RAJALAKSHMI ENGINEERING COLLEGE

An Autonomous Institution, Affiliated to Anna University Rajalakshmi Nagar, Thandalam – 602 105

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

CP23131 – ADVANCED DATA STRUCTURES

(*Regulation 2023*)

LAB MANUAL

Name	: .....
Register No.	: .....
Year / Branch / Section	: .....
Semester	: .....
Academic Year	: .....

RAJALAKSHMI ENGINEERING COLLEGE

An Autonomous Institution, Affiliated to Anna University Rajalakshmi Nagar, Thandalam – 602 105

BONAFIDE CERTIFICATE

Name : Mr/Ms/Mrs

Academic Year : **2025-2027** Semester : **01**

Branch : **Computer Science and Engineering**

Register No.

Certified that this is the Bonafide record of work done by the above student in the ***Advanced Data Structure*** *Laboratory during the year* ***20 25- 20 27***

Signature of Faculty in-charge

Submitted for the Practical Examination held on . . . . . .
. . . . . .

Internal Examiner External Examiner

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Ex. No.:01	Implementation of graph search algorithms.	Date:

AIM :

TO develop a c program that implements a binary search tree (bst) with operations for insertion, deletion, and search, using a menu-driven approach.

procedure

1. Start the program.
2. Define a structure for bst node with key, left, and right pointers.
3. Implement functions to:
    a. create a new node
    b. insert a node
    c. search for a node
    d. delete a node
    e. find the minimum value node
4. int `main()`:
    a. initialize root to null.
    b. use a loop to display a menu and get user input.
    c. call appropriate functions based on the user's choice.
    d. repeat until user chooses to exit.
5. End the program.

PSEUDOCODE:

```
STRUCT Node
  int data
  Node left
  Node right
END STRUCT

FUNCTION Insert(root, key)
  IF root == NULL THEN
    root = NEW Node
    root.data = key
    root.left = NULL
    root.right = NULL
    RETURN root
  END IF

  IF key < root.data THEN
    root.left = Insert(root.left, key)
  ELSE
```

```
      root.right = Insert(root.right, key)
    END IF

    RETURN root
END FUNCTION

FUNCTION Search(root, key)
    IF root == NULL OR root.data == key THEN
      RETURN root
    END IF

    IF key < root.data THEN
      RETURN Search(root.left, key)
    ELSE
      RETURN Search(root.right, key)
    END IF
END FUNCTION

FUNCTION Inorder(root)
    IF root != NULL THEN
      Inorder(root.left)
      PRINT root.data
      Inorder(root.right)
    END IF
END FUNCTION

FUNCTION Preorder(root)
    IF root != NULL THEN
      PRINT root.data
      Preorder(root.left)
      Preorder(root.right)
    END IF
END FUNCTION



FUNCTION Postorder(root)
    IF root != NULL THEN
      Postorder(root.left)
      Postorder(root.right)
      PRINT root.data
    END IF
END FUNCTION
```

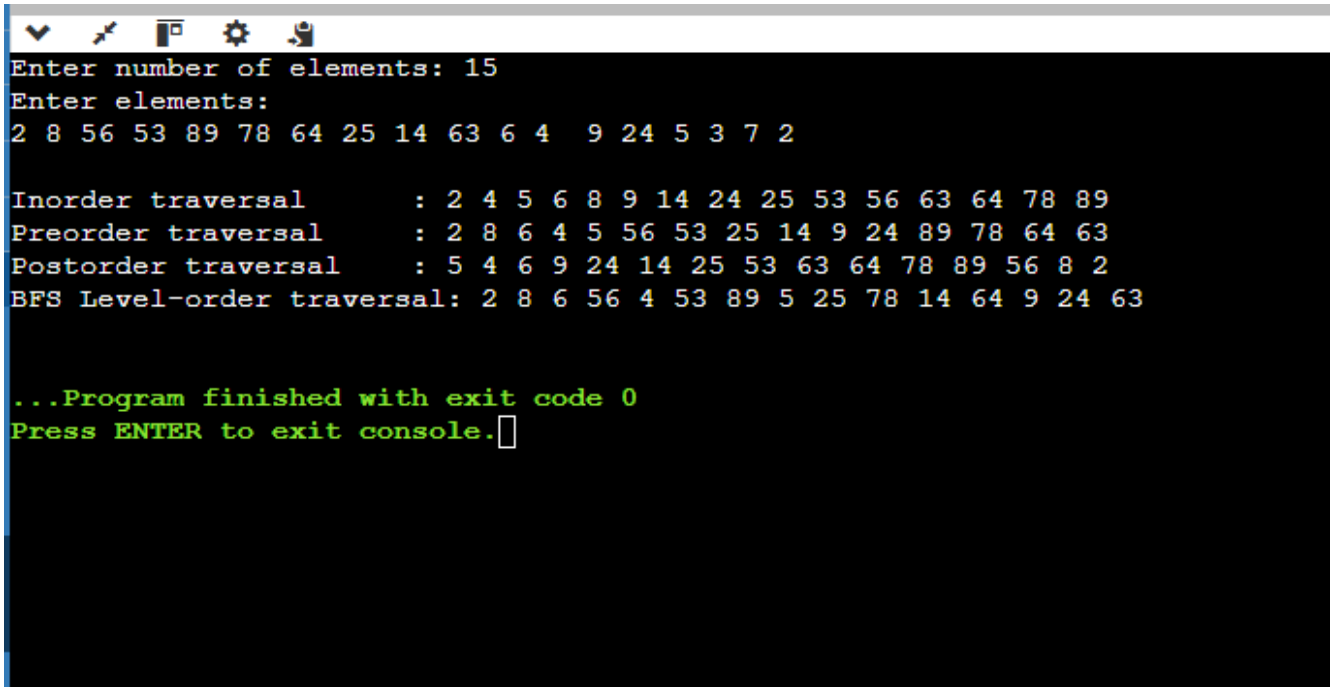
PROGRAM

```
#include <stdio.h>
#include <stdlib.h>

struct Node {
   int data;
   struct Node *left, *right;
};

// Create a new node
struct Node* createNode(int value) {
   struct Node* newNode = (struct Node*) malloc(sizeof(struct Node));
   newNode->data = value;
   newNode->left = newNode->right = NULL;
   return newNode;
}

// Insert a node in BST
struct Node* insert(struct Node* root, int value) {
   if (root == NULL)
      return createNode(value);

   if (value < root->data)
      root->left = insert(root->left, value);
   else if (value > root->data)
      root->right = insert(root->right, value);

   return root;
}

// Inorder Traversal (L, Root, R)
void inorder(struct Node* root) {
   if (root != NULL) {
      inorder(root->left);
      printf("%d ", root->data);
      inorder(root->right);
   }
}

// Preorder Traversal (Root, L, R)
void preorder(struct Node* root) {
   if (root != NULL) {
      printf("%d ", root->data);
      preorder(root->left);
```

```
        preorder(root->right);
    }
}

// Postorder Traversal (L, R, Root)
void postorder(struct Node* root) {
    if (root != NULL) {
        postorder(root->left);
        postorder(root->right);
        printf("%d ", root->data);
    }
}


// BFS (Level-Order Traversal)


// Simple queue for BFS
struct Node* queue[100];
int front = -1, rear = -1;

void enqueue(struct Node* node) {
    if (rear == 99) return; // queue full
    if (front == -1) front = 0;
    queue[++rear] = node;
}

struct Node* dequeue() {
    if (front == -1 || front > rear) return NULL;
    return queue[front++];
}

int isEmpty() {
    return (front == -1 || front > rear);
}

// BFS Traversal
void bfs(struct Node* root) {
    if (root == NULL) return;

    front = rear = -1; // reset queue
    enqueue(root);

    while (!isEmpty()) {
        struct Node* current = dequeue();
```

```
        printf("%d ", current->data);

        if (current->left)
            enqueue(current->left);

        if (current->right)
            enqueue(current->right);
    }
}


int main() {
    struct Node* root = NULL;
    int n, value;

    printf("Enter number of elements: ");
    scanf("%d", &n);

    printf("Enter elements:\n");
    for (int i = 0; i < n; i++) {
        scanf("%d", &value);
        root = insert(root, value);
    }

    printf("\nInorder traversal     : ");
    inorder(root);

    printf("\nPreorder traversal    : ");
    preorder(root);

    printf("\nPostorder traversal   : ");
    postorder(root);

    printf("\nBFS Level-order traversal: ");
    bfs(root);

    printf("\n");
    return 0;
}
```

OUTPUT



RESULT:

The c program for binary search tree (bst) was successfully implemented. the program allowed the user to insert, search, and delete nodes from the tree using a menu-driven interface. all operations were performed correctly, and the tree maintained its structure after each operation

Ex. No.:02	Implementation and application of network flow and linear programming problems	Date:

2.A NETWORK FLOW

FORD-FULKERSON MAXIMUM FLOW

AIM:

To develop a c program that implements the ford-fulkerson algorithm to find the maximum flow in a flow network using depth-first search (dfs).

