

## Introduction to Data Structure, Lists, Linked Lists, and Trees

Data structures are fundamental concepts in computer science that help in organizing and storing data efficiently. They provide a structured way to manage and manipulate data, enabling efficient searching, sorting, and retrieval. Data structures can be broadly categorized into linear and non-linear types, each designed for specific operations and use cases.

Data types define the kind of data that can be stored and manipulated within a program. Primitive data types include integers, floating-point numbers, characters, and booleans. Data structures, on the other hand, refer to the organization and storage format of data, facilitating efficient access and modification. Examples include arrays, linked lists, stacks, queues, trees, and graphs. Abstract Data Types (ADTs) define logical data structures without specifying their implementation details. ADTs include lists, stacks, queues, and trees, which specify the operations that can be performed rather than how they are implemented in memory.

The efficiency of an algorithm is measured in terms of time and space complexity. Time complexity refers to the amount of time an algorithm takes to execute as a function of the input size. It is expressed using asymptotic notation such as Big-O, which represents the worst-case scenario, Omega, which represents the best-case scenario, and Theta, which represents the average-case scenario. Space complexity refers to the amount of memory an algorithm requires for execution, including both fixed and variable memory allocations. Analyzing these complexities helps in selecting the most efficient algorithm for solving a problem.

Linear data structures store data sequentially. Examples include stacks and queues. A stack follows the Last-In-First-Out (LIFO) principle, meaning elements are added and removed from the top. The main operations performed on a stack include inserting an element at the top, removing the top element, retrieving the top element without removing it, and checking if the stack is empty. Stacks are widely used in function calls, recursion, undo operations in text editors, and expression evaluation.

A queue follows the First-In-First-Out (FIFO) principle, meaning elements are added at the rear and removed from the front. The main operations performed on a queue include inserting an element at the rear, removing an element from the front, and checking if the queue is empty. Queues are commonly used in scheduling tasks, handling requests in operating systems, and managing buffers.

Stacks are particularly useful in expression evaluation. Infix expressions, where operators appear between operands (e.g.,  $A + B$ ), can be converted into postfix notation (e.g.,  $AB+$ ) using stacks. Operators are pushed onto a stack while operands are directly placed in the output. In postfix evaluation, the operands appear before the operator, making computation straightforward using a stack. The operands are pushed onto the stack, and whenever an operator is encountered, the required number of operands is popped, the operation is performed, and the result is pushed back.

Lists can be implemented using arrays or linked structures. An array-based implementation stores elements in a fixed-size sequential block of memory, whereas a linked list dynamically allocates memory. Stacks and queues can also be implemented as lists, where stacks allow only push and pop operations at one end, while queues allow insertion at the rear and removal from the front.

A static list structure has a fixed size, meaning memory is allocated at the time of declaration and cannot be changed later. Examples include arrays. A dynamic list structure allows memory allocation and deallocation as needed. Linked lists are an example of dynamic list structures, where elements (nodes) can be added or removed without predefined constraints on size.

A linked list consists of nodes, where each node contains data and a pointer to the next node in the sequence. Unlike arrays, linked lists provide dynamic memory allocation, allowing flexible modifications.

There are different types of linked lists. A singly linked list consists of nodes where each node points to the next node in the sequence. A doubly linked list contains two pointers, one pointing to the next node and another pointing to the previous node, allowing bidirectional traversal. A circular linked list is where the last node of the list points back to the first node, creating a circular connection. Circular linked lists can be singly or doubly linked.

Basic operations on linked lists include creating a linked list, inserting nodes at different positions, and deleting nodes from different positions. Insertion can be done at the beginning, middle, or end of the list. Deletion can be performed by removing nodes from specific positions. Doubly linked lists are particularly useful in applications requiring bidirectional traversal, such as navigation in web browsers and undo-redo operations in text editors.

A tree is a hierarchical, non-linear data structure consisting of nodes connected by edges. The top node is called the root, and every node can have child nodes. Trees are widely used in database indexing, file systems, artificial intelligence, and hierarchical data representation.

A binary tree is a type of tree where each node has at most two children. Operations in a binary tree include insertion, deletion, and searching. Insertion involves adding a new node while maintaining the tree structure. Searching is performed to find whether a specific element exists within the tree. Deletion removes a node while restructuring the tree to maintain its properties.

Traversal in binary trees is done using different methods. Pre-order traversal visits the root node first, then recursively visits the left subtree followed by the right subtree. Post-order traversal visits the left subtree first, then the right subtree, and finally the root node. In-order traversal visits the left subtree first, then the root node, and finally the right subtree. These traversal techniques are used in applications such as expression tree evaluation and hierarchical data processing.

The height of a tree is the longest path from the root node to a leaf node. The level of a node represents the depth at which it exists in the tree, with the root being at level zero. The depth of a node is the number of edges from the root node to that specific node.

An AVL tree is a type of self-balancing binary search tree where the height difference between the left and right subtrees of any node is at most one. If the balance factor of any node exceeds this limit, rotations are performed to restore balance. AVL trees are used in applications requiring efficient searching and sorting, such as database indexing and memory management.