Lab Experiment No. 1

Aim:
Implementation and analysis of Arrays and its operations.
- Insertion
- Deletion
- Searching
- Traversing
- Updating

Background:
An array is a fundamental data structure that stores elements of the same data type in contiguous memory locations. Arrays provide constant-time access to elements using indexing but have a fixed size, meaning their size must be declared at the time of creation and cannot be dynamically changed.

Operations on Arrays
Arrays support various operations, including insertion, deletion, searching, traversing, and updation. Each operation has a specific behavior based on its implementation.

1. Insertion
Insertion involves adding a new element to the array at a specified index. If the insertion is at the end, it is efficient. However, inserting an element at the beginning or middle requires shifting elements, making the process more complex.

2. Deletion
Deletion removes an element from the array. If the element is at the end, the operation is straightforward. However, if it is at the beginning or middle, all subsequent elements need to be shifted to maintain the order.

3. Searching
Searching is used to find an element in an array. Two common algorithms are:
- Linear Search: Used for unsorted arrays. It checks each element sequentially.
- Binary Search: Used for sorted arrays. It follows the divide-and-conquer approach.

4. Traversing
Traversal means visiting each element in the array sequentially. This is required for processing or printing the elements.

5. Updation
Updating an element at a specific index is a direct operation because indexing provides constant-time access.

<u>CODE</u>

```
import java.util.Arrays;

public class ArrayOperations {
    private int[] arr;
    private int size;

    public ArrayOperations(int capacity) {
        arr = new int[capacity];
        size = 0;
    }
```

Insertion:

```
    public void insert(int index, int value) {
        if (size == arr.length) {
            System.out.println("Array is full. Cannot insert.");
            return;
        }
        if (index < 0 || index > size) {
            System.out.println("Invalid index.");
            return;
        }
        for (int i = size - 1; i >= index; i--) {
            arr[i + 1] = arr[i];
        }
        arr[index] = value;
        size++;
    }
```

Deletion

```
    public void delete(int index) {
        if (index < 0 || index >= size) {
            System.out.println("Invalid index.");
            return;
        }
        for (int i = index; i < size - 1; i++) {
            arr[i] = arr[i + 1];
        }
        size--;
    }
```

// Searching (Linear Search)

```
public int linearSearch(int value) {
    for (int i = 0; i < size; i++) {
        if (arr[i] == value) {
            return i;
        }
    }
    return -1;
}
```

// Searching (Binary Search - Assumes Sorted Array)

```
public int binarySearch(int value) {
    int left = 0, right = size - 1;
    while (left <= right) {
        int mid = left + (right - left) / 2;
        if (arr[mid] == value)
            return mid;
        else if (arr[mid] < value)
            left = mid + 1;
        else
            right = mid - 1;
    }
    return -1;
}
```

// Traversing

```
public void traverse() {
    for (int i = 0; i < size; i++) {
        System.out.print(arr[i] + " ");
    }
    System.out.println();
}
```

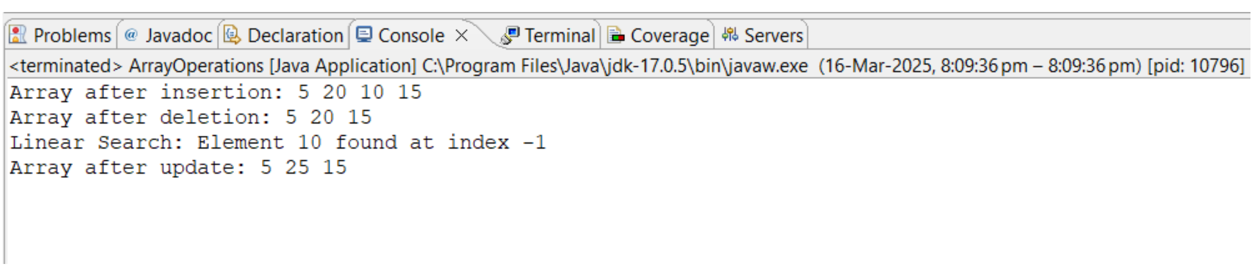
// Updating

```
public void update(int index, int value) {
    if (index < 0 || index >= size) {
        System.out.println("Invalid index.");
        return;
    }
    arr[index] = value;
}
```

TEST

```java
 public static void main(String[] args) {
      ArrayOperations arrayOps = new ArrayOperations(10);
      arrayOps.insert(0, 5);
      arrayOps.insert(1, 10);
      arrayOps.insert(2, 15);
      arrayOps.insert(1, 20); // Insert at index 1

      System.out.print("Array after insertion: ");
      arrayOps.traverse();

      arrayOps.delete(2);
      System.out.print("Array after deletion: ");
      arrayOps.traverse();

      int searchIndex = arrayOps.linearSearch(10);
      System.out.println("Linear Search: Element 10 found at index " + searchIndex);

      arrayOps.update(1, 25);
      System.out.print("Array after update: ");
      arrayOps.traverse();
  }
}
```

Output


Problems @ Javadoc Declaration Console Terminal Coverage Servers
<terminated> ArrayOperations [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe (16-Mar-2025, 8:09:36 pm – 8:09:36 pm) [pid: 10796]

```
Array after insertion: 5 20 10 15
Array after deletion: 5 20 15
Linear Search: Element 10 found at index -1
Array after update: 5 25 15
```

Fig 1.1 Arrays and its operations output

Performance Analysis:

OPERATION	BEST CASE	WORST CASE	AVERAGE CASE
Insertion	O(1)	O(n)	O(n)
Deletion	O(1)	O(n)	O(n)
Searching	O(1)	O(n)	O(n)
Traversing	O(n)	O(n)	O(n)
Updation	O(1)	O(1)	O(1)

Table1.1 Arrays and its operations. Performance Analysis

Conclusion:

- The experiment confirms that array operations vary in efficiency depending on the operation type and position of elements.
- Insertion and Deletion at the beginning or middle are costly due to shifting, reinforcing why linked lists are preferred for frequent insertions and deletions.
- Searching in an unsorted array is linear, while sorting the array beforehand allows efficient binary search.
- Updation is the most efficient operation since modifying an index is direct.
- The limitations of static arrays (fixed size, costly insertions/deletions) suggest the necessity of dynamic arrays or alternative data structures like linked lists, hash tables, or trees in practical applications.

Lab Experiment No. 2

Aim :

- Implementation and analysis of Linked Lists and their operations.
    - Singly Linked List
        - Insertion a new node
        - Deletion of a node
        - Traversing
    - Doubly Linked List
        - Insertion a new node
        - Deletion of a node
        - Traversing
    - Circular Linked List
        - Insertion a new node
        - Deletion of a node
        - Traversing

Background:

1. Singly Linked List

Definition

A **Singly Linked List (SLL)** is a linear data structure where each node contains data and a pointer to the next node in the sequence. The last node's pointer is set to null, indicating the end of the list.

Characteristics

- Each node has **two parts**:
    1. **Data**: The actual value stored in the node.
    2. **Next Pointer**: A reference to the next node in the list.
- The list starts from a **head node**.
- It **does not support backward traversal**.

Operations

1. **Insertion**: A new node can be inserted at the beginning, middle, or end of the list.
2. **Deletion**: A node can be removed by adjusting the next pointers of the previous node.
3. **Traversing**: The list is traversed from the head node to the last node using the next pointer.