ALGORITHM

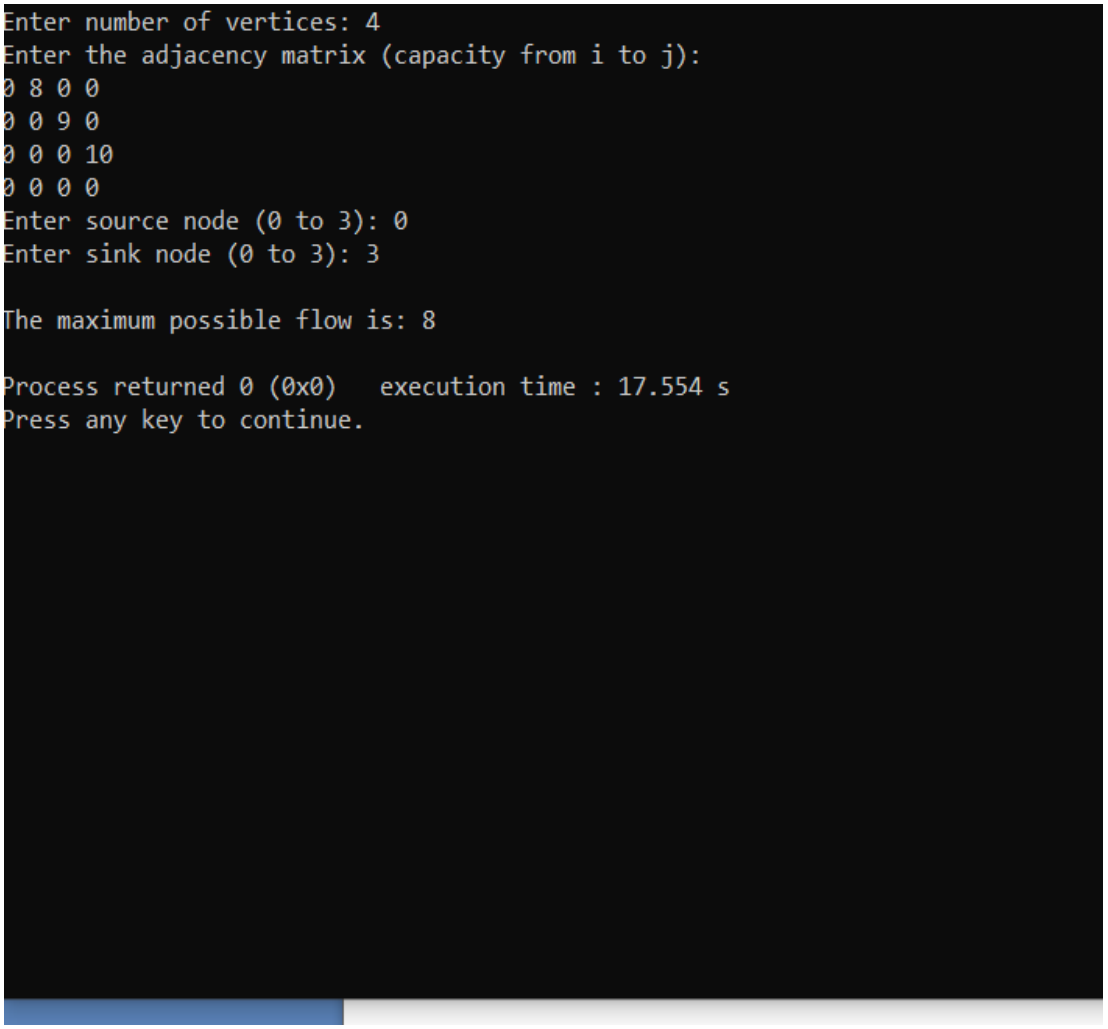
- start the program and input the number of vertices in the graph.
- create a 2d adjacency matrix to represent the capacities of edges between nodes.
- input the capacity values for each edge in the adjacency matrix.
- input the source node and sink node between which the maximum flow is to be found.
- initialize the residual graph as a copy of the original graph.
- use depth-first search (dfs) to find an augmenting path from the source to sink in the residual graph.
- if an augmenting path exists, find the minimum residual capacity (bottleneck) along this path.
- update the residual capacities of the edges and reverse edges along the path by subtracting the bottleneck capacity.
- add the bottleneck capacity to the total max flow.
- repeat the process until no more augmenting paths can be found.
- output the maximum flow value.
- end the program.

PSEUDOCODE

```
START

DEFINE CONSTANT MAX = 100
DECLARE INTEGER V  // NUMBER OF VERTICES

FUNCTION DFS(GRAPH, SOURCE, SINK, VISITED[], PARENT[]):
  VISITED[SOURCE] = TRUE
  IF SOURCE == SINK THEN
    RETURN TRUE
  FOR I = 0 TO V-1 DO
    IF VISITED[I] == FALSE AND GRAPH[SOURCE][I] > 0 THEN
      PARENT[I] = SOURCE
      IF DFS(GRAPH, I, SINK, VISITED, PARENT) == TRUE THEN
        RETURN TRUE
  RETURN FALSE

FUNCTION FORD_FULKERSON(GRAPH[MAX][MAX], SOURCE, SINK):
  CREATE RESIDUAL[MAX][MAX]
  COPY GRAPH INTO RESIDUAL
  INITIALIZE PARENT[] ARRAY
  MAXFLOW = 0

  WHILE TRUE DO
    INITIALIZE VISITED[] ARRAY WITH FALSE
    IF DFS(RESIDUAL, SOURCE, SINK, VISITED, PARENT) == FALSE THEN
      BREAK  // NO MORE AUGMENTING PATHS
    PATHFLOW = INFINITY
    // FIND MINIMUM RESIDUAL CAPACITY ALONG THE PATH FOUND BY DFS
    V = SINK
    WHILE V != SOURCE DO
      U = PARENT[V]
      IF RESIDUAL[U][V] < PATHFLOW THEN
        PATHFLOW = RESIDUAL[U][V]
      V = U
    // UPDATE RESIDUAL CAPACITIES OF EDGES AND REVERSE EDGES
    V = SINK
    WHILE V != SOURCE DO
      U = PARENT[V]
      RESIDUAL[U][V] = RESIDUAL[U][V] - PATHFLOW
      RESIDUAL[V][U] = RESIDUAL[V][U] + PATHFLOW
      V = U
    MAXFLOW = MAXFLOW + PATHFLOW
```

```
   RETURN MAXFLOW

MAIN:
   READ INTEGER V
   DECLARE GRAPH[MAX][MAX]
   FOR I = 0 TO V-1 DO
      FOR J = 0 TO V-1 DO
         READ GRAPH[I][J]

   READ SOURCE, SINK
   RESULT = FORD_FULKERSON(GRAPH, SOURCE, SINK)
   PRINT "MAXIMUM POSSIBLE FLOW:", RESULT

END
PROGRAM
#include <stdio.h>
#include <limits.h>
#include <stdbool.h>
#define MAX 100
int V;
bool dfs(int graph[MAX][MAX], int source, int sink, bool visited[], int parent[])
{
   visited[source] = true;
   if (source == sink) return true;
   for (int i = 0; i < V; i++)
      {
      if (!visited[i] && graph[source][i] > 0)
      {
         parent[i] = source;
         if (dfs(graph, i, sink, visited, parent))
         {
            return true;
         }
      }
   }
  return false;
}
int fordFulkerson(int graph[MAX][MAX], int source, int sink)
{
   int residual[MAX][MAX];
   int parent[MAX];
   int maxFlow = 0;
   for (int i = 0; i < V; i++)
      for (int j = 0; j < V; j++)
```

```
            residual[i][j] = graph[i][j];
        while (1)
        {
            bool visited[MAX] = {false};
            if (!dfs(residual, source, sink, visited, parent))
            break;
            int pathFlow = INT_MAX;
            for (int v = sink; v != source; v = parent[v])
            {
                int u = parent[v];
                if (residual[u][v] < pathFlow)
                    pathFlow = residual[u][v];
            }
            for (int v = sink; v != source; v = parent[v]) {
                int u = parent[v];
                residual[u][v] -= pathFlow;
                residual[v][u] += pathFlow;
            }
            maxFlow += pathFlow;
        }
        return maxFlow;
    }
    int main() {
        int graph[MAX][MAX];
        int source, sink;
        printf("Enter number of vertices: ");
        scanf("%d", &V);
        printf("Enter adjacency matrix (enter 0 if no edge):\n");
        for (int i = 0; i < V; i++)
        {
            for (int j = 0; j < V; j++)
            {
                scanf("%d", &graph[i][j]);
            }
        }

        printf("Enter source node (0 to %d): ", V - 1);
        scanf("%d", &source);
        printf("Enter sink node (0 to %d): ", V - 1);
        scanf("%d", &sink);
        int maxFlow = fordFulkerson(graph, source, sink);
        printf("Maximum possible flow: %d\n", maxFlow);
       return 0;
    }
```



