, **missing income data depend on age (observed)**, but not on the income values themselves.



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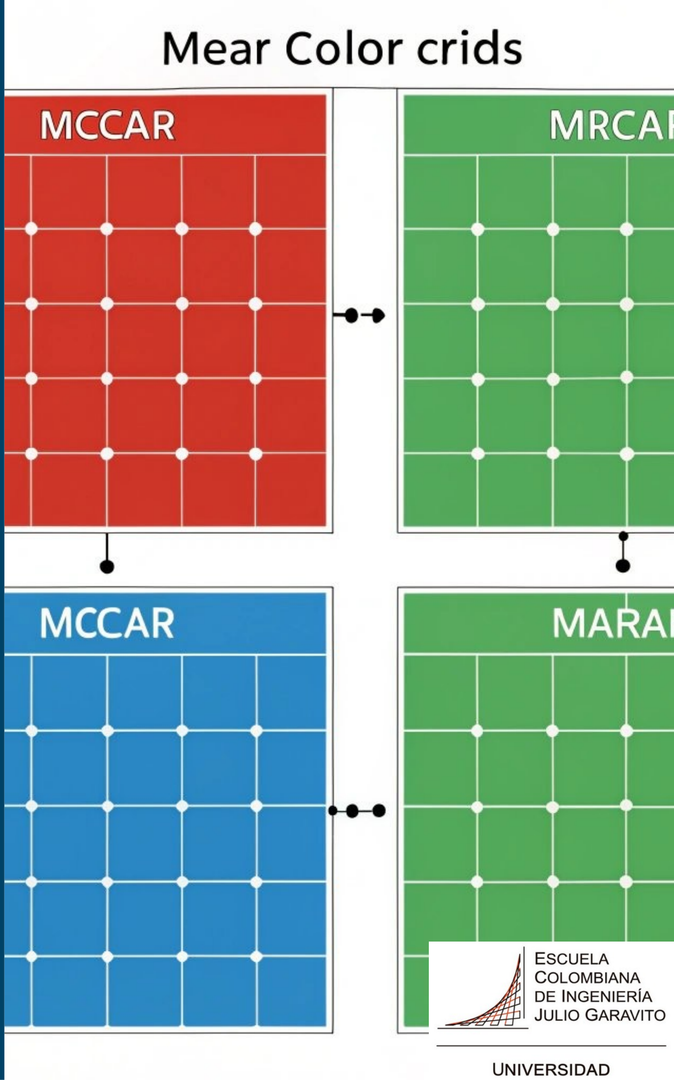
Types of Missing Data (3)

- **3: MNAR (Missing Not at Random)**:
    - **The missingness is related to unobserved data.**
    - Missingness is related to the value of the missing data.

- **Example**: In a survey about income, **people with very high or very low incomes may choose not to report their income**
    - The missingness depends on the income value itself.



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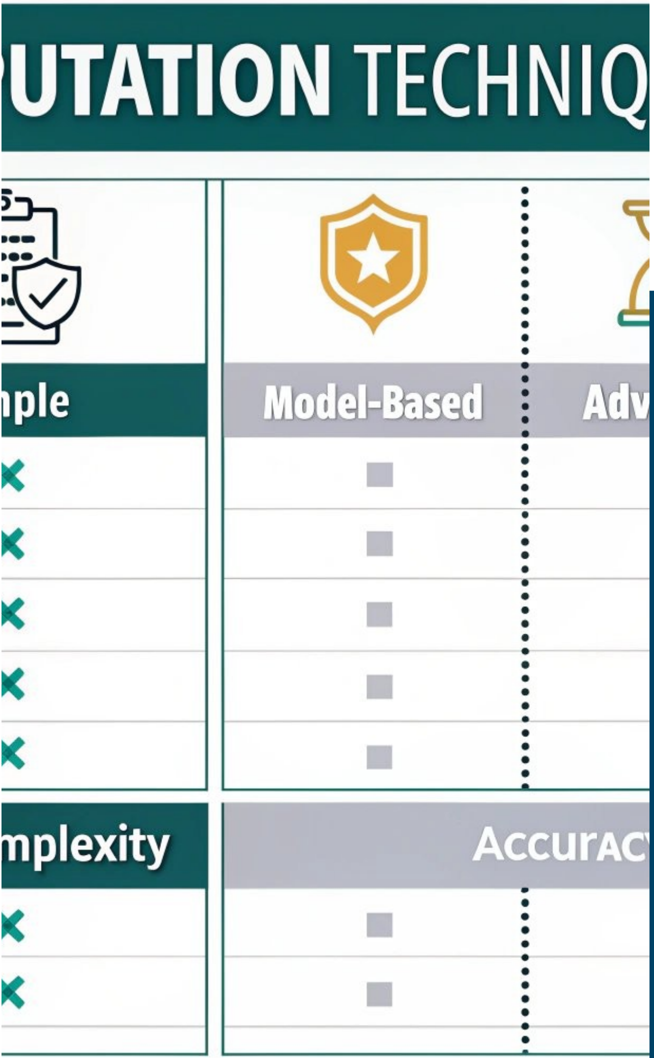
Why Imputation Matters

