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Course: Data Structures and Algorithms

Fundamental Data Structures
Stacks and Queues

Evis Plaku

The classic Stack vs Queue struggle

Queue: *First come, first served (FIFO)*

Stack: Last-minute shoppers (LIFO) be like…

What are stacks and queues

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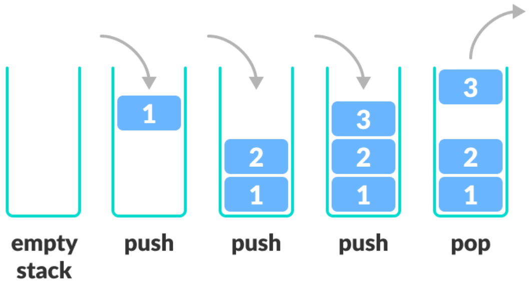
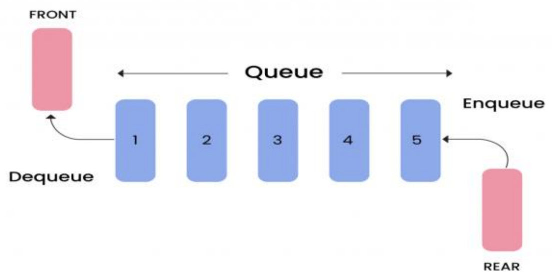
Linear data structures used to store and manage data efficiently





- Store elements like a stack of plates: last added, first removed
- Used in undo/redo, function calls, and expression evaluation

- Works like a line at a checkout: first added, first removed
- Used in task scheduling, buffering, and request handling

Abstract data type overview

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An **Abstract Data Type (ADT)** defines **what operations** a data structure supports, **not how** they are implemented

Key ADTs

- List: indexed collection
- Set: unordered, unique
- Map: key – value pairs
- Graph: nodes and edges
- Stack and Queue: operations performed in particular order

Why ADTs?

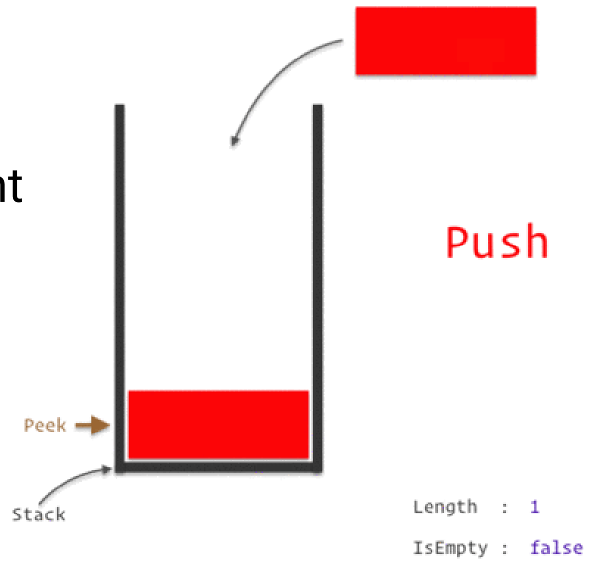
- Separates logic from implementation: focus on functionality, not internal details
- Help design flexible and reusable data structures

Stack Fundamentals

Stack ADT: key concepts and operations

A **Stack** follows **LIFO (Last In, First Out)**
the last element added is the first removed

- `push(x)`: adds x to the top
- `pop()`: removes and returns the top element
- `peek()`: returns the top element without removing it
- `isEmpty()`: check if stack is empty



Stack implementation using arrays

A fixed-size array stores elements, with a top pointer tracking the stack's end

```
class Stack {
    private int[] stack;
    private int top;

    public Stack(int size) {  // Constructor
        stack = new int[size];
        top = -1;
    }

    public void push(int x) { /* Add element */ }
    public int pop() { /* Remove and return top */ }
    public int peek() { /* Return top without removing */ }
    public boolean iEmpty() { /* Check if empty */ }
}
```

[Click here to access complete code]

Stack implementation using linked lists

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A linked list-based stack uses nodes, where the top points to the last added element

```
class Node {
    int data;
    Node next;
}

class Stack {
    private Node top;

    public Stack() { top = null; }

    public void push(int x) { /* Add node at top */ }
    public int pop() { /* Remove and return top node */ }
    public int peek() { /* Return top node value */ }
    public boolean isEmpty() { /* Check if top is null */ }
}
```

[Click here to access complete code]

Applications of stacks in real life

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Undo / Redo in Editors

Function call management

Expression evaluation

Backtracking (maze, puzzles)

Browser history navigation

Parenthesis matching

Stack use case: balanced parentheses problem

Use a **stack** to ensure every opening bracket has a matching closing bracket

$\{[x \cdot (2x + y \; - 3)] + (2x \; - 7)\}$

Algorithm

- Push opening brackets onto the stack
- Pop when a matching closing bracket appears
- Mismatch or non-empty stack at end → not balanced

```
FUNCTION isBalanced(expression):
    CREATE an empty stack

    FOR each character in expression:
        IF character is an opening bracket:
            PUSH it onto the stack
        ELSE IF character is a closing bracket:
            IF stack is empty OR top does not match:
                RETURN false
            POP from stack

    RETURN true IF stack is empty, ELSE false
```