RESULT

The program works correctly to find the maximum flow in a network it uses dfs to find paths and updates the capacities properly. the maximum flow value from the source to the sink is shown as expected. the program gives accurate results for different inputs.

B.LINEAR PROGRAMMING

INTERIOR POINT METHODS

Aim

To implement a **simple Interior Point Method (Barrier Method)** in C for solving a small **Linear Programming (LP)**

Algorithm

1. Start with an initial feasible point inside the region.
2. Choose a positive barrier parameter.
3. Define the barrier objective function.
4. Compute the gradient of the objective function.
5. Move in the negative gradient direction to reduce the objective value.
6. Adjust the step to satisfy all constraints.
7. Decrease the barrier parameter gradually.
8. Repeat the process until the solution becomes stable.
9. Stop when convergence is achieved and output the final result.

PSEUDOCODE

```
START

INITIALIZE X1 AND X2 WITH A FEASIBLE VALUE

INITIALIZE MU

WHILE MU > SMALL_VALUE DO

    FOR CERTAIN NUMBER OF ITERATIONS DO

        CALCULATE GRADIENTS

        COMPUTE STEP VALUES

        ADJUST STEP TO SATISFY CONSTRAINTS

        UPDATE X1 AND X2

        ENSURE X1 AND X2 ARE POSITIVE

    END FOR

    PRINT CURRENT MU, X1, X2
```

REDUCE MU

END WHILE

PRINT FINAL X1, X2, AND OBJECTIVE FUNCTION VALUE

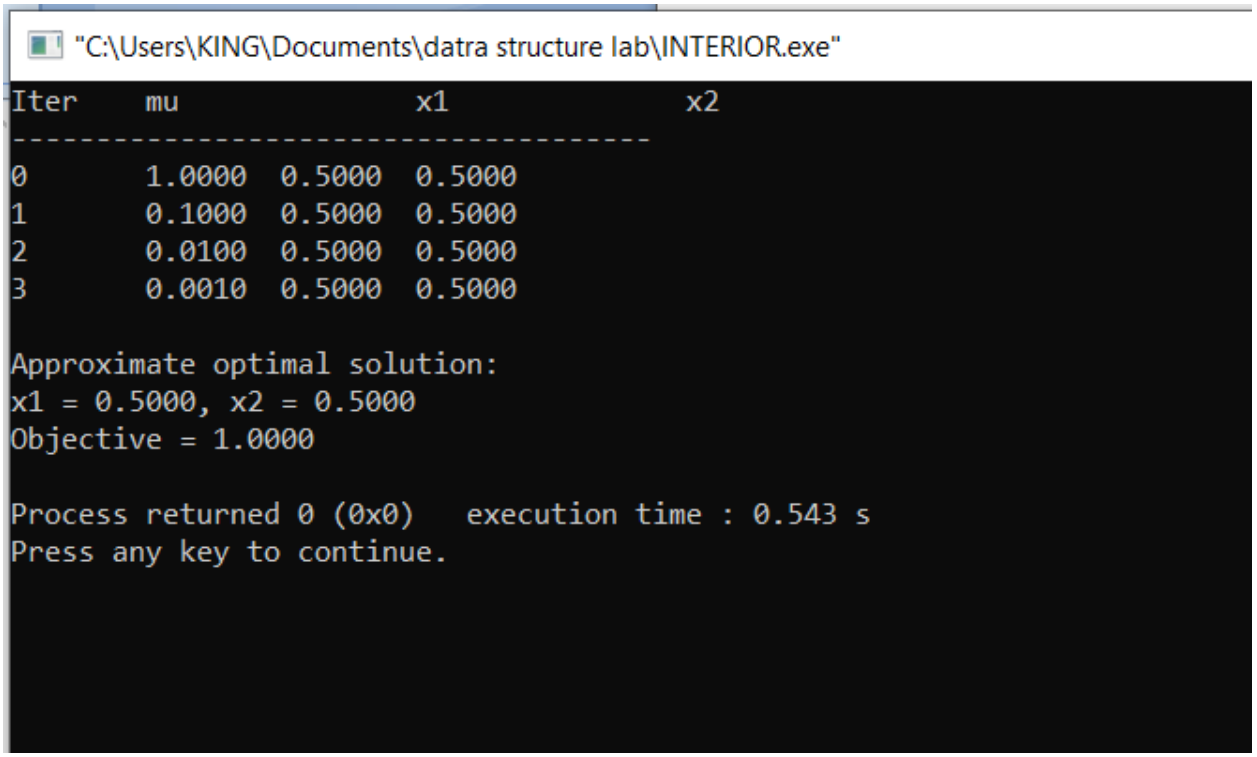
STOP

PROGRAM

```
#include <stdio.h>
#include <math.h>
int main() {
   // Example: minimize z = x1 + x2
   // subject to x1 + x2 = 1, and x1, x2 >= 0
   double x1 = 0.5, x2 = 0.5;   // start from a feasible interior point
   double mu = 1.0;            // barrier parameter
   double grad1, grad2;
   int iter = 0;
   printf("Iter\tmu\t\tx1\t\tx2\n");
   printf("-------------------------------------\n");
   // Loop until barrier term becomes very small
   while (mu > 1e-3) {
      for (int k = 0; k < 10; k++) {
         // Gradient of barrier function:
         // f(x) = x1 + x2 - mu*(ln x1 + ln x2)
         grad1 = 1 - mu / x1;
         grad2 = 1 - mu / x2;
         // Take a small step in negative gradient direction
         double dx1 = -grad1;
         double dx2 = -grad2;
         // Adjust direction so that x1 + x2 = 1 always holds
         double corr = (dx1 + dx2) / 2.0;
         dx1 -= corr;
         dx2 -= corr;
         // Update variables with a small step size
         x1 += 0.1 * dx1;
         x2 += 0.1 * dx2;
         // Ensure positivity (stay inside feasible region)
         if (x1 < 1e-6) x1 = 1e-6;
         if (x2 < 1e-6) x2 = 1e-6;
      }
      printf("%d\t%.4f\t%.4f\t%.4f\n", iter, mu, x1, x2);
      mu *= 0.1;   // decrease barrier parameter
```

```
        iter++;
    }
 printf("\nApproximate optimal solution:\n");
    printf("x1 = %.4f, x2 = %.4f\n", x1, x2);
    printf("Objective = %.4f\n", x1 + x2);
    return 0;
}
```

OUTPUT



RESULT:

The program ran successfully and found the optimal solution the method converges while staying inside the feasible region.