Advantages

Uses memory efficiently as each node contains only one pointer.
Dynamic memory allocation prevents memory wastage.

Disadvantages

Searching is slow (O(n)) since we must traverse the list sequentially.
Cannot traverse backward since there is no reference to the previous node.

2. Doubly Linked List

Definition
A **Doubly Linked List (DLL)** is an extension of the singly linked list where each node contains two pointers:

1. **Next Pointer**: Points to the next node.
2. **Previous Pointer**: Points to the previous node.

Characteristics

- Each node has **three parts**:
  1. **Data**
  2. **Pointer to the Next Node**
  3. **Pointer to the Previous Node**
- The list starts with a **head** and ends with a **tail**.
- It allows **both forward and backward traversal**.

Operations

1. **Insertion**: A node can be added at the beginning, middle, or end, adjusting both next and prev pointers.
2. **Deletion**: A node can be removed by updating both pointers in neighboring nodes.
3. **Traversing**: The list can be traversed in both forward and backward directions.

Advantages
Faster traversal as it supports **both directions**.
More efficient deletion since we have direct access to the previous node.
Disadvantages
Requires **extra memory** due to the additional pointer in each node.
Insertion and deletion involve updating two pointers, making it slightly more complex.

3. Circular Linked List
Definition
A **Circular Linked List (CLL)** is a variation of the singly or doubly linked list where the last node points back to the first node instead of null, forming a **circular structure**.
Types of Circular Linked Lists

1. **Singly Circular Linked List**: The last node's next pointer connects to the head node.
2. **Doubly Circular Linked List**: Both next and prev pointers form a circular connection.

Characteristics

- There is **no null at the end**; the last node links back to the first.
- Can be implemented as **singly or doubly linked**.
- Traversal can start from **any node** and continue indefinitely.

Operations

1. **Insertion**: A new node can be added at any position while maintaining the circular structure.
2. **Deletion**: A node can be removed, adjusting pointers to maintain continuity.
3. **Traversing**: Since there is no null, traversal stops when we reach the starting node again.

Advantages
Efficient for **buffered or cyclic operations** (e.g., scheduling algorithms).
Can be traversed infinitely without needing to restart.
Disadvantages
More complex than singly and doubly linked lists.
Risk of **infinite loops** if not handled properly.

Comparison Table

Feature	Singly Linked List	Doubly Linked List	Circular Linked List
Memory Usage	Low (1 pointer per node)	Medium (2 pointers per node)	Medium (depends on type)
Traversal Direction	Forward Only	Forward & Backward	Forward (or both if doubly)
Insertion Complexity	O(1) (at head), O(n) (elsewhere)	O(1) (at head), O(n) (elsewhere)	O(1) (at head), O(n) (elsewhere)
Deletion Complexity	O(1) at head, O(n) elsewhere	O(1) if node reference is given	O(1) at head, O(n) elsewhere
Circular Structure	No	No	Yes
Best Use Cases	Simple, linear data storage	Doubly connected data traversal	Cyclic tasks, scheduling

Table 2.1 Comparison Table Linked Lists and their operations

CODE :

```
/ Singly Linked List Implementation

class SinglyLinkedList {
    class Node {
        int data;
        Node next;
        Node(int data) {
            this.data = data;
            this.next = null;
        }
    }

    private Node head;

    public void insert(int data) {
        Node newNode = new Node(data);
        if (head == null) {
            head = newNode;
            return;
        }
        Node temp = head;
        while (temp.next != null) {
            temp = temp.next;
        }
        temp.next = newNode;
    }

    public void delete(int key) {
```

```
        if (head == null) return;
        if (head.data == key) {
            head = head.next;
            return;
        }
        Node temp = head;
        while (temp.next != null && temp.next.data != key) {
            temp = temp.next;
        }
        if (temp.next != null) temp.next = temp.next.next;
    }

    public void traverse() {
        Node temp = head;
        while (temp != null) {
            System.out.print(temp.data + " -> ");
            temp = temp.next;
        }
        System.out.println("NULL");
    }
}
```

// Doubly Linked List Implementation

```
class DoublyLinkedList {
    class Node {
        int data;
        Node prev, next;
        Node(int data) {
            this.data = data;
        }
    }

    private Node head;

    public void insert(int data) {
        Node newNode = new Node(data);
        if (head == null) {
            head = newNode;
            return;
        }
        Node temp = head;
        while (temp.next != null) {
            temp = temp.next;
        }
        temp.next = newNode;
        newNode.prev = temp;
    }
```

```
    public void delete(int key) {
        if (head == null) return;
        if (head.data == key) {
            head = head.next;
            if (head != null) head.prev = null;
            return;
        }
        Node temp = head;
        while (temp != null && temp.data != key) {
            temp = temp.next;
        }
        if (temp == null) return;
        if (temp.next != null) temp.next.prev = temp.prev;
        if (temp.prev != null) temp.prev.next = temp.next;
    }

    public void traverse() {
        Node temp = head;
        while (temp != null) {
            System.out.print(temp.data + " <-> ");
            temp = temp.next;
        }
        System.out.println("NULL");
    }
}
```

// Circular Linked List Implementation

```
class CircularLinkedList {
    class Node {
        int data;
        Node next;
        Node(int data) {
            this.data = data;
        }
    }

    private Node last;

    public void insert(int data) {
        Node newNode = new Node(data);
        if (last == null) {
            last = newNode;
            last.next = last;
            return;
        }
        newNode.next = last.next;
        last.next = newNode;
        last = newNode;
```

```java
    }

    public void delete(int key) {
        if (last == null) return;
        if (last == last.next && last.data == key) {
            last = null;
            return;
        }
        Node temp = last;
        do {
            if (temp.next.data == key) {
                temp.next = temp.next.next;
                if (last.data == key) last = temp;
                return;
            }
            temp = temp.next;
        } while (temp != last);
    }

    public void traverse() {
        if (last == null) {
            System.out.println("List is empty");
            return;
        }
        Node temp = last.next;
        do {
            System.out.print(temp.data + " -> ");
            temp = temp.next;
        } while (temp != last.next);
        System.out.println("(back to head)");
    }
}
```

TEST

```
// Main Class to Test the Linked List Implementations
public class LinkedListDemo {
    public static void main(String[] args) {
        System.out.println("Singly Linked List:");
        SinglyLinkedList sll = new SinglyLinkedList();
        sll.insert(10);
        sll.insert(20);
        sll.insert(30);
        sll.traverse();
        sll.delete(20);
        sll.traverse();

        System.out.println("\nDoubly Linked List:");
        DoublyLinkedList dll = new DoublyLinkedList();
        dll.insert(40);
        dll.insert(50);
        dll.insert(60);
        dll.traverse();
        dll.delete(50);
        dll.traverse();

        System.out.println("\nCircular Linked List:");
        CircularLinkedList cll = new CircularLinkedList();
        cll.insert(70);
        cll.insert(80);
        cll.insert(90);
        cll.traverse();
        cll.delete(80);
        cll.traverse();
    }
}
```

OUTPUT :

