DATA STRUCTURES REFERENCE

A quick reference of the big O costs and core properties of every data structure.

Data Structure and Types

What are Data Structures?

Data structure is a storage that is used to store and organize data. It is a way of arranging data on a computer so that it can be accessed and updated efficiently.

Depending on your requirement and project, it is important to choose the right data structure for your project. For example, if you want to store data sequentially in the memory, then you can go for the Array data structure.

Types of Data Structure

Basically, data structures are divided into two categories:

- Linear data structure
- Non-linear data structure

Linear data structures

In linear data structures, the elements are arranged in sequence one after the other. Since elements are arranged in particular order, they are easy to implement.

However, when the complexity of the program increases, the linear data structures might not be the best choice because of operational complexities.

1. Array Data Structure
2. Stack Data Structure
3. Queue Data Structure
4. Linked List Data Structure

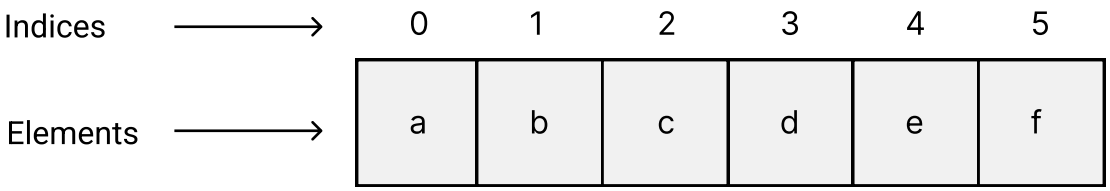
Non linear data structures

Unlike linear data structures, elements in non-linear data structures are not in any sequence. Instead they are arranged in a hierarchical manner where one element will be connected to one or more elements.

Non-linear data structures are further divided into graph and tree based data structures.

1. Graph Data Structure
2. Trees Data Structure
    - Binary Tree
    - Binary Search Tree
    - AVL Tree
    - B-Tree
    - B+ Tree
    - Red-Black Tree

Array



Summary:

a collection that stores elements in order and looks them up by index. Also known as: fixed array, static array.

Important facts:

- Stores elements sequentially, one after another.
- Each array element has an index. Zero-based indexing is used most often: the first index is 0, the second is 1, and so on.
- Is created with a fixed size. Increasing or decreasing the size of an array is impossible.
- Can be one-dimensional (linear) or multi-dimensional.
- Allocates contiguous memory space for all its elements.

Pros:

- Ensures constant time access by index.
- Constant time append (insertion at the end of an array).

Cons:

- Fixed size that can't be changed.
- Search, insertion and deletion are O(n). After insertion or deletion, all subsequent elements are moved one index further.
- Can be memory intensive when capacity is underused.

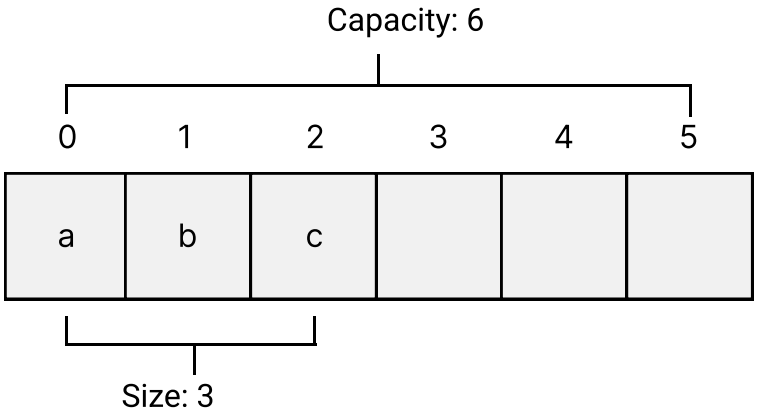
Notable uses:

- The String data type that represents text is implemented in programming languages as an array that consists of a sequence of characters plus a terminating character.