EXP .NO:03	Implementation of algorithms using dynamic programming techniques.	DATE:

3.A Longest Common Subsequence

Aim:

To find the **Longest Common Subsequence (LCS)** between two strings using **Dynamic Programming**, and display its **length** and the **subsequence itself**

Algorithm:

- **Start**
- **Input** two strings, `X` and `Y`.
- Find lengths of the strings: `m = length(X)`, `n = length(Y)`.
- Create a 2D array `L[m+1][n+1]` to store LCS lengths.
- **Initialize** first row and first column of `L` to 0.
- **Fill the table** using the rules:
  - If `X[i-1] == Y[j-1]` → `L[i][j] = L[i-1][j-1] + 1`
  - Else → `L[i][j] = max(L[i-1][j], L[i][j-1])`
- The **length of LCS** is `L[m][n]`.
- **Trace back** from `L[m][n]` to construct the **LCS string**:
  - If `X[i-1] == Y[j-1]` → include character in LCS and move diagonally.
  - Else → move to the larger of `L[i-1][j]` or `L[i][j-1]`.
- **Display** the LCS length and string.
- **Stop**

Pseudocode

```
BEGIN
  INPUT string X
  INPUT string Y
  m = length of X
  n = length of Y
```

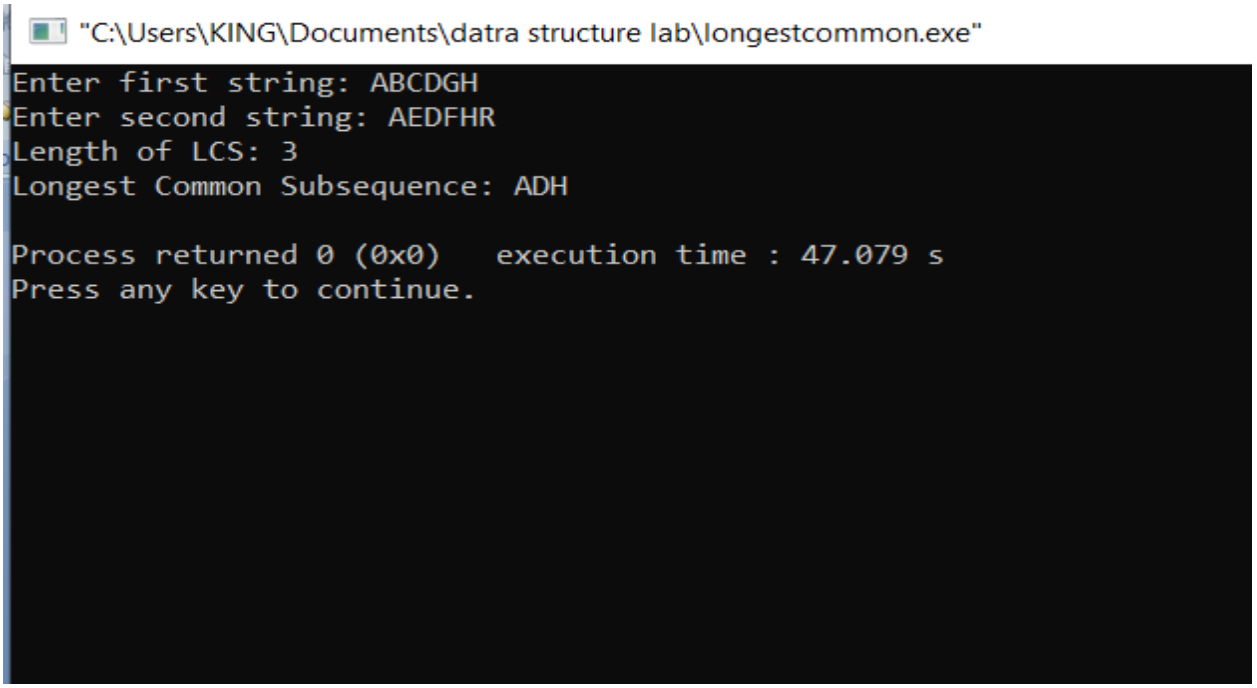
```
   DECLARE array L[m+1][n+1]
   // Fill LCS table
   FOR i = 0 TO m
      FOR j = 0 TO n
         IF i == 0 OR j == 0 THEN
            L[i][j] = 0
         ELSE IF X[i-1] == Y[j-1] THEN
            L[i][j] = L[i-1][j-1] + 1
         ELSE
            L[i][j] = max(L[i-1][j], L[i][j-1])
         PRINT "Length of LCS: ", L[m][n]
END
```

PROGRAM

```
#include <stdio.h>
#include <string.h>
int max(int a, int b) {
   return (a > b) ? a : b;
}
int main() {
   char X[100], Y[100];
   printf("Enter first string: ");
   scanf("%s", X);
   printf("Enter second string: ");
   scanf("%s", Y);
   int m = strlen(X);
   int n = strlen(Y);
   int L[m+1][n+1];
   // Build the LCS table using dynamic programming
   for (int i = 0; i <= m; i++) {
      for (int j = 0; j <= n; j++) {
         if (i == 0 || j == 0)
            L[i][j] = 0;
         else if (X[i-1] == Y[j-1])
            L[i][j] = L[i-1][j-1] + 1;
         else
            L[i][j] = max(L[i-1][j], L[i][j-1]);
      }
   }
   // Length of LCS
   printf("Length of LCS: %d\n", L[m][n]);
   // Reconstruct the LCS string
   int index = L[m][n];
   char lcsStr[index+1];
```

```
    lcsStr[index] = '\0';
    int i = m, j = n;
    while (i > 0 && j > 0) {
        if (X[i-1] == Y[j-1]) {
            lcsStr[index-1] = X[i-1];
            i--; j--; index--;
        } else if (L[i-1][j] > L[i][j-1])
            i--;
        else
            j--;
    }
    printf("Longest Common Subsequence: %s\n", lcsStr);
    return 0;
}
```

OUTPUT



RESULT:

The program successfully finds the **Longest Common Subsequence (LCS)** of two strings.
It displays both the **length** of the LCS and the **subsequence** itself.

3.B FIBONACCI SERIES

AIM:

To generate the **FIBONACCI SERIES** up to `n` terms using **Dynamic Programming**.

ALGORITHM:

1. **Start**
2. Input the number of terms `n`.
3. Declare an array `fib[n]` to store Fibonacci numbers.
4. Initialize the first two terms:
   - `fib[0] = 0`
   - `fib[1] = 1` (if n > 1)
5. Use a loop from 2 to n-1 to fill the array using:
   - `fib[i] = fib[i-1] + fib[i-2]`
6. Print the Fibonacci series from `fib[0]` to `fib[n-1]`.
7. **Stop**

PSEUDOCODE:

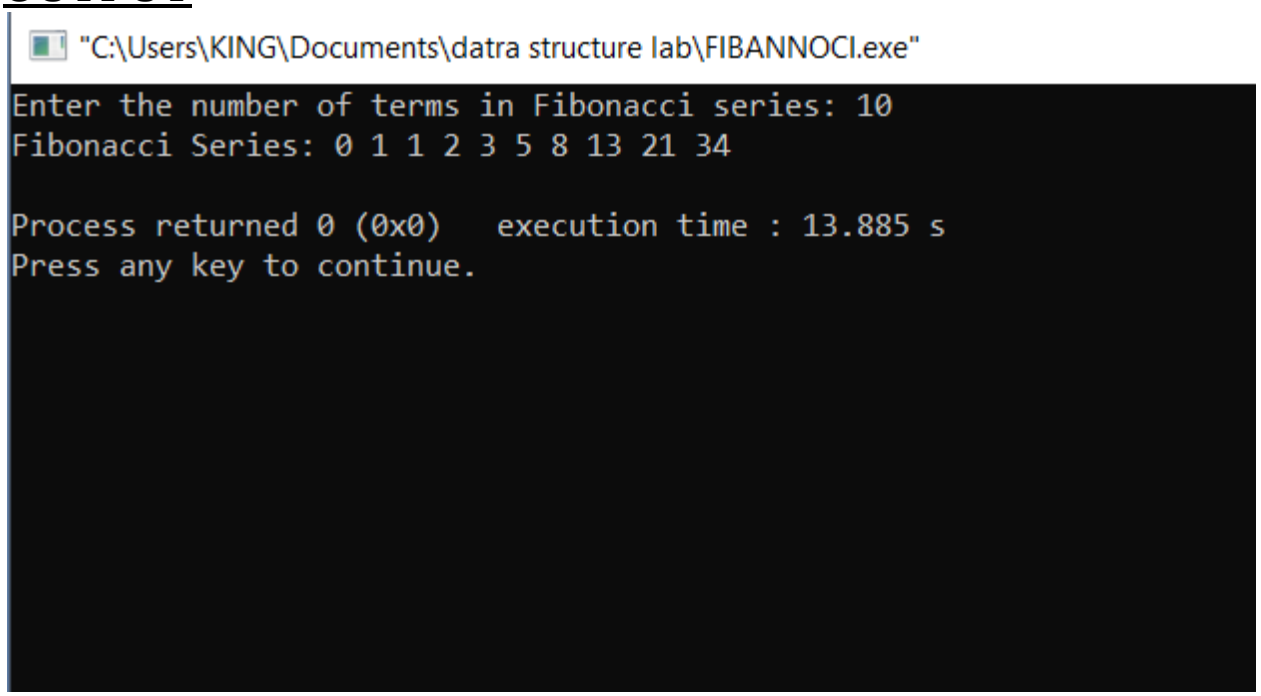
```
BEGIN
 INPUT n
   DECLARE array fib[0..n-1]
   IF n >= 1 THEN
      fib[0] = 0
   IF n >= 2 THEN
      fib[1] = 1
   FOR i = 2 TO n-1 DO
      fib[i] = fib[i-1] + fib[i-2]
   PRINT "FIBONACCI SERIES: "
   FOR i = 0 TO n-1 DO
      PRINT fib[i]
END
```

PROGRAM

```
#include <stdio.h>
int main() {
   int n;
   printf("Enter the number of terms in Fibonacci series: ");
   scanf("%d", &n);
   if (n <= 0) {
      printf("Please enter a positive number.\n");
      return 0;
   }
```

```
    long long fib[n];  // Array to store Fibonacci numbers
    fib[0] = 0;
    if (n > 1)
        fib[1] = 1;
    // Fill the Fibonacci series using DP
    for (int i = 2; i < n; i++) {
        fib[i] = fib[i-1] + fib[i-2];
    }
    printf("Fibonacci Series: ");
    for (int i = 0; i < n; i++) {
        printf("%lld ", fib[i]);
    }
    printf("\n");
 return 0;
}
```

OUTPUT



RESULT:

The program successfully generates the **FIBONACCI SERIES** of any given number of terms using **Dynamic Programming**

EXP.NO:04	Implementation of recursive backtracking algorithm	DATE:

4.A 8-Queens problem

AIM:

To solve the **8-Queens problem** and display all possible solutions using **recursive backtracking**.

ALGORITHM:

1. **Start**
2. Initialize an 8×8 chessboard with all zeros.
3. Place queens column by column starting from the first column.
4. For each column, try placing a queen in every row:
    - Check if the position is safe (no other queen attacks it).
    - If safe, place the queen and move to the next column (recursive call).
    - If not safe or no solution ahead, backtrack (remove the queen).
5. Repeat until all queens are placed.
6. Print the board when a solution is found.
7. Count the total number of solutions.
8. **Stop**

PSEUDOCODE:

```
BEGIN

  DEFINE N = 8

  DECLARE board[N][N] = {0}

  DECLARE solutionCount = 0

 FUNCTION isSafe(board, row, col)

    FOR i = 0 TO col-1

      IF board[row][i] == 1 RETURN false

    FOR (i,j) = (row,col) TO upper-left diagonal

      IF board[i][j] == 1 RETURN false

    FOR (i,j) = (row,col) TO lower-left diagonal
```

```
        IF board[i][j] == 1 RETURN false
      RETURN true
  END FUNCTION
 FUNCTION solveNQueensUtil(board, col, solutionCount)
      IF col >= N
        PRINT board
        solutionCount = solutionCount + 1
        RETURN
      FOR row = 0 TO N-1
        IF isSafe(board, row, col)
          board[row][col] = 1
          CALL solveNQueensUtil(board, col+1, solutionCount)
          board[row][col] = 0
  END FUNCTION
  CALL solveNQueensUtil(board, 0, solutionCount)
  PRINT "Total solutions:", solutionCount
END
```