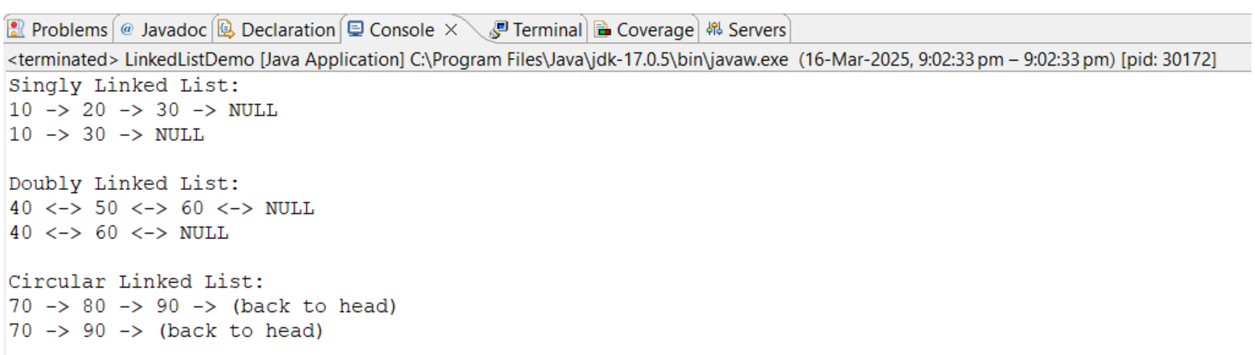


Fig 2.1 Output Linked Lists and their operations

Performance Analysis:

Operation	Singly Linked List	Doubly Linked List	Circular Linked List
Insertion at beginning	O(1)	O(1)	O(1)
Insertion at end	O(n)	O(n)	O(1) (if tail is maintained)
Insertion at middle	O(n)	O(n)	O(n)
Deletion at beginning	O(1)	O(1)	O(1)
Deletion at end	O(n)	O(n)	O(n)
Deletion at middle	O(n)	O(n)	O(n)
Searching (Linear)	O(n)	O(n)	O(n)
Searching (Binary)	Not possible	Not possible	Not possible
Forward Traversal	O(n)	O(n)	O(n)
Backward Traversal	Not possible	O(n)	O(n) (Doubly Circular Only)

Table 2.2 Performance Analysis Linked Lists and their operations

Use Case	Recommended Linked List
Simple insertions/deletions at the start	Singly Linked List
Frequent forward and backward traversals	Doubly Linked List
Cyclic operations like CPU scheduling	Circular Linked List

Table 2.2 Use Case Linked Lists and their operations

Conclusion

Singly Linked List (SLL)

Efficient for **insertions and deletions at the beginning** (**O(1)**).
Inefficient for searching and inserting/deleting at the end (**O(n)**).
Best suited for **stack-like operations** (LIFO structures).

Doubly Linked List (DLL)

More versatile with **bidirectional traversal**.
Slightly **higher memory overhead** due to two pointers per node.
Best for **applications needing both forward and backward traversal** (e.g., browser history, undo/redo functionality).

Circular Linked List (CLL)

Eliminates null references and improves **end insertions (O(1))**.
Efficient in **cyclic applications** like **CPU scheduling, music playlists, and round-robin execution**.
Slightly **complex to implement** compared to SLL and DLL.

Lab Experiment No. 3

AIM: Compare Arrays with Linked Lists and analyse their performance in different scenarios.

Background:

An **Array** and a **Linked List** are two fundamental data structures used to store collections of elements.

- **Arrays** store elements in **contiguous memory locations** and allow **constant-time access** using indexing. However, their size is fixed once declared, making dynamic resizing costly.
- **Linked Lists** store elements dynamically using **nodes** that contain data and pointers to the next node. While they allow **efficient insertions and deletions**, they require extra memory for storing pointers and have **sequential access**, making searching slower.

Both have their advantages and disadvantages, depending on the **operation** and **use case**.

Scenario Best - Choice

Random Access Required - **Array**

Frequent Insertions/Deletions at Start/Middle - **Linked List**

Searching Large Sorted Data- - **Array (Binary Search)**

Memory-Efficient Structure - **Array**

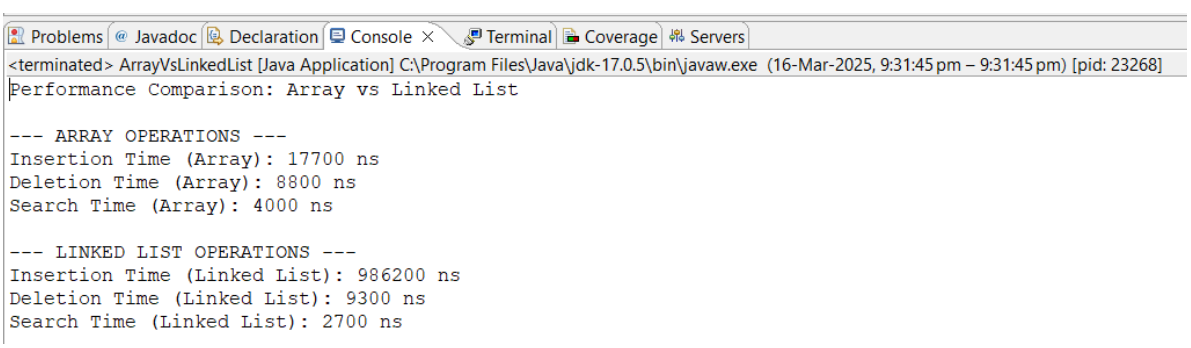
Dynamic Size Requirement - **Linked List**

CODE:

```
import java.util.*;

public class ArrayVsLinkedList {
    public static void main(String[] args) {
        System.out.println("Performance Comparison: Array vs Linked List");

        // Array Operations
        System.out.println("\n--- ARRAY OPERATIONS ---");
        List<Integer> arrayList = new ArrayList<>();

        long startTime = System.nanoTime();
        arrayList.add(0, 10);  // Insertion at the beginning (O(n))
        arrayList.add(20);     // Insertion at the end (O(1))
        arrayList.add(1, 15);  // Insertion at middle (O(n))
        long endTime = System.nanoTime();
        System.out.println("Insertion Time (Array): " + (endTime - startTime) + " ns");

        startTime = System.nanoTime();
        arrayList.remove(0);  // Deletion at the beginning (O(n))
        arrayList.remove(1);  // Deletion in the middle (O(n))
        arrayList.remove(arrayList.size() - 1); // Deletion at the end (O(1))
        endTime = System.nanoTime();
        System.out.println("Deletion Time (Array): " + (endTime - startTime) + " ns");
```

```
        startTime = System.nanoTime();
        arrayList.contains(15);  // Searching (O(n))
        endTime = System.nanoTime();
        System.out.println("Search Time (Array): " + (endTime - startTime) + " ns");

        // Linked List Operations
        System.out.println("\n--- LINKED LIST OPERATIONS ---");
        LinkedList<Integer> linkedList = new LinkedList<>();

        startTime = System.nanoTime();
        linkedList.addFirst(10);  // Insertion at the beginning (O(1))
        linkedList.addLast(20);   // Insertion at the end (O(1))
        linkedList.add(1, 15);    // Insertion at middle (O(n))
        endTime = System.nanoTime();
        System.out.println("Insertion Time (Linked List): " + (endTime - startTime) + " ns");

        startTime = System.nanoTime();
        linkedList.removeFirst();  // Deletion at the beginning (O(1))
        linkedList.remove(1);  // Deletion in the middle (O(n))
        linkedList.removeLast(); // Deletion at the end (O(1))
        endTime = System.nanoTime();
        System.out.println("Deletion Time (Linked List): " + (endTime - startTime) + " ns");

        startTime = System.nanoTime();
        linkedList.contains(15);  // Searching (O(n))
        endTime = System.nanoTime();
        System.out.println("Search Time (Linked List): " + (endTime - startTime) + " ns");
    }
}
```