Notable uses:

- Access: O(1)
- Search: O(n)
- Insertion: O(n) (append: O(1))
- Deletion: O(n)

Dynamic Array



Summary:

an array that can resize itself, array list, list, growable array, resizable array, mutable array, dynamic table.

Important facts:

- Same as array in most regards: stores elements sequentially, uses numeric indexing, allocates contiguous memory space.
- Expands as you add more elements. Doesn't require setting initial capacity.
- When it exhausts capacity, a dynamic array allocates a new contiguous memory space that is double the previous capacity, and copies all values to the new location.
- Time complexity is the same as for a fixed array except for worst-case appends: when capacity needs to be doubled, append is O(n). However, the average append is still O(1).

Pros:

- Variable size. A dynamic array expands as needed.
- Constant time access.

Cons:

- Slow worst-case appends: O(n). Average appends: O(1).
- Insertion and deletion are still slow because subsequent elements must be moved a single index further. Worst-case (insertion into/deletion from the first index, a.k.a. prepending) for both is O(n).

Time complexity (worst case):

- Access: O(1)
- Search: O(n)
- Insertion: O(n) (append: O(n))
- Deletion: O(n)

Linked List

Summary:

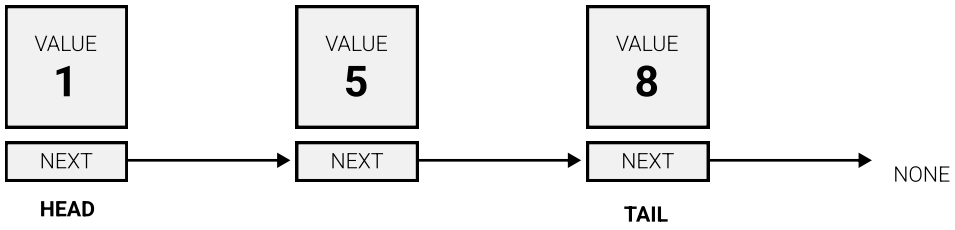
a linear collection of elements ordered by links instead of physical placement in memory. Nodes are sequential. Each node stores a reference (pointer) to one or more adjacent nodes:

Important facts:

- Each element is called a node.
  - The first node is called the head.
  - The last node is called the tail.
- Stacks and queues are usually implemented using linked lists, and less often using arrays.

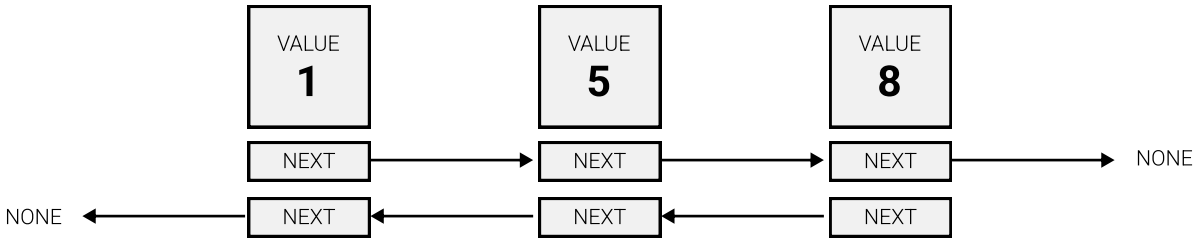
Singly linked list:

In a singly linked list, each node stores a reference to the next node.



Doubly linked list

In a doubly linked list, each node stores references to both the next and the previous nodes. This enables traversing a list backwards.



Pros:

- Optimized for fast operations on both ends, which ensures constant time insertion and deletion.
- Flexible capacity. Doesn't require setting initial capacity, can be expanded indefinitely.