- Imputation allows us to retain all observations by **filling in missing values**, preserving statistical power, and reducing bias.



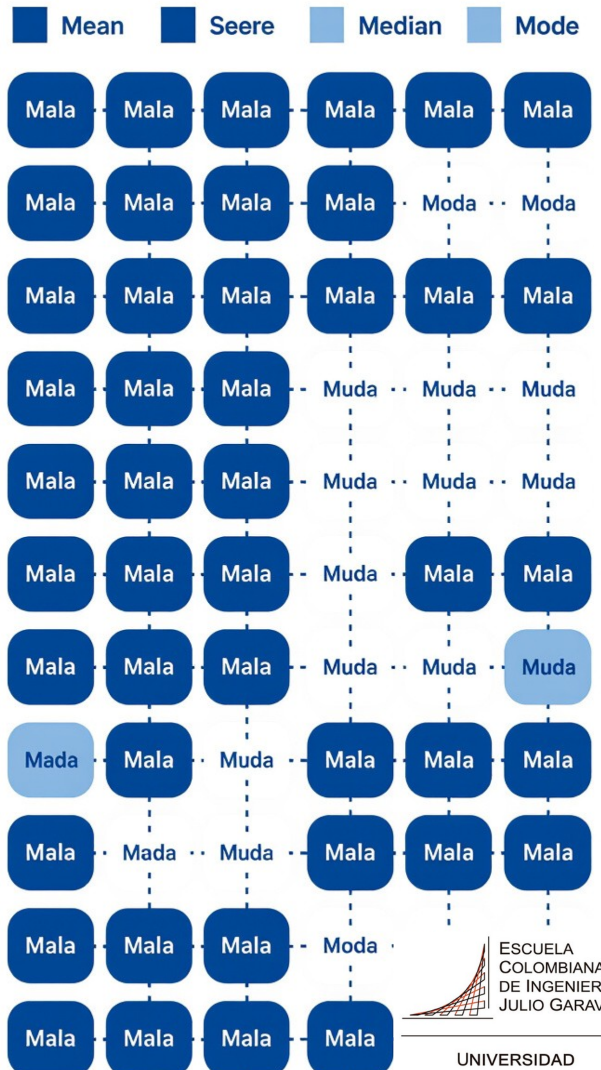
Overview of Imputation Techniques

- Imputation methods can be broadly categorized into:
  - **Simple Imputation** (mean, median, mode)
  - **Model-based Imputation** (regression, k-NN, MICE)
  - **Advanced Techniques** (deep learning, GANs) Each method has trade-offs in terms of complexity, accuracy, and computational cost.

Mean/Median/Mode Imputation

This is the simplest method where missing values are replaced with the **mean (for continuous)**, **median (for skewed)**, or **mode (for categorical)** of the variable.

- **Pros**: Easy to implement, fast.
- **Cons**: Ignores feature relationships, underestimates variance.
- **Example**: Replacing missing age values with the average age.