Output :



```
Problems  Javadoc  Declaration  Console  Terminal  Coverage  Servers
<terminated> ArrayVsLinkedList [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe (16-Mar-2025, 9:31:45 pm – 9:31:45 pm) [pid: 23268]
Performance Comparison: Array vs Linked List

--- ARRAY OPERATIONS ---
Insertion Time (Array): 17700 ns
Deletion Time (Array): 8800 ns
Search Time (Array): 4000 ns

--- LINKED LIST OPERATIONS ---
Insertion Time (Linked List): 986200 ns
Deletion Time (Linked List): 9300 ns
Search Time (Linked List): 2700 ns
```

Fig 3.1 Output Compare Arrays with Linked Lists

Performance Analysis:

Operation	Array (Time Complexity)	Linked List (Time Complexity)	Remarks
Insertion at Beginning	O(n) (shifting required)	O(1)	Linked List is faster
Insertion at End	O(1) (if space available) / O(n) (if resizing needed)	O(n) (Singly LL), O(1) (if tail pointer is maintained)	Arrays are faster if no resizing
Insertion at Middle	O(n) (shifting required)	O(n) (traversal required)	Similar performance
Deletion at Beginning	O(n) (shifting required)	O(1)	Linked List is faster
Deletion at End	O(1) (if no resizing needed)	O(n) (Singly LL), O(1) (Doubly LL with tail)	Arrays are generally better
Deletion at Middle	O(n) (shifting required)	O(n) (traversal required)	Similar performance
Accessing Elements (Search by Index)	O(1) (direct indexing)	O(n) (sequential search)	Arrays are much faster
Searching for an Element	O(n) (Linear Search) / O(log n) (Binary Search for sorted array)	O(n) (Linear Search)	Arrays are better for sorted data
Memory Usage	Fixed Size, No Overhead	Extra memory for pointers	Arrays are memory-efficient

Table 3.1 Performance Analysis of Arrays vs Linked Lists

Conclusion :

Array
Fast access to elements (O(1)) via indexing.
Efficient **for small datasets** where resizing is not frequent.
Ideal for **sorting and searching** (Binary Search is possible in sorted arrays).
Not ideal for dynamic operations due to high-cost insertions and deletions in the middle or beginning (O(n)).
Linked List
Fast insertions and deletions (O(1)) at the beginning or middle.
Efficient memory allocation since it grows dynamically.
Best for applications requiring frequent insertions and deletions, like queues, stacks, and scheduling systems.
Not ideal for searching and accessing elements since it takes **O(n) time** for traversal.

Lab Experiment No. 4

Aim :

Implementation and analysis of Graph based single source shortest distance algorithms.

- Breadth first search
- Depth first search
- Dijkstra's algorithm
- Topological Sort
- Floyd–Warshall algorithm

Background:

A **graph** is a fundamental data structure used to model real-world relationships like road networks, social networks, and communication systems. Graph algorithms are essential for solving various shortest path problems. The key algorithms analyzed in this document are:

4.1 Breadth-First Search (BFS)

BFS is an algorithm used to traverse graphs level by level. It finds the shortest path in **unweighted graphs**. BFS is implemented using a **queue** and follows a **FIFO** approach.

4.2 Depth-First Search (DFS)

DFS explores as far as possible along a branch before backtracking. It is implemented using **recursion** or a **stack** and is useful in cycle detection, pathfinding, and connectivity checking.

4.3 Dijkstra's Algorithm

Dijkstra's Algorithm is used to find the shortest path from a **single source** to all other vertices in a graph with **non-negative weights**. It uses a **priority queue** (min-heap) for efficient processing.

4.4 Topological Sort

Topological Sorting is used for **Directed Acyclic Graphs (DAGs)** to determine the correct order of tasks or dependencies. It is commonly used in **task scheduling** and **course prerequisites resolution**.

4.5 Floyd–Warshall Algorithm

Floyd–Warshall Algorithm is an **all-pairs shortest path** algorithm that finds the shortest distance between **every pair of vertices** in a graph. It is a **dynamic programming** approach.

Code :

4.1 Breadth-First Search (BFS)

```
import java.util.*;

public class BFS {
    public static void bfsTraversal(Map<Integer, List<Integer>> graph, int startNode) {
        Queue<Integer> queue = new LinkedList<>();
        Set<Integer> visited = new HashSet<>();

        queue.add(startNode);
        visited.add(startNode);

        while (!queue.isEmpty()) {
            int node = queue.poll();
            System.out.print(node + " ");

            for (int neighbor : graph.getOrDefault(node, new ArrayList<>())) {
                if (!visited.contains(neighbor)) {
                    queue.add(neighbor);
                    visited.add(neighbor);
                }
            }
        }
    }

    public static void main(String[] args) {
        Map<Integer, List<Integer>> graph = new HashMap<>();
        graph.put(0, Arrays.asList(1, 2));
        graph.put(1, Arrays.asList(3, 4));
        graph.put(2, Arrays.asList(5, 6));
        graph.put(3, Arrays.asList());
        graph.put(4, Arrays.asList());
        graph.put(5, Arrays.asList());
        graph.put(6, Arrays.asList());

        System.out.println("BFS Traversal: ");
        bfsTraversal(graph, 0);
    }
}
```

4.2 Depth-First Search (DFS)

```
import java.util.*;

public class DFS {
   public static void dfsTraversal(Map<Integer, List<Integer>> graph, int node, Set<Integer> visited) {
      if (visited.contains(node)) return;

      visited.add(node);
      System.out.print(node + " ");

      for (int neighbor : graph.getOrDefault(node, new ArrayList<>())) {
         dfsTraversal(graph, neighbor, visited);
      }
   }

   public static void main(String[] args) {
      Map<Integer, List<Integer>> graph = new HashMap<>();
      graph.put(0, Arrays.asList(1, 2));
      graph.put(1, Arrays.asList(3, 4));
      graph.put(2, Arrays.asList(5, 6));

      System.out.println("DFS Traversal: ");
      dfsTraversal(graph, 0, new HashSet<>());
   }
}
```