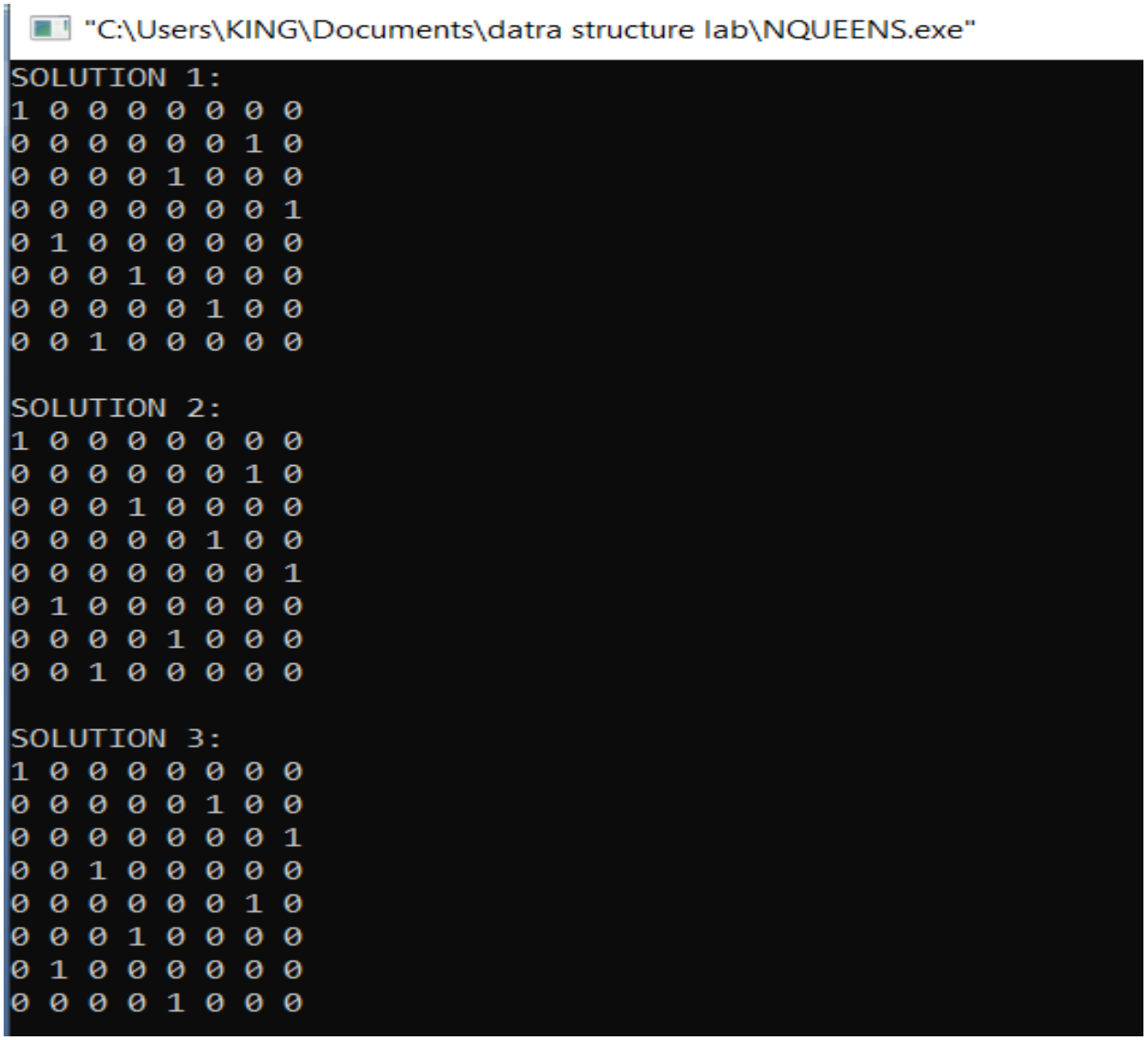
PROGRAM

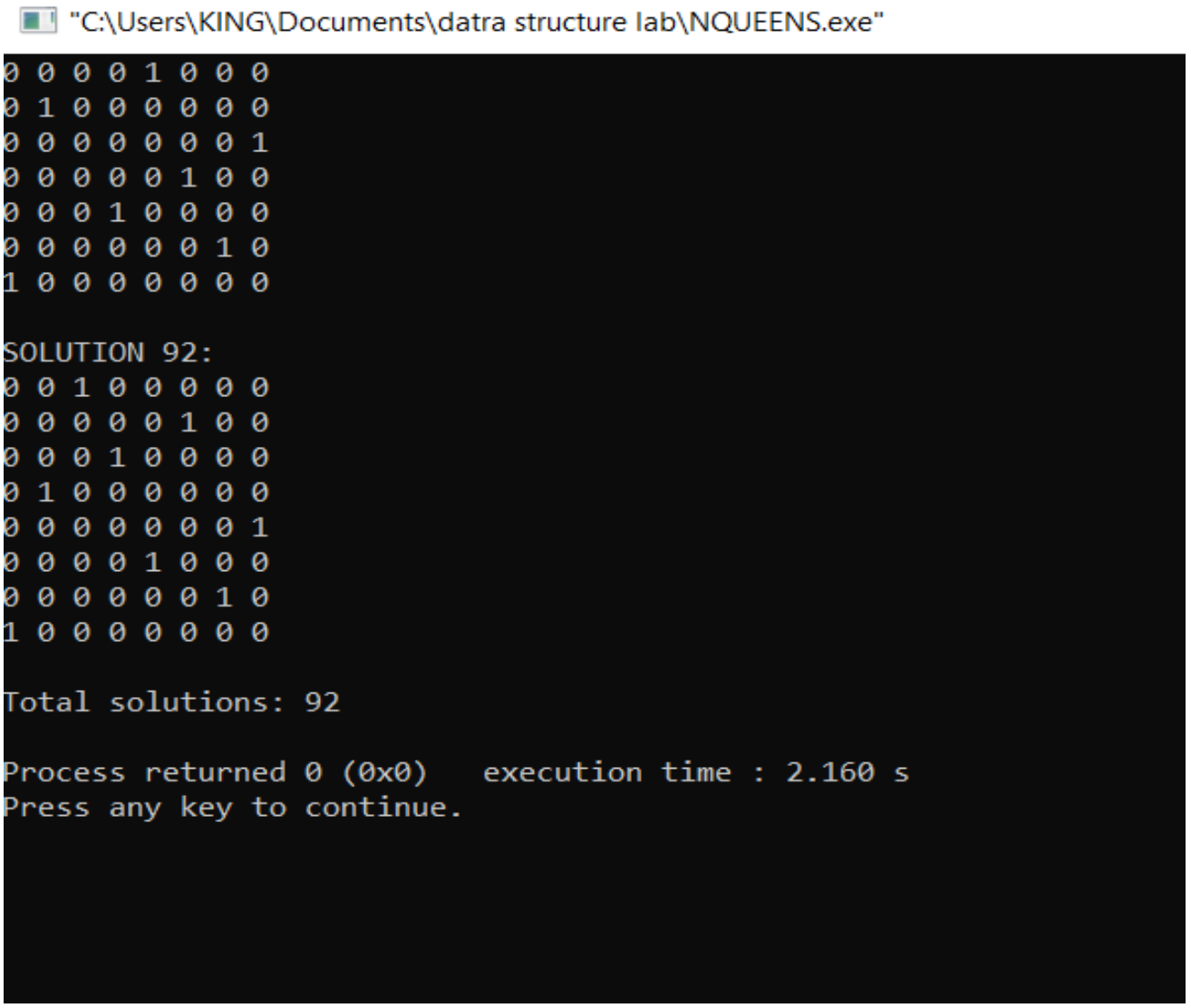
```
#include <stdio.h>
#include <stdbool.h>
#define N 8  // 8x8 chessboard
// Function to print the chessboard
void printSolution(int board[N][N]) {
   for (int i = 0; i < N; i++) {
      for (int j = 0; j < N; j++)
         printf("%d ", board[i][j]);
      printf("\n");
   }
   printf("\n");
```

```
}
// Check if placing a queen at board[row][col] is safe
bool isSafe(int board[N][N], int row, int col) {
   int i, j;
 // Check row on the left
   for (i = 0; i < col; i++)
      if (board[row][i])
         return false;
 // Check upper diagonal on the left
   for (i = row, j = col; i >= 0 && j >= 0; i--, j--)
      if (board[i][j])
         return false;
   // Check lower diagonal on the left
   for (i = row, j = col; i < N && j >= 0; i++, j--)
      if (board[i][j])
         return false;
   return true;
}
// Recursive function to solve N-Queens and print all solutions
void solveNQueensUtil(int board[N][N], int col, int *solutionCount) {
   if (col >= N) {
      printf("SOLUTION %d:\n", ++(*solutionCount));
      printSolution(board);
      return;
   }
 for (int i = 0; i < N; i++) {
      if (isSafe(board, i, col)) {
         board[i][col] = 1;  // Place queen
         solveNQueensUtil(board, col + 1, solutionCount);
         board[i][col] = 0;  // Backtrack
      }
   }
}
// Solve the 8-Queens problem
void solveNQueens() {
   int board[N][N] = {0};
   int solutionCount = 0;
   solveNQueensUtil(board, 0, &solutionCount);
 if (solutionCount == 0)
      printf("No solution exists.\n");
   else
      printf("Total solutions: %d\n", solutionCount);
}
int main() {
   solveNQueens();
```

```
    return 0;
}
```

OUTPUT





RESULT:

The program successfully solves the **8-Queens problem** using **recursive backtracking**. It displays all valid arrangements of queens on the 8×8 chessboard and counts the total number of solutions.

4.B GRAPH COLORING

AIM:

To color a graph using a given number of colors such that **no two adjacent vertices have the** same color using **recursive backtracking**.

ALGORITHM:

1. **Start**
2. Initialize the graph and the number of colors.
3. Assign colors to vertices one by one using recursion:
    - For each vertex, try coloring it with each available color.
    - Check if the color is **safe** (no adjacent vertex has the same color).
    - If safe, assign the color and recursively move to the next vertex.
    - If stuck, **backtrack** and try a different color.
4. Repeat until all vertices are colored.
5. Print the valid coloring solution.
6. **Stop**

PSEUDOCODE:

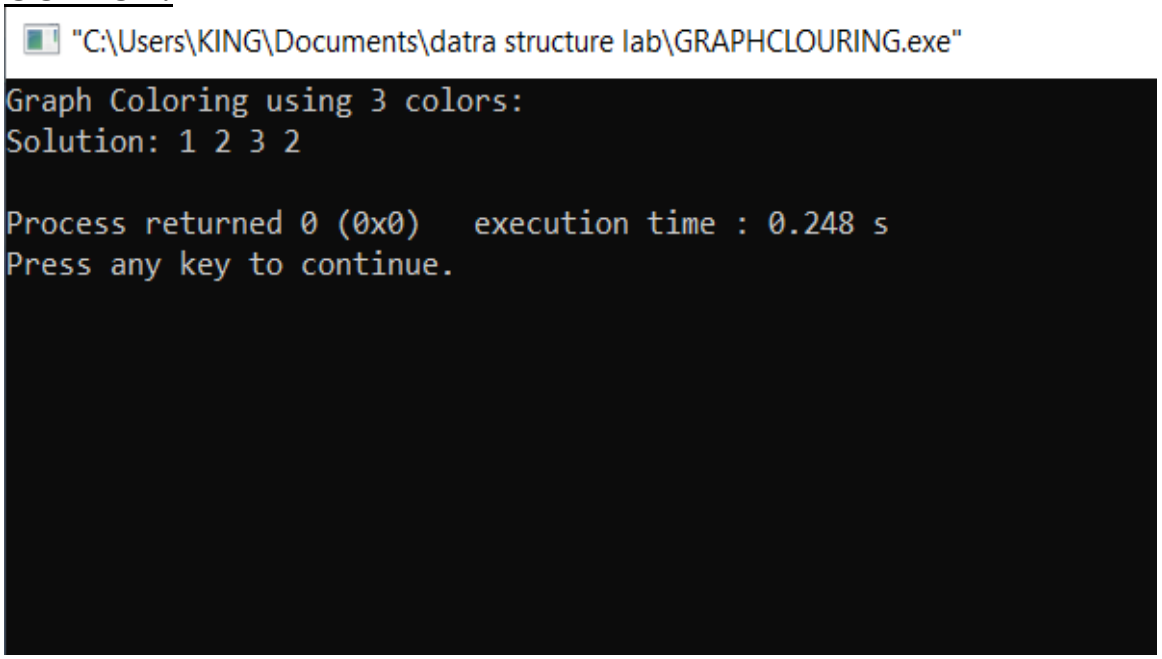
```
BEGIN
   DEFINE V = number of vertices
   DEFINE M = number of colors
   DECLARE graph[V][V]
   DECLARE color[V] = {0}
 FUNCTION isSafe(vertex, color)
      FOR each adjacent vertex i
         IF graph[vertex][i] == 1 AND color[i] == color[vertex]
            RETURN false
      RETURN true
   END FUNCTION
  FUNCTION graphColoringUtil(vertex)
      IF vertex == V
         PRINT color array
         RETURN true
      FOR c = 1 TO M
         IF isSafe(vertex, c)
            color[vertex] = c
            IF graphColoringUtil(vertex + 1) RETURN true
            color[vertex] = 0  // backtrack
      RETURN false
   END FUNCTION
   CALL graphColoringUtil(0)
END
```

PROGRAM:

```
#include <stdio.h>
#include <stdbool.h>
#define V 4  // Number of vertices
#define M 3  // Number of colors
// Function to print the color assignment
void printSolution(int color[]) {
   printf("Solution: ");
   for (int i = 0; i < V; i++)
      printf("%d ", color[i]);
   printf("\n");
}
// Check if the current vertex can be colored with color c
bool isSafe(int vertex, int graph[V][V], int color[], int c) {
   for (int i = 0; i < V; i++)
      if (graph[vertex][i] && color[i] == c)
         return false;
   return true;
}
// Recursive function to solve the graph coloring problem
bool graphColoringUtil(int graph[V][V], int m, int color[], int vertex) {
   if (vertex == V) {  // All vertices are colored
      printSolution(color);
      return true;  // return true to find one solution
   }
   for (int c = 1; c <= m; c++) {
      if (isSafe(vertex, graph, color, c)) {
         color[vertex] = c;  // Assign color
         if (graphColoringUtil(graph, m, color, vertex + 1))
            return true;
         color[vertex] = 0;  // Backtrack
      }
   }
   return false;
}
// Solve the graph coloring problem
void graphColoring(int graph[V][V], int m) {
   int color[V] = {0};
   if (!graphColoringUtil(graph, m, color, 0)) {
      printf("No solution exists.\n");
      return;
   }
}
int main() {
```

```
    int graph[V][V] = {
        {0, 1, 1, 1},
        {1, 0, 1, 0},
        {1, 1, 0, 1},
        {1, 0, 1, 0}
    };
    printf("Graph Coloring using %d colors:\n", M);
    graphColoring(graph, M);
    return 0;
}
```

OUTPUT:



RESULT:

The program successfully colors the graph using the given number of colors without assigning the same color to **adjacent vertices**. It finds a valid coloring solution using **recursive backtracking**.

EXP.NO:05	Implementation of randomized algorithms	DATE:

5.A QUICK SORT

AIM:

To sort an array of integers using **Quick Sort** with a **randomized pivot** to improve efficiency and avoid worst-case scenarios.

ALGORITHM:

1. **Start**
2. Read the number of elements `n` and the array elements.
3. If the array has more than one element, perform the following recursively:
   - Select a **random pivot** element.
   - Partition the array so that elements **less than or equal to pivot** are on the left, and elements **greater than pivot** are on the right.
   - Recursively apply Quick Sort to the left and right subarrays.
4. Print the **sorted array**.
5. **Stop**

PSEUDOCODE:

```
BEGIN
   INPUT n
   INPUT array A[0..n-1]
FUNCTION swap(a, b)
      temp = a
      a = b
      b = temp
   END FUNCTION
   FUNCTION randomizedPartition(A, low, high)
      randomIndex = random(low, high)
      swap(A[randomIndex], A[high])
      pivot = A[high]
      i = low - 1
      FOR j = low TO high - 1
         IF A[j] <= pivot
            i = i + 1
            swap(A[i], A[j])
      swap(A[i+1], A[high])
      RETURN i + 1
   END FUNCTION
   FUNCTION quickSort(A, low, high)
```

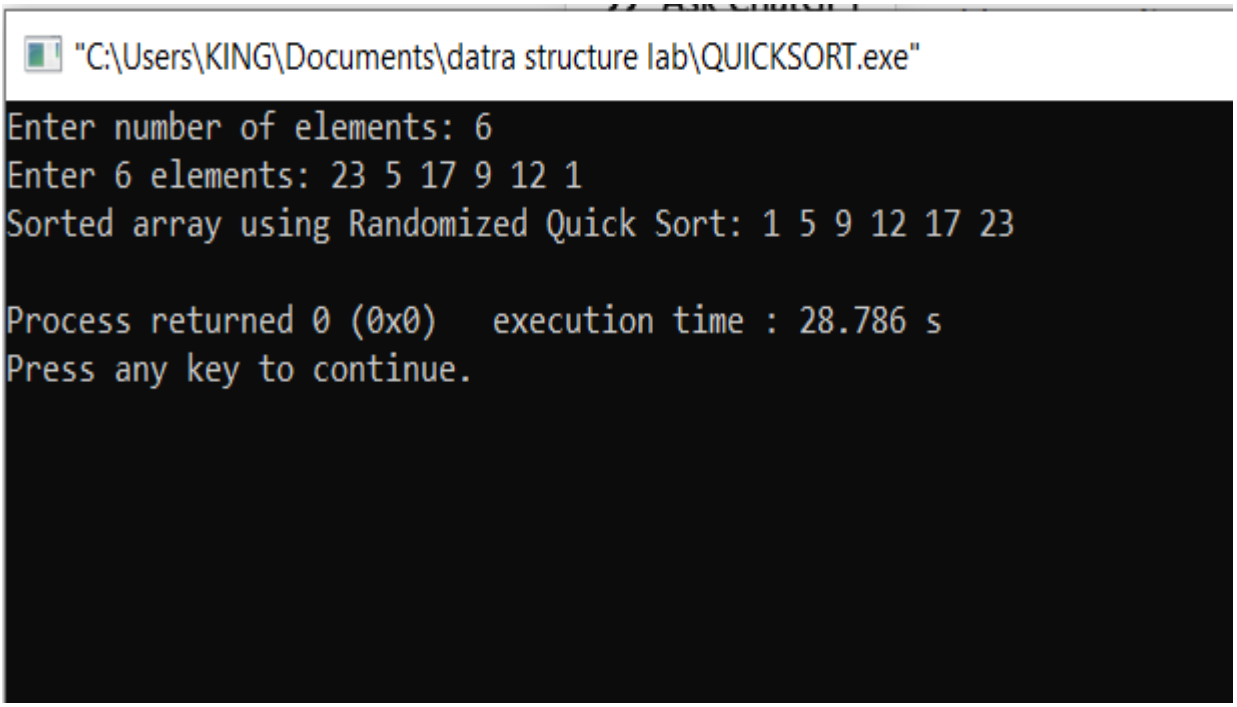
```
    IF low < high
        pi = randomizedPartition(A, low, high)
        quickSort(A, low, pi-1)
        quickSort(A, pi+1, high)
  END FUNCTION
  CALL quickSort(A, 0, n-1)
  PRINT A
END
```