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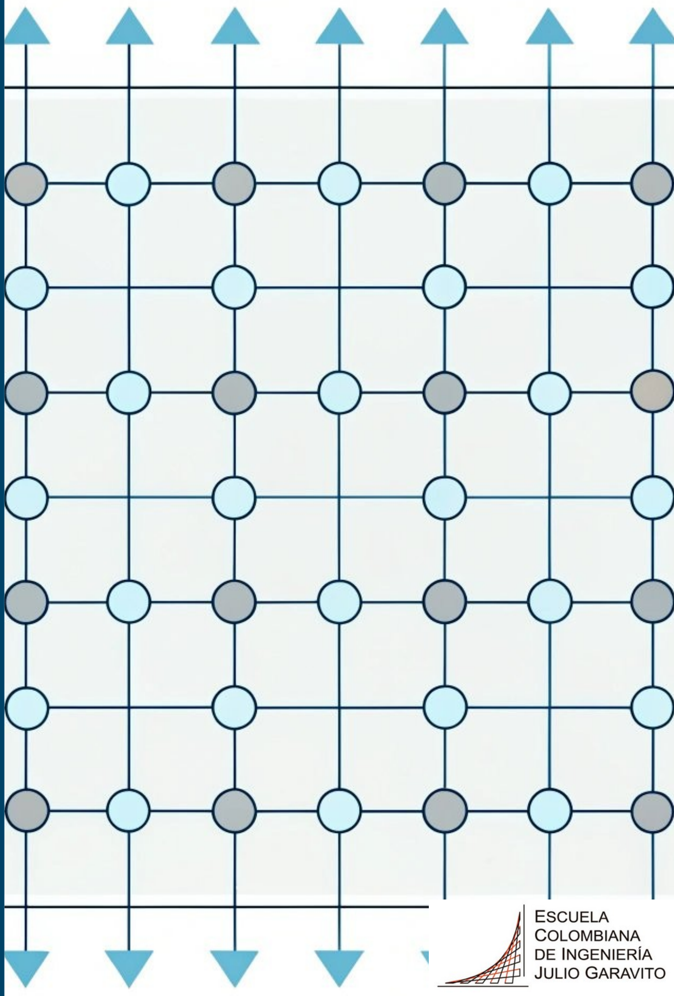
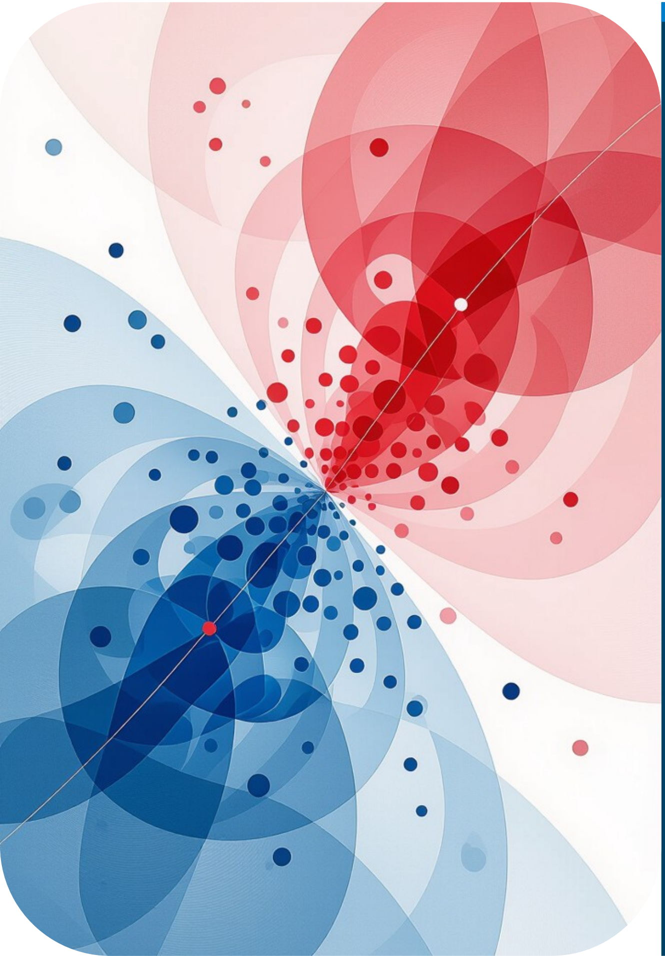
Constant Value Imputation

A fixed value (e.g., -999 or “Unknown”) is used to fill missing entries.