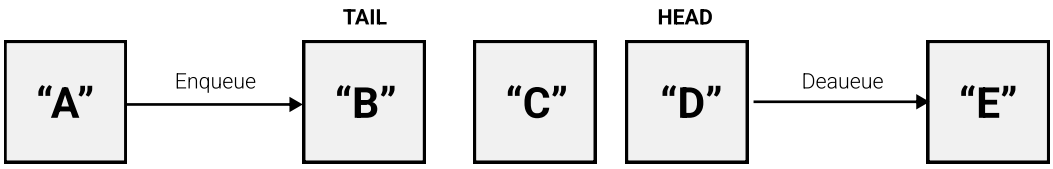
Cons:

- Costly access and search.
- Linked list nodes don't occupy continuous memory locations, which makes iterating a linked list somewhat slower than iterating an array.

Time complexity (worst case):

- Access: O(n)
- Search: O(n)
- Insertion: O(1)
- Deletion: O(1)

Queue



Summary:

a sequential collection where elements are added at one end and removed from the other end.

Important facts:

- Modeled after a real-life queue: first come, first served.
- First in, first out (FIFO) data structure.
- Similar to a linked list, the first (last added) node is called the tail, and the last (next to be removed) node is called the head.
- Two fundamental operations are enqueuing and dequeuing:
  - To enqueue, insert at the tail of the linked list.
  - To dequeue, remove at the head of the linked list.
- Usually implemented on top of linked lists because they're optimized for insertion and deletion, which are used to enqueue and dequeue elements.

Pros:

- Constant-time insertion and deletion.

Cons:

- Access and search are O(n).

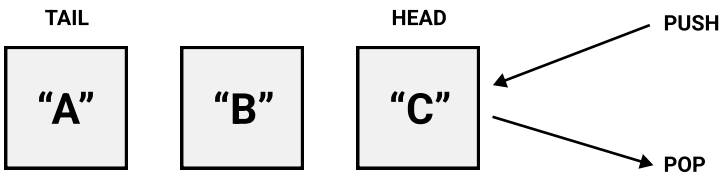
Notable uses:

- CPU and disk scheduling, interrupt handling and buffering.

Time complexity (worst case):

- Access: O(n)
- Search: O(n)
- Insertion (enqueuing): O(1)
- Deletion (dequeuing): O(1)

Stack



Summary:

a sequential collection where elements are added to and removed from the same end.

Important facts:

- First-in, last-out (FILO) data structure.
- Equivalent of a real-life pile of papers on desk.
- In stack terms, to insert is to push, and to remove is to pop.
- Often implemented on top of a linked list where the head is used for both insertion and removal. Can also be implemented using dynamic arrays.

Pros:

- Fast insertions and deletions: O(1).

Cons:

- Access and search are O(n).

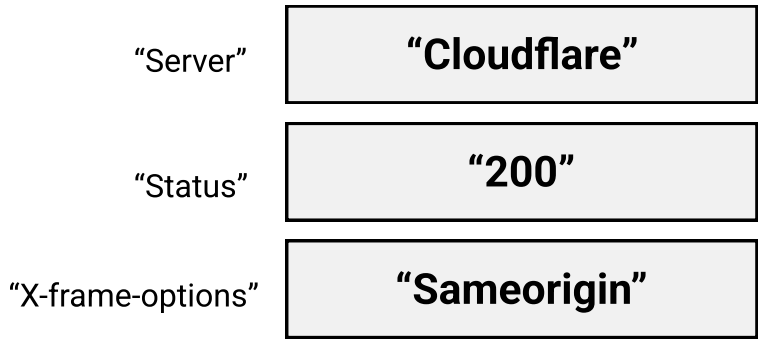
Notable uses:

- Maintaining undo history.
- Tracking execution of program functions via a call stack.
- Reversing order of items.

Time complexity (worst case):

- Access: O(n)
- Search: O(n)
- Insertion (pushing): O(1)
- Deletion (popping): O(1)

Hash Table



Summary:

unordered collection that maps keys to values using hashing. Also known as: hash, hash map, map, unordered map, dictionary, associative array.