4.3 Dijkstra’s Algorithm

```
import java.util.*;

class Dijkstra {
   public static void dijkstra(Map<Integer, List<int[]>> graph, int source) {
      PriorityQueue<int[]> pq = new PriorityQueue<>(Comparator.comparingInt(a -> a[1]));
      Map<Integer, Integer> distances = new HashMap<>();

      pq.add(new int[]{source, 0});
      distances.put(source, 0);

      while (!pq.isEmpty()) {
         int[] current = pq.poll();
         int node = current[0], cost = current[1];

         for (int[] neighbor : graph.getOrDefault(node, new ArrayList<>())) {
            int nextNode = neighbor[0], weight = neighbor[1];
            int newDist = cost + weight;
```

```
            if (newDist < distances.getOrDefault(nextNode, Integer.MAX_VALUE)) {
                distances.put(nextNode, newDist);
                pq.add(new int[]{nextNode, newDist});
            }
        }
    }

    System.out.println("Shortest distances: " + distances);
}

public static void main(String[] args) {
    Map<Integer, List<int[]>> graph = new HashMap<>();
    graph.put(0, Arrays.asList(new int[]{1, 4}, new int[]{2, 1}));
    graph.put(1, Arrays.asList(new int[]{3, 1}));
    graph.put(2, Arrays.asList(new int[]{1, 2}, new int[]{3, 5}));

    dijkstra(graph, 0);
}
}
```

4.4 Topological Sort

```
import java.util.*;

public class TopologicalSort {
    public static void topologicalSort(Map<Integer, List<Integer>> graph, int vertices) {
        int[] inDegree = new int[vertices];
        for (List<Integer> edges : graph.values()) {
            for (int node : edges) {
                inDegree[node]++;
            }
        }

        Queue<Integer> queue = new LinkedList<>();
        for (int i = 0; i < vertices; i++) {
            if (inDegree[i] == 0) queue.add(i);
        }

        while (!queue.isEmpty()) {
            int node = queue.poll();
            System.out.print(node + " ");

            for (int neighbor : graph.getOrDefault(node, new ArrayList<>())) {
                if (--inDegree[neighbor] == 0) {
                    queue.add(neighbor);
                }
            }
        }
    }

    public static void main(String[] args) {
```

```
        Map<Integer, List<Integer>> graph = new HashMap<>();
        graph.put(0, Arrays.asList(1, 2));
        graph.put(1, Arrays.asList(3));
        graph.put(2, Arrays.asList(3));

        System.out.println("Topological Sort: ");
        topologicalSort(graph, 4);
    }
}
```

4.5 Floyd–Warshall Algorithm

```
import java.util.*;

public class FloydWarshall {
    static final int INF = 99999;

    public static void floydWarshall(int[][] graph) {
        int V = graph.length;
        int[][] dist = Arrays.copyOf(graph, V);

        for (int k = 0; k < V; k++) {
            for (int i = 0; i < V; i++) {
                for (int j = 0; j < V; j++) {
                    if (dist[i][k] != INF && dist[k][j] != INF) {
                        dist[i][j] = Math.min(dist[i][j], dist[i][k] + dist[k][j]);
                    }
                }
            }
        }

        System.out.println("Shortest distances: " + Arrays.deepToString(dist));
    }

    public static void main(String[] args) {
        int[][] graph = {
            {0, 3, INF, INF},
            {INF, 0, 1, INF},
            {INF, INF, 0, 2},
            {INF, INF, INF, 0}
        };

        floydWarshall(graph);
    }
}
```

Output

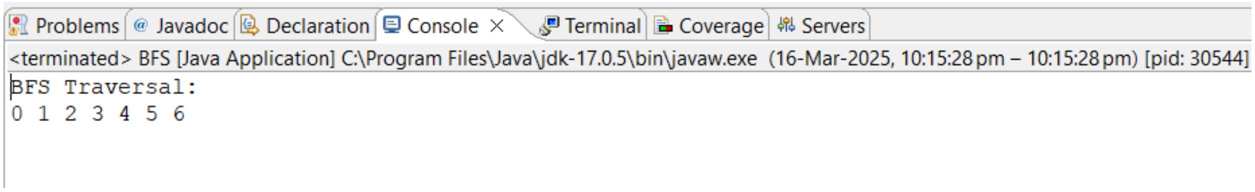


Fig4.1 Output Breadth-First Search (BFS)

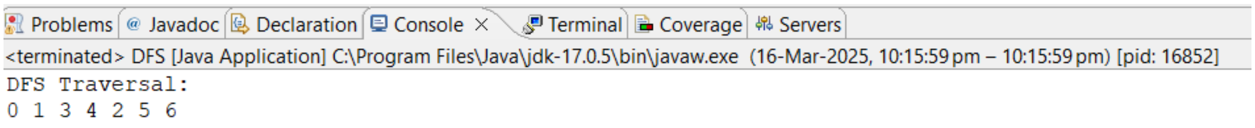


Fig 4.2 Output Depth-First Search (DFS)

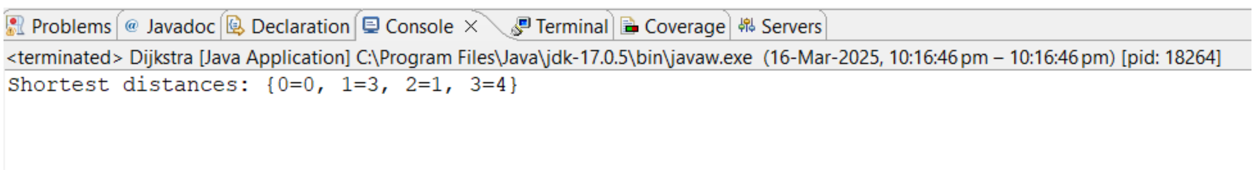


Fig 4.3 Output Dijkstra's Algorithm

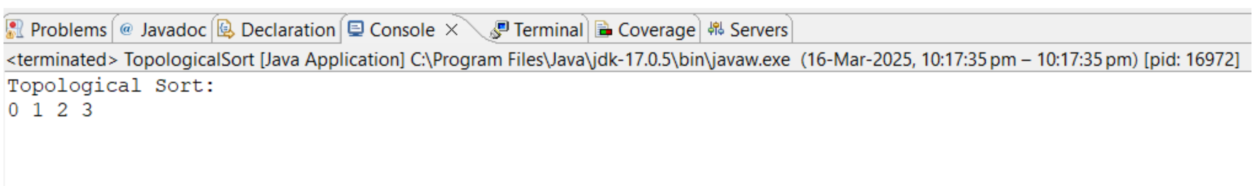


Fig 4.4 Output Topological Sort

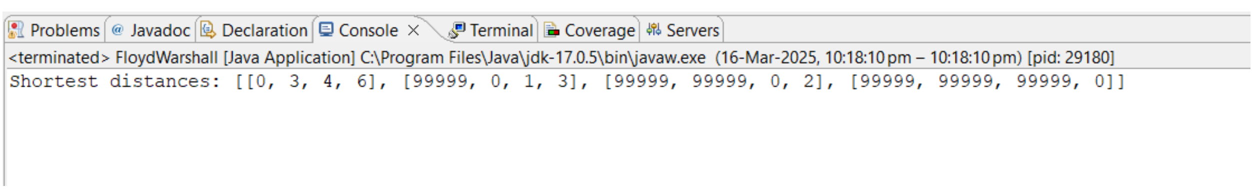


Fig 4.5 Output Floyd–Warshall Algorithm

Performance Analysis

The performance of each algorithm depends on the type of graph (sparse/dense), the number of vertices (V), and the number of edges (E). Below is a comparative analysis of the time and space complexity of each algorithm:

Algorithm	Time Complexity	Space Complexity	Best Used For
BFS	$O(V + E)$	$O(V)$	Finding the shortest path in an unweighted graph
DFS	$O(V + E)$	$O(V)$	Cycle detection, connectivity checking, and pathfinding
Dijkstra's	$O((V + E) \log V)$	$O(V + E)$	Single-source shortest path with non-negative weights
Topological Sort	$O(V + E)$	$O(V)$	Ordering tasks in DAGs
Floyd-Warshall	$O(V^3)$	$O(V^2)$	Finding shortest paths between all pairs of vertices

Table 4.1 Breadth first search ,Depth first search ,Dijkstra's algorithm , Topological , Sort Floyd–Warshall algorithm Performance Analysis

Detailed Analysis

1. BFS & DFS
   - Best for unweighted graphs.
   - BFS is efficient for shortest path in such graphs.
   - DFS is useful for cycle detection, topological sorting, and traversing graphs.
2. Dijkstra's Algorithm
   - Uses a priority queue (Min Heap) for efficiency.
   - Best for graphs with non-negative edge weights.
   - Suitable for sparse graphs, but inefficient for dense graphs.
3. Topological Sorting
   - Used for directed acyclic graphs (DAGs).
   - Helps in scheduling problems like course prerequisites.
4. Floyd-Warshall Algorithm
   - Computes the shortest path between every pair of nodes.
   - Takes $O(V^3)$ time, making it impractical for large graphs.
   - Best for small dense graphs.

Conclusion :

- BFS and DFS are fundamental graph traversal techniques. BFS is better for shortest paths in unweighted graphs, while DFS is more suited for connectivity problems.
- Dijkstra's Algorithm is the best single-source shortest path algorithm for graphs with non-negative weights, but it struggles in dense graphs.
- Topological Sort is useful only for DAGs and helps in task scheduling.
- Floyd-Warshall is a brute-force approach for shortest paths between all pairs but is only practical for small graphs due to its $O(V^3)$ complexity.

Lab Experiment No. 5

Aim:

1. Implementation and analysis of Priority Queues using arrays, linked list and heaps.

Background :

A Priority Queue is an abstract data type where each element has a priority, and elements are served based on their priority rather than their order of insertion. It follows either Max-Priority (highest priority dequeued first) or Min-Priority (lowest priority dequeued first).
Priority Queues can be implemented in different ways:

1. Using an Array – Simple but inefficient for priority-based insertions and deletions.
2. Using a Linked List – Can maintain a sorted order but still has linear-time complexity for some operations.
3. Using a Heap – Most efficient method, offering logarithmic time complexity for insertions and deletions.

CODE :

1. Priority Queue using Arrays

```
import java.util.Arrays;

class PriorityQueueArray {
    private int[] arr;
    private int size;

    public PriorityQueueArray(int capacity) {
        arr = new int[capacity];
        size = 0;
    }

    public void insert(int value) {
        if (size == arr.length) {
            System.out.println("Queue is full");
            return;
        }
        arr[size++] = value;
    }

    public int deleteMax() { // Max-priority queue
        if (size == 0) return -1;
        int maxIdx = 0;

        for (int i = 1; i < size; i++) {
            if (arr[i] > arr[maxIdx]) {
                maxIdx = i;
            }
        }
```

```
        int maxVal = arr[maxIdx];
        arr[maxIdx] = arr[--size]; // Replace max with last element
        return maxVal;
    }

    public void printQueue() {
        System.out.println("Queue: " + Arrays.toString(Arrays.copyOf(arr, size)));
    }

    public static void main(String[] args) {
        PriorityQueueArray pq = new PriorityQueueArray(5);
        pq.insert(3);
        pq.insert(5);
        pq.insert(1);
        pq.insert(4);

        pq.printQueue();
        System.out.println("Deleted max: " + pq.deleteMax());
        pq.printQueue();
    }
}
```

2. Priority Queue using Linked List

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

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

class PriorityQueueLinkedList {
    private Node head; // Head always holds the highest priority element

    public void insert(int value) {
        Node newNode = new Node(value);
        if (head == null || value > head.data) { // Insert at head if priority is highest
            newNode.next = head;
            head = newNode;
        } else {
            Node temp = head;
            while (temp.next != null && temp.next.data > value) {
                temp = temp.next;
            }
            newNode.next = temp.next;
            temp.next = newNode;
        }
    }
```

```
    public int deleteMax() {
        if (head == null) return -1;
        int maxValue = head.data;
        head = head.next; // Remove the highest priority element
        return maxValue;
    }

    public void printQueue() {
        Node temp = head;
        System.out.print("Queue: ");
        while (temp != null) {
            System.out.print(temp.data + " ");
            temp = temp.next;
        }
        System.out.println();
    }

    public static void main(String[] args) {
        PriorityQueueLinkedList pq = new PriorityQueueLinkedList();
        pq.insert(3);
        pq.insert(5);
        pq.insert(1);
        pq.insert(4);

        pq.printQueue();
        System.out.println("Deleted max: " + pq.deleteMax());
        pq.printQueue();
    }
}
```

Priority Queue using Heap (Binary Heap - Min Heap)

```
import java.util.PriorityQueue;

public class PriorityQueueHeap {
    public static void main(String[] args) {
        PriorityQueue<Integer> pq = new PriorityQueue<>(); // Min-Heap

        pq.add(3);
        pq.add(5);
        pq.add(1);
        pq.add(4);

        System.out.println("Priority Queue: " + pq);
        System.out.println("Deleted min: " + pq.poll()); // Removes smallest element
        System.out.println("Priority Queue after deletion: " + pq);
    }
```

Output:

```
<terminated> PriorityQueueArray [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe (16-Mar-2025, 11:40:59 pm – 11:40:59 pm) [pid: 8916]
Queue: [3, 5, 1, 4]
Deleted max: 5
Queue: [3, 4, 1]
```

Fig 5.1 Output Priority Queue using Arrays

```
Problems  Javadoc  Declaration  Console ×  Terminal  Coverage  Servers
<terminated> PriorityQueueLinkedList [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe (16-Mar-2025, 11:53:59 pm – 11:54:00 pm) [pid: 27636]
Queue: 5 4 3 1
Deleted max: 5
Queue: 4 3 1
```

Fig 5.2 Output Priority Queue using Linked List