- **Pros**: Useful for flagging missingness explicitly.
- **Cons**: Can introduce bias or mislead models if not handled properly. Often used in tree-based models that can treat such values separately.





k-Nearest Neighbors (k-NN) Imputation

Imputes missing values using the average of the k most similar instances:

- **Pros**: Captures local structure and relationships.
- **Cons**: Computationally expensive, sensitive to distance metric.
- **Example**: Filling missing income based on similar individuals' profiles.

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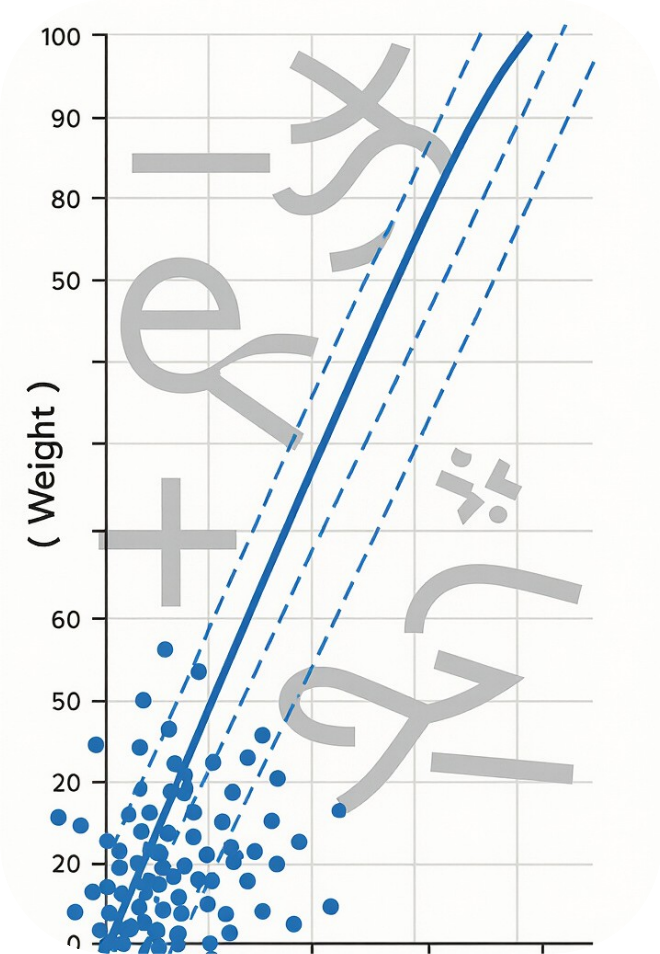

Regression Imputation

Predicts missing values using a regression model trained on observed data:

- **Pros**: Utilizes relationships between variables.
- **Cons**: Can lead to overfitting, underestimates variability.
- **Example**: Predicting missing weight using height and age.

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Multiple Imputation by Chained Equations (MICE)

Each variable with missing values is imputed using a model based on other variables:

- **Pros**: Accounts for uncertainty, flexible with variable types.
- **Cons**: Computationally intensive, requires careful tuning. Widely used in medical and social sciences.