Important facts:

- Stores data as key-value pairs.
- Can be seen as an evolution of arrays that removes the limitation of sequential numerical indices and allows using flexible keys instead.
- For any given non-numeric key, hashing helps get a numeric index to look up in the underlying array.
- If hashing two or more keys returns the same value, this is called a hash collision. To mitigate this, instead of storing actual values, the underlying array may hold references to linked lists that, in turn, contain all values with the same hash.
- A set is a variation of a hash table that stores keys but not values.

Pros:

- Keys can be of many data types. The only requirement is that these data types are hashable.
- Average search, insertion and deletion are O(1).

Cons:

- Worst-case lookups are O(n).
- No ordering means looking up minimum and maximum values is expensive.
- Looking up the value for a given key can be done in constant time, but looking up the keys for a given value is O(n).

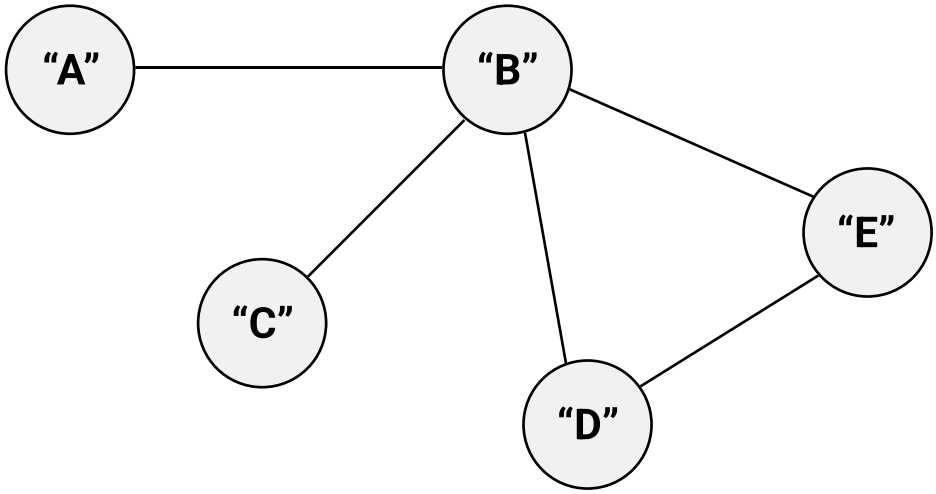
Notable uses:

- Caching.
- Database partitioning..

Time complexity (worst case):

- Access: O(1)
- Search: O(n)
- Insertion: O(n) (append: O(n))
- Deletion: O(n)

Graph



Summary:

a data structure that stores items in a connected, non-hierarchical network.

Important facts:

- Each graph element is called a node, or vertex.
- Graph nodes are connected by edges.
- Graphs can be directed or undirected.
- Graphs can be cyclic or acyclic. A cyclic graph contains a path from at least one node back to itself.
- Graphs can be weighted or unweighted. In a weighted graph, each edge has a certain numerical weight.
- Graphs can be traversed. See important facts under Tree for an overview of traversal algorithms.

Pros:

- Ideal for representing entities interconnected with links.

Cons:

- Low performance makes scaling hard.

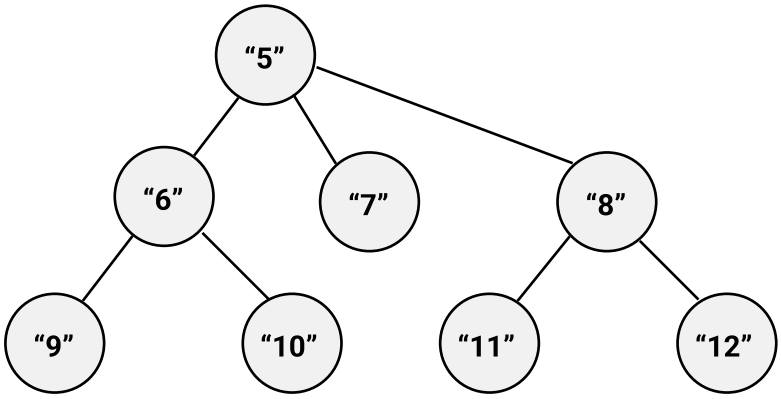
Notable uses:

- Social media networks.
- Recommendations in ecommerce websites.
- Mapping services.

