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BCA Honours | Semester I | Calicut University

Discrete Structures for Computer Applications

Course Code: BCA1CJ103 • Module 3 Notes

MODULE III: GRAPH THEORY

1. Graph Foundations and Theorems

A graph $G = (V, E)$ consists of a non-empty set of vertices V and a set of edges E connecting pairs of vertices. Graphs model computer networks, social connections, highway navigation, and database dependencies.

- **Handshaking Theorem:** In every graph $G = (V, E)$, the sum of the degrees of all vertices equals twice the total number of edges:

  $$sum_{v in V} deg(v) = 2 |E|$$

  Corollary: In any graph, the number of vertices with odd degree must be even.
- **Eulerian vs. Hamiltonian Graphs:**
  - *Euler Path/Circuit:* Traverses every edge in G exactly once. An undirected connected graph has an Euler circuit if and only if **every vertex has an even degree**. It has an Euler path if and only if exactly 0 or 2 vertices have odd degree.
  - *Hamiltonian Path/Cycle:* Visits every vertex in G exactly once.
- **Planar Graphs & Euler's Formula:** A graph is planar if it can be drawn in a plane without intersecting edges. For any connected planar graph with V vertices, E edges, and F faces:

  $$V - E + F = 2$$

2. Illustrative Computational Working: Step-by-Step Numerical Example

Worked Numerical Example: Handshaking Theorem Verification & Euler Graph Analysis

Problem Statement:

1. A connected graph G has 12 vertices. Four of the vertices have degree 5, three vertices have degree 4, and the remaining five vertices have degree 3.

Determine: (a) Total sum of degrees, (b) Exact number of edges in G, and (c) Verify whether G can possess an Euler circuit or an Euler path.

2. A connected planar graph has 14 vertices and divides the plane into 8 faces. Calculate the exact number of edges in the graph using Euler's Planar Formula.

Solution & Step-by-Step Working:

Part 1: Graph Degree and Edge Calculation

Step 1.1: Calculate total sum of degrees:

$$sum_{v in V} deg(v) = (4 \times 5) + (3 \times 4) + (5 \times 3) = 20 + 12 + 15 = \mathbf{47}$$

Validation Check: The sum of degrees must be an **even integer** by the Handshaking Theorem ($sum deg(v) = 2|E|$). A sum of 47 is odd! Therefore, **no such graph can physically exist**.

Correction / Practical Adjustment: Let the remaining five vertices have degree 4 instead of degree 3, yielding:

$$sum_{vinV}\, deg(v) = (4 \times 5) + (3 \times 4) + (5 \times 4) = 20 + 12 + 20 = \mathbf{52}$$

Step 1.2: Number of edges:

$$|E| = \frac{sumdeg(v)}{2} = \frac{52}{2} = \mathbf{26} \text{ edges}$$

Step 1.3: Eulerian Analysis:

Examine vertex degrees: Four vertices have degree 5 (odd), and eight vertices have degree 4 (even).

Number of odd-degree vertices = 4.

- For an Euler circuit: Number of odd vertices must be 0. Result: **No Euler circuit**.
- For an Euler path: Number of odd vertices must be exactly 2. Result: **No Euler path**.

Part 2: Euler's Planar Formula

Given: $V = 14$ vertices, $F = 8$ faces.

Euler's Planar Formula states: $V - E + F = 2$.

$$14 - E + 8 = 2 implies 22 - E = 2 impliesE = 22 - 2 = \mathbf{20}$$

Result: The planar graph contains exactly **20 edges**.

Advanced Theoretical Extensions & Industrial Systems Synthesis

In modern computer science and professional software engineering, mastering Discrete Structures for Computer Applications demands a rigorous integration of pure theory with large-scale industrial computational realities. Contemporary enterprises operate in distributed, multi-threaded environments where mathematical precision, algorithmic efficiency, and statutory compliance govern mission-critical architectures.

1. Contemporary Engineering Dilemmas and Architectural Solutions

Organizations and software architects managing Discrete Structures for Computer Applications must systematically navigate complex computational trade-offs:

- **Computational Precision versus Execution Latency:** In numerical computing and algorithmic workflows related to Graph Theory and Planar Networks, arbitrary-precision arithmetic eliminates floating-point rounding errors and catastrophic cancellation, but introduces substantial runtime overhead compared to hardware-accelerated IEEE 754 single- and double-precision floating-point arithmetic. High-performance computational frameworks dynamically adjust numerical precision based on problem conditioning and error-tolerance thresholds.
- **Theoretical Purity versus Practical Memory Constraints:** While mathematical abstractions often assume infinite address spaces and unbounded memory arrays, real-world implementations must operate within strict L1/L2/L3 cache hierarchies, virtual memory page tables, and hardware memory bandwidth ceilings. Structuring algorithms for spatial and temporal cache locality dramatically accelerates execution throughput.
- **Deterministic Standardization versus Dynamic Agility:** Enterprise systems require standardized standard operating procedures (SOPs) and formal verification to maintain reproducibility and

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2. Empirical Comparative Framework

A structured comparative assessment clarifies operational distinctions across conventional and contemporary paradigms in Discrete Structures for Computer Applications:

Evaluation Dimension	Conventional Traditional Practice	Contemporary Integrated Paradigm	Strategic Impact Metric
Analytical Methodology	Manual heuristic calculation relying on static, disconnected analytical models.	Automated high-throughput computation utilizing optimized vector libraries (BLAS, LAPACK, NumPy) and parallel GPU acceleration.	Orders-of-magnitude reduction in computation latency and elimination of human clerical error.
System Integration	Isolated functional silos characterized by localized data stores and fragmented reporting.	Interoperable service-oriented architectures communicating via standardized REST, gRPC, and message-driven data streams.	Seamless end-to-end data pipelines and real-time operational observability.
Risk & Governance Architecture	Periodic manual code inspections and statutory compliance reviews.	Automated static code analysis, formal software verification, continuous integration testing, and cryptographic audit trails.	Comprehensive intellectual property protection and provable statutory compliance.
Scalability & Resource Allocation	Static on-premise hardware provisioning with rigid capacity limits.	Dynamic containerized virtualization (Docker, Kubernetes) responsive to real-time workload fluctuations.	Optimized infrastructure utilization, high availability, and reduced operational expenditures.

3. Step-by-Step Implementation and Operational Governance Roadmap

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Industrial Risk Governance, Statutory Compliance & Failure Mode Analysis

Computational systems must withstand rigorous scrutiny across legal, ethical, operational, and data-integrity dimensions. Software architects deploy structured risk evaluation matrices to eliminate vulnerabilities across four core exposure categories:

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Numerical & Algorithmic Risk	Ill-conditioned matrices, division by zero, arithmetic overflow/underflow, non-terminating loops.	Loss of significant digits, NaN/Infinity propagation, execution timeouts, diverging residuals.	Condition number monitoring, robust numerical pivoting, loop invariant assertions, automated fuzz testing.
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