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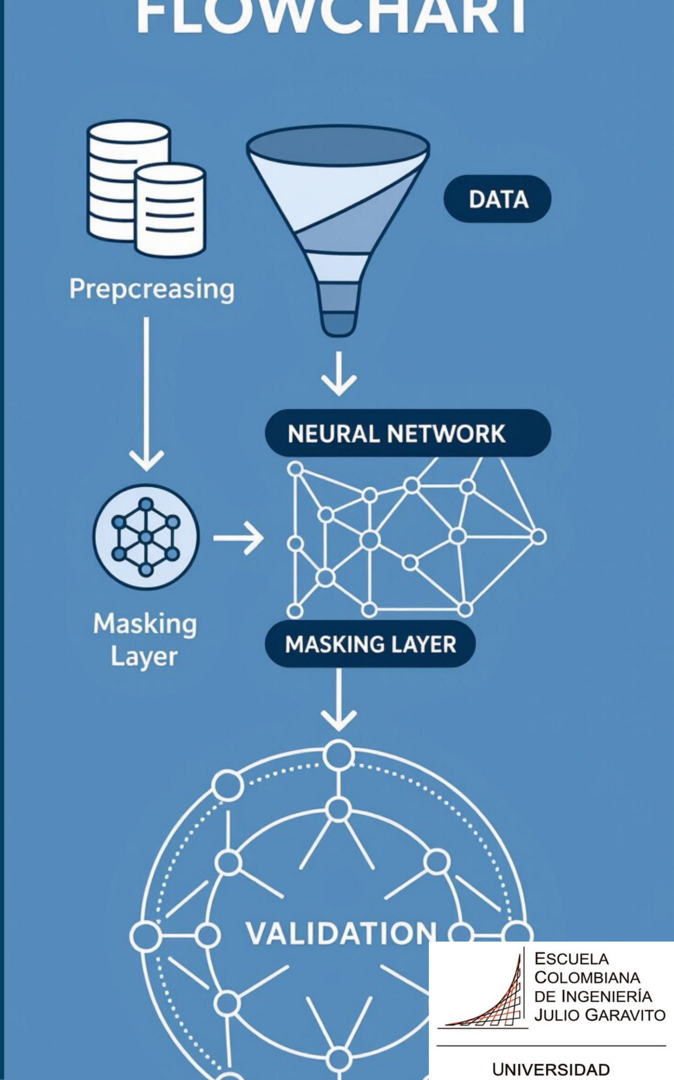
Imputation in Neural Networks

Neural networks require complete data. Imputation can be done:

- **Preprocessing step** (before training)
- **Within the model** (e.g., masking layers)
- **Best Practices**: Normalize after imputation, avoid data leakage, validate with cross-validation.



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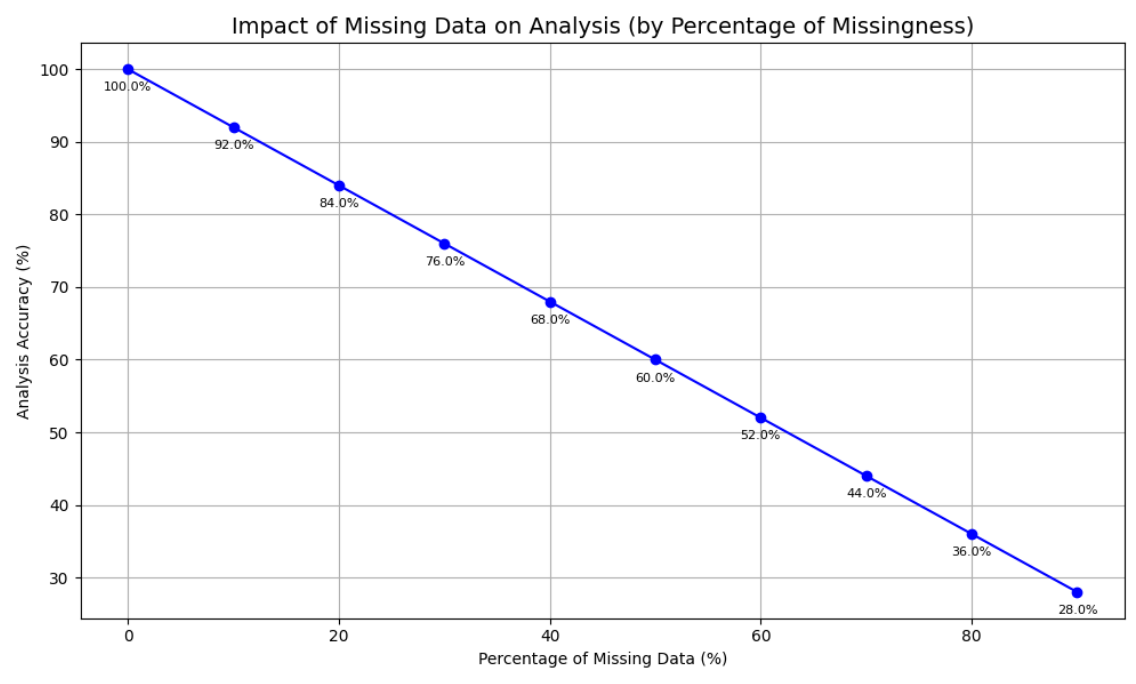
Impact of Missing Data:

- **0-5%:** minimal impact.
- **5-15%:** Impact becomes noticeable; imputation methods are recommended to reduce bias and loss of power.
- **15-30%:** Missing data can seriously affect results; advanced imputation or modeling techniques should be applied.
- **>30%:** High risk of bias and unreliable conclusions.



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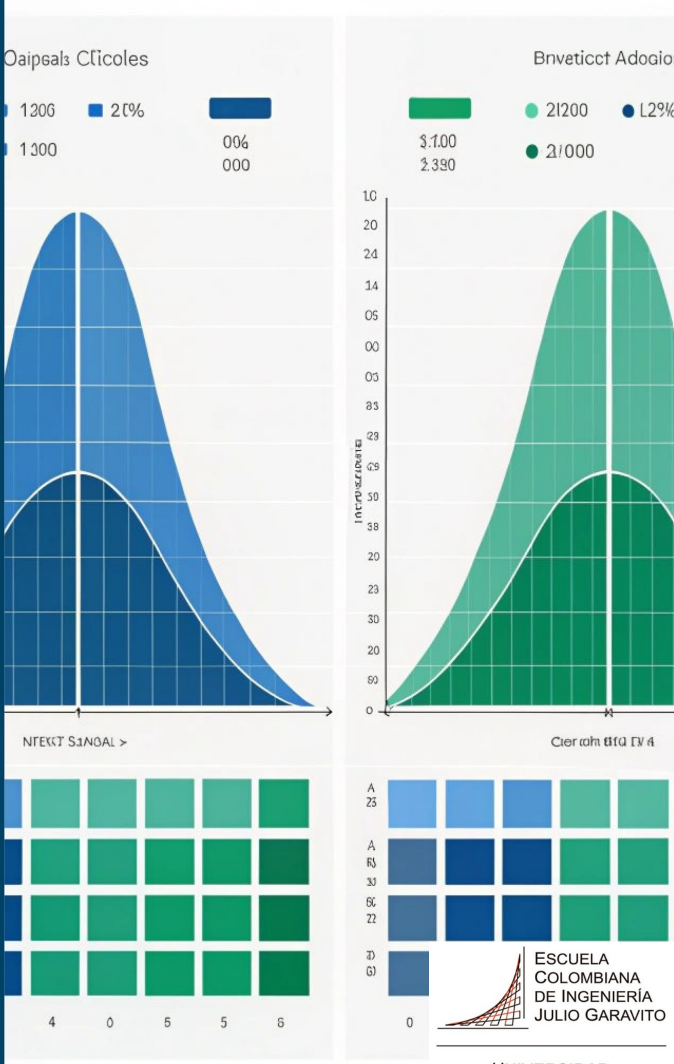
Evaluation of Imputation Methods

Evaluate imputation using:

- **RMSE/MAE** for numerical data
- **Classification accuracy** for categorical data
- **Visual inspection** (e.g., distribution plots) Use simulated missingness to benchmark methods.