Time complexity (worst case):

- varies depending on the choice of algorithm. O(n*lg(n)) or slower for most graph algorithms.

Tree



Summary:

a data structure that stores a hierarchy of values.

Important facts:

- Organizes values hierarchically.
- A tree item is called a node, and every node is connected to 0 or more child nodes using links.
- A tree is a kind of graph where between any two nodes, there is only one possible path.
- The top node in a tree that has no parent nodes is called the root.
- Nodes that have no children are called leaves.
- The number of links from the root to a node is called that node's depth.
- The height of a tree is the number of links from its root to the furthest leaf.
- In a binary tree, nodes cannot have more than two children.
    - Any node can have one left and one right child node.
    - Used to make binary search trees.
    - In an unbalanced binary tree, there is a significant difference in height between subtrees.
    - An completely one-sided tree is called a degenerate tree and becomes equivalent to a linked list.
- Trees (and graphs in general) can be traversed in several ways:
    - Breadth first search (BFS): nodes one link away from the root are visited first, then nodes two links away, etc. BFS finds the shortest path between the starting node and any other reachable node.
    - Depth first search (DFS): nodes are visited as deep as possible down the leftmost path, then by the next path to the right, etc. This method is less memory intensive than BFS. It comes in several flavors, including:
        - Pre order traversal (similar to DFS): after the current node, the left subtree is visited, then the right subtree.

    - In order traversal: the left subtree is visited first, then the current node, then the right subtree.
    - Post order traversal. the left subtree is visited first, then the right subtree, and finally the current node.

Pros:

- For most operations, the average time complexity is O(log(n)), which enables solid scalability. Worst time complexity varies between O(log(n)) and O(n).

Cons:

- Performance degrades as trees lose balance, and re-balancing requires effort.
- No constant time operations: trees are moderately fast at everything they do.

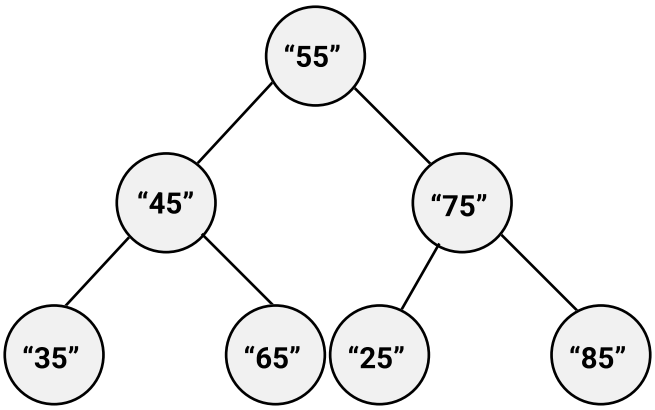
Notable uses:

- File systems.
- Database indexing.
- Syntax trees.
- Comment threads.

Time complexity (worst case):

- varies for different kinds of trees.

Binary Search Tree



Summary:

a kind of binary tree where nodes to the left are smaller, and nodes to the right are larger than the current node.

Important facts:

- Nodes of a binary search tree (BST) are ordered in a specific way:
  - All nodes to the left of the current node are smaller (or sometimes smaller or equal) than the current node.
  - All nodes to the right of the current node are larger than the current node.
- Duplicate nodes are usually not allowed.

Pros:

- Balanced BSTs are moderately performant for all operations.
- Since BST is sorted, reading its nodes in sorted order can be done in O(n), and search for a node closest to a value can be done in O(log(n))

Cons:

- Same as trees in general: no constant time operations, performance degradation in unbalanced trees.

Time complexity (worst case):

- Access: O(n)
- Search: O(n)
- Insertion: O(n)
- Deletion: O(n)

Time complexity (average case):

- Access: O(log(n))
- Search: O(log(n))
- Insertion: O(log(n))
- Deletion: O(log(n))