```
Problems  Javadoc  Declaration  Console ×  Terminal  Coverage  Servers
<terminated> PriorityQueueHeap [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe (16-Mar-2025, 11:55:15 pm – 11:55:15 pm) [pid: 28040]
Priority Queue: [1, 4, 3, 5]
Deleted min: 1
Priority Queue after deletion: [3, 4, 5]
```

Fig 5.3. Output Priority Queue using Heap (Binary Heap - Min Heap)

Performance Analysis:

Implementation	**Insertion Time Complexity**	**Deletion Time Complexity**	**Space Complexity**
Array (Unsorted)	O(1)	O(n)	O(n)
Linked List	O(n)	O(1)	O(n)
Heap (Binary Heap)	O(log n)	O(log n)	O(n)

Table 5.1 Priority Queue Time Complexvity Analysis

Observations:

1. **Array-based PQ** is **fastest for insertion** but **slowest for deletion** (since finding the max/min takes O(n)).
2. **Linked List PQ** allows **fast deletion (O(1))** but **slow insertion** (O(n)).
3. **Heap-based PQ** offers **efficient insertion and deletion** (both O(log n)), making it **the best choice** for large-scale applications.

Conclusion

- **For small data sizes**, an **array-based priority queue** is simple to implement.
- **If deletion operations are more frequent**, a **linked list** implementation is preferred.
- **For large-scale applications**, a **heap-based priority queue** is the most efficient choice due to its logarithmic performance.

Lab Experiment No. 6

Aim:

Analyse the applications aspects of Skip Lists and compare with basic data structures..

Background :

A Skip List is a probabilistic data structure that allows fast searching, insertion, and deletion operations, making it an alternative to balanced trees like AVL trees or Red-Black trees. It extends a linked list by adding multiple layers that enable efficient binary search-like traversal.

Key Characteristics:

- Skip lists maintain multiple levels of linked lists, where higher levels "skip" more elements.
- The expected time complexity for search, insertion, and deletion is O(log n).
- They provide an alternative to self-balancing trees with a simpler implementation.

Applications of Skip Lists

Skip Lists are particularly useful in:

1. Databases (Indexing & Caching) – Used in database indexing (e.g., Redis) to store sorted key-value pairs.
2. Networking – Used in distributed systems (e.g., P2P networks) for routing.
3. Concurrent Programming – Skip lists allow efficient concurrent access compared to trees.
4. Graph Algorithms – Efficient for maintaining dynamic connectivity in graphs.
5. Memory Management – Used in garbage collection algorithms for efficient memory management.

Data Structure	Search Complexity	Insertion Complexity	Deletion Complexity	Space Complexity	Best Use Case
Skip List	O(log n)	O(log n)	O(log n)	O(n)	Efficient ordered list operations
Array	O(n)	O(n)	O(n)	O(n)	Simple but slow for dynamic operations
Linked List	O(n)	O(1) (at head)	O(1) (at head)	O(n)	Fast insertion/removal at ends
BST (Balanced)	O(log n)	O(log n)	O(log n)	O(n)	Fast searching and modifications
Hash Table	O(1) (average), O(n) (worst)	O(1) (avg)	O(1) (avg)	O(n)	Unordered key-value lookups

Table.6.1 Comparison with Other Data Structures

Observations

- Skip Lists and Balanced Trees (like AVL, Red-Black Trees) have O(log n) complexity, but Skip Lists are simpler to implement.
- Skip Lists outperform Linked Lists for searching but use more space.
- Hash Tables offer O(1) search on average but lack order, making Skip Lists better for sorted data.

CODE :

```
import java.util.Random;

class SkipListNode {
    int key;
    SkipListNode[] forward;

    public SkipListNode(int key, int level) {
        this.key = key;
        this.forward = new SkipListNode[level + 1]; // Array of forward pointers
    }
}

class SkipList {
    private static final int MAX_LEVEL = 16;
    private final double P = 0.5; // Probability factor
    private final Random random;
    private SkipListNode head;
    private int level;

    public SkipList() {
        this.head = new SkipListNode(-1, MAX_LEVEL);
        this.level = 0;
        this.random = new Random();
    }

    // Generate random level for a new node
    private int randomLevel() {
        int lvl = 0;
        while (random.nextDouble() < P && lvl < MAX_LEVEL) {
            lvl++;
        }
        return lvl;
    }

    // Insert a key into the Skip List
    public void insert(int key) {
        SkipListNode[] update = new SkipListNode[MAX_LEVEL + 1];
        SkipListNode curr = head;

        for (int i = level; i >= 0; i--) {
            while (curr.forward[i] != null && curr.forward[i].key < key) {
                curr = curr.forward[i];
            }
            update[i] = curr;
        }
```

```
        int newLevel = randomLevel();
        if (newLevel > level) {
            for (int i = level + 1; i <= newLevel; i++) {
                update[i] = head;
            }
            level = newLevel;
        }

        SkipListNode newNode = new SkipListNode(key, newLevel);
        for (int i = 0; i <= newLevel; i++) {
            newNode.forward[i] = update[i].forward[i];
            update[i].forward[i] = newNode;
        }
    }

    // Search for a key in the Skip List
    public boolean search(int key) {
        SkipListNode curr = head;
        for (int i = level; i >= 0; i--) {
            while (curr.forward[i] != null && curr.forward[i].key < key) {
                curr = curr.forward[i];
            }
        }
        curr = curr.forward[0];
        return curr != null && curr.key == key;
    }

    // Delete a key from the Skip List
    public void delete(int key) {
        SkipListNode[] update = new SkipListNode[MAX_LEVEL + 1];
        SkipListNode curr = head;

        for (int i = level; i >= 0; i--) {
            while (curr.forward[i] != null && curr.forward[i].key < key) {
                curr = curr.forward[i];
            }
            update[i] = curr;
        }

        curr = curr.forward[0];
        if (curr != null && curr.key == key) {
            for (int i = 0; i <= level; i++) {
                if (update[i].forward[i] != curr) break;
                update[i].forward[i] = curr.forward[i];
            }

            while (level > 0 && head.forward[level] == null) {
```

```
                level--;
            }
        }
    }

    // Print the Skip List
    public void printList() {
        for (int i = level; i >= 0; i--) {
            SkipListNode node = head.forward[i];
            System.out.print("Level " + i + ": ");
            while (node != null) {
                System.out.print(node.key + " ");
                node = node.forward[i];
            }
            System.out.println();
        }
    }

    public static void main(String[] args) {
        SkipList skipList = new SkipList();
        skipList.insert(3);
        skipList.insert(6);
        skipList.insert(7);
        skipList.insert(9);
        skipList.insert(12);
        skipList.insert(19);
        skipList.printList();
        System.out.println("Search 7: " + skipList.search(7));
        System.out.println("Search 15: " + skipList.search(15));

        skipList.delete(6);
        System.out.println("After deletion of 6:");
        skipList.printList();
    }
}
```

OUTPUT :