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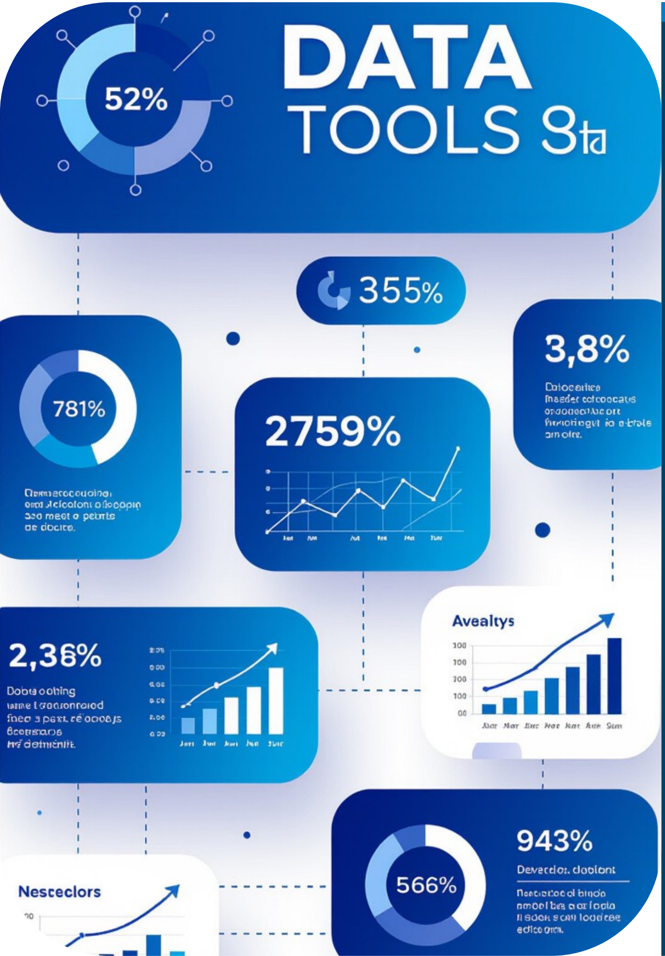

Tools and Libraries

Popular Python libraries for imputation:

- **pandas**: fillna()
- **scikit-learn**: SimpleImputer, KNNImputer
- **fancyimpute**: MICE, SoftImpute
- **PyTorch/TensorFlow**: For deep learning-based imputation
  Choose tools based on data size, type, and model requirements.

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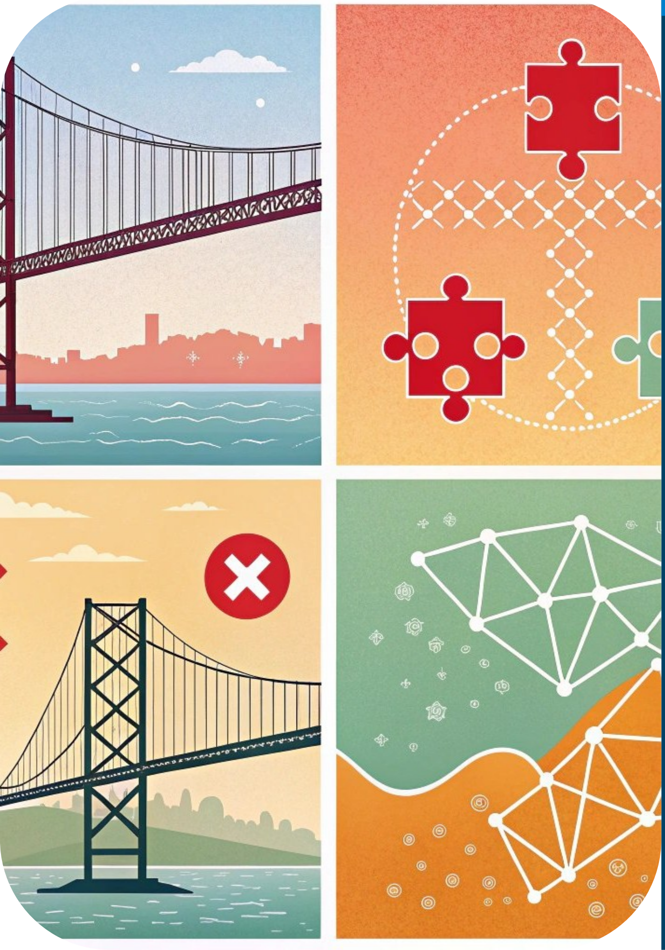

Common Pitfalls

- Imputing test data with training statistics
- Ignoring the mechanism of missingness
- Overfitting with complex imputation models
- Not validating imputation impact on model performance

Always document and justify your imputation strategy.

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Summary

- Missing data is a critical issue in data mining and neural networks.
- Imputation methods range from simple to advanced.
- Choice depends on data type, missingness mechanism, and model goals.
- Evaluate and validate imputation strategies rigorously.

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