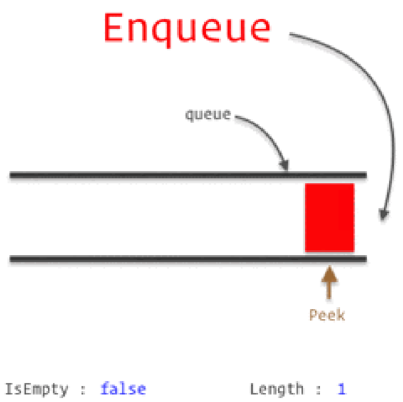
Click here to access Java implementation

Queue Fundamentals

Queue ADT: key concepts and operations

A **Queue** follows **FIFO (First In, First Out)**
Elements added in back and removed in front

- Enqueue/add: insert at the rear
- Dequeue: remove element from front
- peek(): returns the front element without removing it
- isEmpty(): check if queue is empty



Queue implementation using arrays

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Follows **FIFO**
(First In, First Out)

Use array with front and rear pointers

```java
class Queue {
    private int[] arr;
    private int front, rear, size, capacity;

    public Queue(int capacity) {
        this.capacity = capacity;
        arr = new int[capacity];
        front = size = 0;
        rear = -1;
    }

    public void enqueue(int item) { /* Add item at rear */
}   public int dequeue() { /* Remove item from front */ }
    public int front() { /* Get front element */ }
    public boolean isEmpty() { /* Check if empty */ }
}
```

Click here to access Java implementation

Queue implementation using linked lists

Store elements in nodes with pointers to the next element.

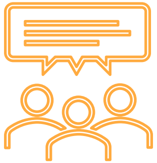
Add element at back, remove from front

```
class Queue<T> {
    private Node<T> front, rear;
    private int size;

    static class Node<T> {
        T data;
        Node<T> next;

        Node(T data) {
            this.data = data;
            this.next = null;
        }
    }

    public Queue() {
        front = rear = null;
        size = 0;
    }

    public void enqueue(T item) { /* Add item at rear */ }
    public T dequeue() { /* Remove item from front */ }
    public T front() { /* Get front element */ }
    public boolean isEmpty() { /* Check if empty */ }
}
```

[Click here to access Java implementation]

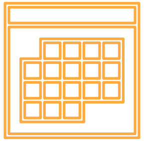
Applications of queues in real life

Customer service

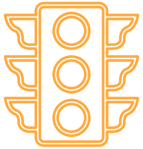


Print spooling

CPU scheduling



Traffic management



Call center systems

Breadth – first search

Queue use case: call center simulation

Queues & multi-threading are essential for simulating real-time systems like call centers

- Queues manage incoming calls and prioritize based on availability
- Agent availability is tracked to allocate customers to free agents
- Multi-threading simulates parallel call handling, improving system responsiveness

Queues ensure efficient task management and fair resource allocation

Advanced variations: circular queues & deques

Circular queue

- Overcomes limitations of regular queues by reusing empty space
- The rear pointer loops back to the front when space is available
- Efficient memory usage in applications like buffering and round-robin scheduling

Dequeue

- Allows insertion and removal of elements from both ends
- Supports both FIFO and LIFO operations
- Useful in scenarios requiring both stack and queue functionality, like task scheduling

Complexity and Performance Analysis

Complexity and performance analysis

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Both stacks and queues offer efficient time complexities for common operations

Operation	Stack	Queue
Push / enqueue	$O(1)$	$O(1)$
Pop / dequeue	$O(1)$	$O(1)$
Peek	$O(1)$	$O(1)$
Access / search	$O(n)$	$O(n)$
Sort	$O(n \cdot \log n)$	$O(n \cdot \log n)$

Analyzing Big O for various data structures

Choose data structures based on access speed, insertion/deletion needs, and memory efficiency

Data Structure	Access	Search	Insert	Delete
Array	$O(1)$	$O(n)$	$O(n)$	$O(n)$
Linked list	$O(n)$	$O(n)$	$O(1)$	$O(1)$
Stack	$O(n)$	$O(n)$	$O(1)$	$O(1)$
Queue	$O(n)$	$O(n)$	$O(1)$	$O(1)$

Key Takeaways

- Stacks follow LIFO, queues follow FIFO for ordering elements
- Stacks are ideal for recursion, backtracking, and undo operations
- Queues are used in scheduling, buffers, and handling real-time data
- Both can be implemented using arrays or linked lists with different performance

Helpful resources on arrays and linked lists

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- 🔍 VisualAlgo: an interactive platform that visualizes data structures and algorithms

- 🎥 BroCode video to learn linked lists in a concise and interactive manner

- 📚 Programiz: beginner-friendly tutorials on data structures and algorithms with clear explanations and examples

- 💻 FreeCodeCamp course on algorithms and data structures

Quote of the Week

Stacks push you to the top,

but queues keep you in line