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BCA Honours | Semester III | Calicut University

Data Structures using C

Course Code: BCA3CJ201 • Module 3 Notes

MODULE III: NON-LINEAR DATA STRUCTURES - TREES

1. Binary Trees and Binary Search Trees (BST)

A binary tree is a non-linear data structure where each node has at most two children. In a **Binary Search Tree (BST)**, for every node X, all values in the left subtree are strictly less than X, and all values in the right subtree are strictly greater than X. An in-order traversal of a BST always visits nodes in strictly ascending numerical order.

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

Worked Example: BST Construction, Traversal, and Two-Child Node Deletion

Problem Statement:

1. Construct a Binary Search Tree (BST) by sequentially inserting the following keys into an initially empty tree:

$$Keys = [40, 20, 60, 10, 30, 50, 70, 25]$$

2. Write the resulting In-order, Pre-order, and Post-order traversals.

3. Trace the step-by-step deletion of node 20 (which possesses two children: 10 and 30) using its **in-order successor**.

Solution & Step-by-Step Working:

Part 1: Sequential Insertion Trace

- Insert 40: Root node.
- Insert 20: $20 < 40 implies$ Left child of 40.
- Insert 60: $60 > 40 implies$ Right child of 40.
- Insert 10: $10 < 40, 10 < 20 implies$ Left child of 20.
- Insert 30: $30 < 40, 30 > 20 implies$ Right child of 20.
- Insert 50: $50 > 40, 50 < 60 implies$ Left child of 60.
- Insert 70: $70 > 40, 70 > 60 implies$ Right child of 60.
- Insert 25: $25 < 40, 25 > 20, 25 < 30 implies$ Left child of 30.

Part 2: Tree Traversals

- **In-Order (Left, Root, Right):** $10, \quad 20, \quad 25, \quad 30, \quad 40, \quad 50, \quad 60, \quad 70$ (Ascending order).
- **Pre-Order (Root, Left, Right):** $40, \quad 20, \quad 10, \quad 30, \quad 25, \quad 60, \quad 50, \quad 70.$
- **Post-Order (Left, Right, Root):** $10, \quad 25, \quad 30, \quad 20, \quad 50, \quad 70, \quad 60, \quad 40.$

Part 3: Deletion of Node 20 with Two Children

To delete node 20 without violating the BST invariant:

1. Find the **in-order successor** (the minimum key in the right subtree of 20).
   The right child of 20 is 30, whose left child is 25. The minimum key is 25.
2. Copy the key value 25 into the node currently occupied by 20.

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3. Delete the original node 25 from its leaf position in the right subtree.

Resulting Tree In-Order Traversal: $10, \quad 25, \quad 30, \quad 40, \quad 50, \quad 60, \quad 70$. The tree maintains full BST validity.

Advanced Architectural Extensions & Industrial Systems Synthesis

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1. Contemporary Engineering Dilemmas and Architectural Solutions

Engineering teams designing systems centered around Data Structures using C must systematically navigate fundamental computational trade-offs:

- **Time Complexity Optimization versus Space Consumption:** In high-throughput algorithmic pipelines related to Binary Search Trees and Balancing, pre-computing intermediate lookup tables (memoization, spatial indices, hash tables) achieves near-instantaneous $O(1)$ query latency, but inflates physical memory footprints. Conversely, in-place algorithms minimize RAM utilization at the expense of higher cycle counts. Modern architectures dynamically calibrate memory allocations using memory-mapped I/O and cache-aware data layouts.
- **Concurrency Scalability versus Thread Contention:** While multi-core architectures allow massive 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 Real-World Heuristic Scalability:** Exact mathematical algorithms frequently encounter NP-hard combinatorial explosions as problem dimensions scale. Contemporary industrial 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 and modern paradigms in Data Structures using C:

Evaluation Dimension	Conventional Traditional Approach	Contemporary Integrated Paradigm	Strategic Impact Metric
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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System Telemetry & Auditing	Static text logging with periodic post-incident analysis.	Distributed tracing (OpenTelemetry), structured JSON metrics, and automated root-cause diagnostics.	Mean Time to Detection (MTTD) and Recovery (MTTR) reduced from hours to seconds.

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

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Industrial Risk Governance, Statutory Compliance & Failure Mode Analysis

Mission-critical systems must withstand rigorous scrutiny across operational, legal, and cyber-security dimensions. System architects deploy structured risk evaluation matrices to eliminate vulnerabilities across critical operational categories:

Risk Category	Primary Sources of Vulnerability	Diagnostic Warning Indicators	Mitigation Protocol & Internal Controls
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Statutory & Regulatory Risk	Non-compliance with national data protection regulations (DPDP Act, GDPR), audit trail gaps.	Unencrypted sensitive user data at rest, unlogged administrative data modifications.	Automated encryption (AES-256), immutable cryptographic audit logs, periodic external compliance audits.

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