```
Problems  Javadoc  Declaration  Console  Terminal  Coverage  Servers
<terminated> SkipList [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe  (17-Mar-2025, 12:04:20 am – 12:04:21 am) [pid: 10164]
Level 3: 7
Level 2: 7
Level 1: 7
Level 0: 3 6 7 9 12 19
Search 7: true
Search 15: false
After deletion of 6:
Level 3: 7
Level 2: 7
Level 1: 7
Level 0: 3 7 9 12 19
```

Fig 6.1 Output Skip List in Java

Performance Analysis of Skip Lists

Operation	Average Complexity	Worst-Case Complexity
Search	O(log n)	O(n)
Insertion	O(log n)	O(n)
Deletion	O(log n)	O(n)

Table 6.1 Analysis of Skip Lists

Average case: **O(log n)** due to the layered structure that allows efficient traversal.
Worst case: **O(n)** occurs when the randomization fails (rare case).

Conclusion

- **Skip Lists** are an alternative to balanced trees, providing efficient **O(log n)** performance for search, insert, and delete.
- They **require extra space** due to multiple layers but have simpler implementation than AVL or Red-Black trees.
- **Best used for** scenarios where ordered data retrieval is needed (e.g., **databases, caches, distributed systems**).
- **Not ideal** when memory is a constraint, as it requires extra pointers.

Lab Experiment No. 7

Aim:

Analyse the applications aspects of Splay Trees and compare with basic data structures

Background :

A Splay Tree is a self-adjusting binary search tree (BST) that improves performance by moving frequently accessed elements closer to the root through a process called splaying. This helps in optimizing the access time for frequently used elements, making Splay Trees useful for caching, memory management, and dynamic sets.

Key Characteristics:

- Self-adjusting BST: Every time a node is accessed, it is moved to the root using splaying.
- No explicit balancing like AVL or Red-Black Trees.
- Faster access to recently used elements (temporal locality).
- Amortized time complexity: O(log n) for search, insertion, and deletion.

Applications of Splay Trees

Splay Trees are used in scenarios where frequent access to recently used elements is required, including:

1. Memory Caching – Used in operating systems (OS) and web browsers to manage frequently accessed data efficiently.
2. Garbage Collection – Helps in tracking memory allocation and deallocation.
3. Network Routing – Used in dynamic network routing for quick updates of frequently accessed routes.
4. Database Systems – Improves efficiency of indexing and key-value storage.
5. File Systems – Used in Unix file system page management for fast access to recently used files.

Comparison with Other Data Structures

Data Structure	Search Complexity	Insertion Complexity	Deletion Complexity	Self-Balancing?	Best Use Case
Splay Tree	O(log n) (amortized)	O(log n) (amortized)	O(log n) (amortized)	Yes (self-adjusting)	Caching & frequently accessed elements
AVL Tree	O(log n)	O(log n)	O(log n)	Yes (strict balancing)	Search-heavy applications
Red-Black Tree	O(log n)	O(log n)	O(log n)	Yes (looser balancing)	Dynamic ordered data operations
Binary Search Tree (BST)	O(n) worst	O(n) worst	O(n) worst	No	Simple implementation
Skip List	O(log n)	O(log n)	O(log n)	No explicit balancing	Probabilistic alternative to trees
Hash Table	O(1) (average), O(n) worst	O(1) avg	O(1) avg	No	Fast key-value lookup

Table 7.1 Comparison with Other Data Structures

Observations:

- Splay Trees provide O(log n) complexity in amortized cases, making them faster than regular BSTs but slightly less predictable than AVL trees.
- Unlike AVL and Red-Black Trees, Splay Trees do not maintain strict balancing, but they self-adjust based on access patterns.
- Skip Lists and Hash Tables are alternatives but do not support order-based operations efficiently.

CODE:

```
class SplayTree {
  class Node {
    int key;
    Node left, right;

    public Node(int key) {
      this.key = key;
      this.left = this.right = null;
    }
  }

  private Node root;

  // Right Rotation
  private Node rightRotate(Node x) {
    Node y = x.left;
    x.left = y.right;
    y.right = x;
    return y;
  }

  // Left Rotation
  private Node leftRotate(Node x) {
    Node y = x.right;
    x.right = y.left;
    y.left = x;
    return y;
  }

  // Splaying operation: Moves a given key to the root
  private Node splay(Node root, int key) {
    if (root == null || root.key == key) return root;

    // Left subtree case
    if (key < root.key) {
      if (root.left == null) return root;

      if (key < root.left.key) { // Zig-Zig (Left Left)
        root.left.left = splay(root.left.left, key);
        root = rightRotate(root);
      } else if (key > root.left.key) { // Zig-Zag (Left Right)
        root.left.right = splay(root.left.right, key);
        if (root.left.right != null)
```

```
            root.left = leftRotate(root.left);
        }
        return (root.left == null) ? root : rightRotate(root);
    }
    // Right subtree case
    else {
        if (root.right == null) return root;

        if (key > root.right.key) { // Zag-Zag (Right Right)
            root.right.right = splay(root.right.right, key);
            root = leftRotate(root);
        } else if (key < root.right.key) { // Zag-Zig (Right Left)
            root.right.left = splay(root.right.left, key);
            if (root.right.left != null)
                root.right = rightRotate(root.right);
        }
        return (root.right == null) ? root : leftRotate(root);
    }
}

// Insert operation
public void insert(int key) {
    if (root == null) {
        root = new Node(key);
        return;
    }
    root = splay(root, key);
    if (root.key == key) return;

    Node newNode = new Node(key);
    if (key < root.key) {
        newNode.right = root;
        newNode.left = root.left;
        root.left = null;
    } else {
        newNode.left = root;
        newNode.right = root.right;
        root.right = null;
    }
    root = newNode;
}

// Search operation
public boolean search(int key) {
    root = splay(root, key);
    return root != null && root.key == key;
}

// Delete operation
public void delete(int key) {
    if (root == null) return;
    root = splay(root, key);
```

```
        if (root.key != key) return;

        if (root.left == null) {
            root = root.right;
        } else {
            Node temp = root.right;
            root = splay(root.left, key);
            root.right = temp;
        }
    }

    // Preorder traversal
    public void preOrder(Node root) {
        if (root != null) {
            System.out.print(root.key + " ");
            preOrder(root.left);
            preOrder(root.right);
        }
    }

    public void printTree() {
        preOrder(root);
        System.out.println();
    }

    public static void main(String[] args) {
        SplayTree tree = new SplayTree();
        tree.insert(10);
        tree.insert(20);
        tree.insert(30);
        tree.insert(40);
        tree.insert(50);
        tree.insert(25);

        System.out.println("Splay Tree after insertions:");
        tree.printTree();

        System.out.println("Search for 30: " + tree.search(30));
        tree.printTree();

        System.out.println("Deleting 20...");
        tree.delete(20);
        tree.printTree();
    }
}
```

Output:

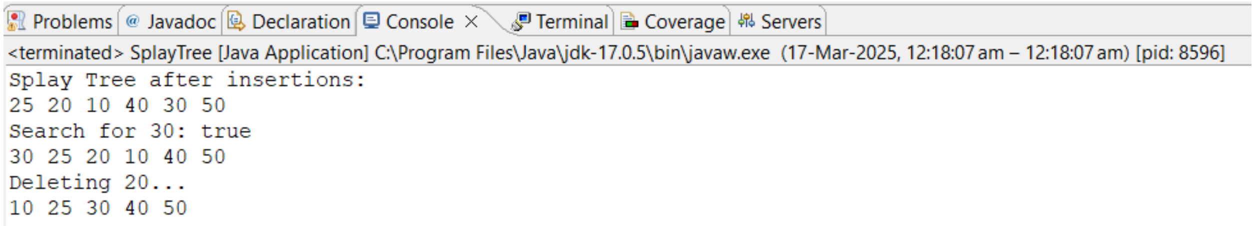


Fig7.1Output splay Tree operation

Performance Analysis of Splay Trees

Operation	Average Complexity	Worst-Case Complexity
Search	O(log n) (amortized)	O(n) (single access)
Insertion	O(log n) (amortized)	O(n) (worst)
Deletion	O(log n) (amortized)	O(n) (worst)

Table 7.1 Performance Analysis of Splay Trees

- **Amortized time complexity** is **O(log n)** for most operations due to self-adjustment.
- **Worst-case complexity** is **O(n)** if access patterns are unfavorable (like a sorted insertion sequence without rotations).

Conclusion:

- **Splay Trees** are useful for **frequently accessed elements** due to self-adjusting behavior.
- They are **simpler than AVL trees** but lack strict balancing.
- **Ideal for caching, dynamic operations, and memory management**.
- **Not ideal for uniformly random access patterns**, where AVL or Red-Black Trees may be better.