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BCA Honours | Semester II | BCA2CJ102

Statistical Foundation for Computer Applications

Module 4 Comprehensive Notes

Module 4: Correlation and Regression Analysis

Bivariate statistical methods examine joint variation between two numerical attributes, establishing mathematical measures of linear association (correlation) and formulating predictive models (regression).

4.1 Bivariate Data and Karl Pearson's Correlation Coefficient

Let $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ denote paired observations of continuous variables X and Y. Pearson's product-moment correlation coefficient r measures the strength and direction of their linear relationship:

$$r = \frac{\operatorname{Cov}(X, Y)}{\sigma_X \sigma_Y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where: r = Pearson's product-moment correlation coefficient, bounded in [-1, +1], measuring linear association strength between variables X and Y.

Mathematical Properties of *r*

- **Bounded Range:** By the Cauchy-Schwarz inequality, $-1 \leq r \leq +1$.
- **Interpretation:** $r = +1$ indicates perfect positive linear correlation; $r = -1$ indicates perfect negative linear correlation; $r = 0$ signifies absence of linear correlation.
- **Invariance to Scale and Origin:** If transformed variables $u = \frac{X-a}{h}$ and $v = \frac{Y-b}{k}$ are defined, $r_{uv} = r_{xy}$ when h, k > 0.

4.2 Spearman's Rank Correlation Coefficient

When data cannot be measured on an interval or ratio scale, or when underlying normality assumptions fail, Spearman's rank correlation ρ assesses monotonic relationships using ordinal ranks:

$$\rho = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2 - 1)}$$

Where: $d_i = R(x_i) - R(y_i)$ represents the difference between paired ranks of the i-th observation, and n is sample size.

4.3 Linear Regression Modeling and the Principle of Least Squares

Regression analysis formulates a functional relationship to estimate the conditional mean of dependent response variable Y based on known independent predictor X. The linear regression model is expressed as:

$$Y = a + bX$$

Where: $Y = a + bX$ represents the estimated line of regression, where $b = Cov(X,Y)/ \sigma_X^2$ is the regression slope and a is the intercept.

Derivation via Ordinary Least Squares (OLS)

The principle of least squares minimizes the sum of squared residual errors: $S(a, b) = \sum_{i=1}^{n}[y_i - (a + bx_i)]^2$. Setting partial derivatives $\frac{\partial S}{\partial a} = 0$ and $\frac{\partial S}{\partial b} = 0$ produces the standard Normal Equations:

$$\sum y = na + b\sum x$$

$$\sum xy = a\sum x + b\sum x^2$$

Solving these simultaneous equations yields the regression coefficients for the two regression lines:

Regression Line	Standard Equation	Slope Coefficient Formula
Y* on *X (predicting Y)	$Y - \bar{y} = b_{yx}(X - \bar{x})$	$b_{yx} = r\frac{\sigma_Y}{\sigma_X} = \frac{n\sum xy - \sum x\sum y}{n\sum x^2 - (\sum x)^2}$
X* on *Y (predicting X)	$X - \bar{x} = b_{xy}(Y - \bar{y})$	$b_{xy} = r\frac{\sigma_X}{\sigma_Y} = \frac{n\sum xy - \sum x\sum y}{n\sum y^2 - (\sum y)^2}$

Properties of Regression Coefficients

1. **Geometric Mean Relationship:** The correlation coefficient is the geometric mean of the two regression coefficients: $r = \pm\sqrt{b_{yx} \cdot b_{xy}}$. The sign of r must match the identical signs of b_{yx} and b_{xy}.
2. **Bounded Product:** Since $|r| \leq 1$, the product of regression slopes cannot exceed unity: $b_{yx} \cdot b_{xy} \leq 1$. If one slope exceeds 1, the other must be less than 1.
3. **Intersection at Means:** The two regression lines always intersect at the bivariate mean coordinate $(\bar{x}, \bar{y})$.

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1. Architectural Trade-offs and Computational Complexity

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- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 4 Core Concepts and Methods, pre-computing intermediate lookup tables, spatial indices, and hashing structures achieves near-instantaneous O(1) query latency, but inflates the physical memory footprint. Conversely, in-place algorithms minimize RAM utilization at the cost of higher CPU cycle counts. Modern architectures dynamically calibrate memory allocations using memory-mapped files and cache-aware structures.
- **Concurrency Scalability versus Thread Contention:** While multi-core hardware allows horizontal execution, concurrent modifications to shared state structures create severe lock contention, thread synchronization bottlenecks, and cache line invalidation storms. High-performance frameworks deploy lock-free algorithms, optimistic concurrency control, and atomic compare-and-swap (CAS) primitives.
- **Algorithmic Determinism versus Heuristic Scalability:** Exact mathematical algorithms frequently encounter NP-hard combinatorial barriers as problem dimensions scale. Contemporary systems bridge this gap by deploying bounded approximation algorithms and meta-heuristics that produce near-optimal solutions within guaranteed execution time windows.

2. Empirical Comparative Framework

A structured comparative assessment clarifies operational distinctions across conventional paradigms and modern production implementations in Statistical Foundation for Computer Applications:

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Architecture Paradigm	Monolithic single-threaded architectures with tightly coupled state.	Distributed microservices with asynchronous event queues and thread-safe data structures.	Linear scalability and resilient fault isolation under peak transactional loads.
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3. Production Implementation Patterns and Resilience Engineering

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