PROGRAM:

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
// Function to swap two elements
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
// Function to choose a random pivot and partition the array
int randomizedPartition(int arr[], int low, int high) {
    // Choose a random index between low and high
    int randomIndex = low + rand() % (high - low + 1);
    swap(&arr[randomIndex], &arr[high]); // Swap pivot with last element
    int pivot = arr[high];
    int i = low - 1;
    for (int j = low; j < high; j++) {
        if (arr[j] <= pivot) {
            i++;
            swap(&arr[i], &arr[j]);y
        }
    }
    swap(&arr[i + 1], &arr[high]);
    return i + 1;
}
// Quick Sort function using randomized pivot
void quickSort(int arr[], int low, int high) {
    if (low < high) {
        int pi = randomizedPartition(arr, low, high);
        quickSort(arr, low, pi - 1);
        quickSort(arr, pi + 1, high);
    }
}
// Function to print an array
void printArray(int arr[], int n) {
```

```
    for (int i = 0; i < n; i++)
        printf("%d ", arr[i]);
    printf("\n");
}
int main() {
    int n;
    printf("Enter number of elements: ");
    scanf("%d", &n);
    int arr[n];
    printf("Enter %d elements: ", n);
    for (int i = 0; i < n; i++)
        scanf("%d", &arr[i]);
    srand(time(NULL));  // Seed random number generator
    quickSort(arr, 0, n - 1);
    printf("Sorted array using Randomized Quick Sort: ");
    printArray(arr, n);
    return 0;
}
```

OUTPUT:



RESULT:

The program successfully sorts the array using **Randomized Quick Sort**. Random pivot selection improves performance and avoids worst-case scenarios. The array is sorted in **ascending order**.

5.B Monte Carlo

AIM:

To estimate the value of π using the **Monte Carlo method**, a randomized algorithm, by generating random points in a unit square and counting how many lie inside the unit circle.

ALGORITHM:

1. **Start**
2. Initialize the number of random points `N`.
3. Set a counter `pointsInsideCircle = 0`.
4. Repeat for each random point:
   - Generate a random point `(x, y)` where `0 ≤ x, y ≤ 1`.
   - If `x² + y² ≤ 1`, increment `pointsInsideCircle`.
5. Estimate π using the formula:

π≈4×pointsInsideCircleN\pi \approx 4 \times \frac{\text{pointsInsideCircle}}{N}π≈4×NpointsInsideCircle

6. Display the estimated value of π.
7. **Stop**

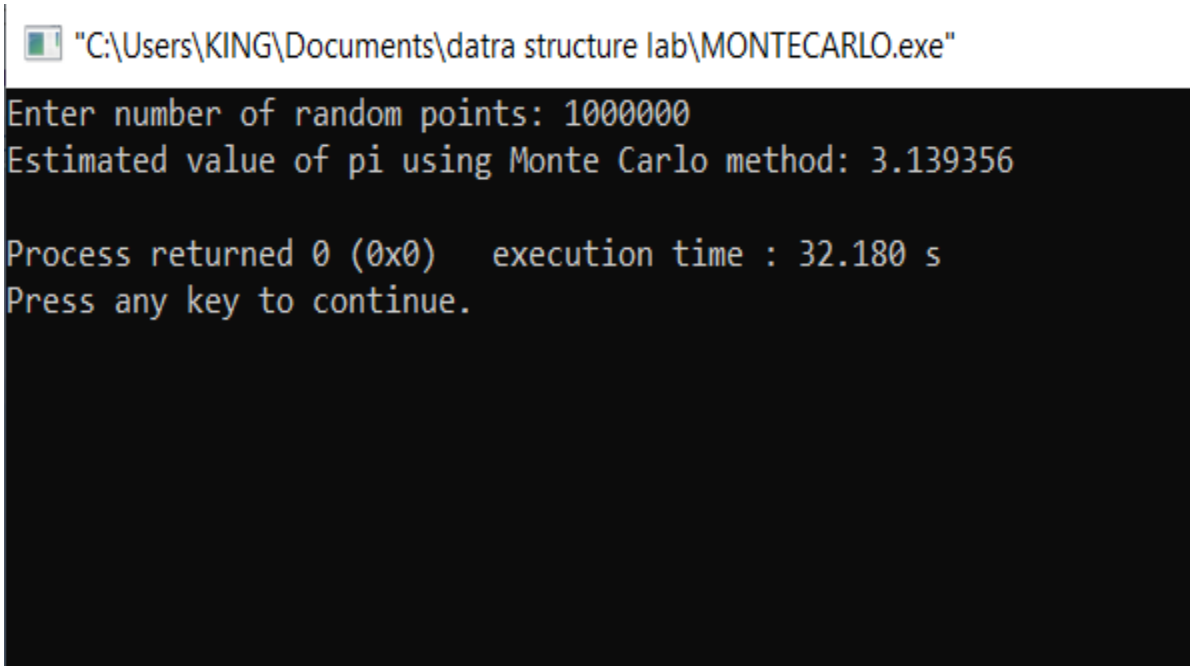
PSEUDOCODE :

```
BEGIN
INPUT N  // number of random points
   pointsInsideCircle = 0
FOR i = 1 TO N
      x = random(0,1)
      y = random(0,1)
      IF (x*x + y*y <= 1)
         pointsInsideCircle = pointsInsideCircle + 1
   END FOR
  piEstimate = 4 * pointsInsideCircle / N
   PRINT piEstimate
END
```

PROGRAM

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <math.h>
int main() {
   long long int numPoints, pointsInsideCircle = 0;
   double x, y, piEstimate;
   printf("Enter number of random points: ");
   scanf("%lld", &numPoints);
   // Initialize random number generator
   srand(time(NULL));
   for (long long int i = 0; i < numPoints; i++) {
      // Generate random point (x, y) in [0,1] x [0,1]
      x = (double)rand() / RAND_MAX;
      y = (double)rand() / RAND_MAX;
      // Check if point lies inside unit circle
      if (x * x + y * y <= 1.0)
         pointsInsideCircle++;
   }
   // Estimate π using ratio of points inside circle
   piEstimate = 4.0 * pointsInsideCircle / numPoints;
   printf("Estimated value of pi using Monte Carlo method: %lf\n", piEstimate);
   return 0;
}
```

OUTPUT



RESULT:

The program successfully estimates the value of π using the **Monte Carlo randomized algorithm**. Increasing the number of random points improves the accuracy.

EXPNO:	**Implementation of various locking and synchronization mechanisms for concurrent linked lists, concurrent queues and concurrent stacks.**	DATE:

LOCK BASED CONCURRENT QUEUE IMPLEMENTATION

AIM:

To implement a concurrent queue using locks (mutexes) to ensure thread-safe enqueue and dequeue operations in a multi-threaded environment.

ALGORITHM:

1. **Initialize Queue:**
   - Create a queue data structure (linked list or array).
   - Initialize a lock (mutex).
2. **Enqueue Operation:**
   - Acquire the lock.
   - Insert the new element at the rear of the queue.
   - Release the lock.
3. **Dequeue Operation:**
   - Acquire the lock.
   - Remove the element from the front of the queue.
   - Release the lock.
4. **Thread Execution:**
   - Multiple producer threads call enqueue().
   - Multiple consumer threads call dequeue().
   - Lock ensures mutual exclusion, preventing race conditions.

PSEUDOCODE:

```
Initialize Queue Q
Initialize Lock L

function ENQUEUE(Q, item):
   acquire(L)
   add item to rear of Q
   release(L)

function DEQUEUE(Q):
   acquire(L)
   if Q is not empty:
```

```
        remove item from front of Q
        return item
    else:
        return "Queue Empty"
    release(L)

Main:
    create multiple threads
    each thread performs enqueue/dequeue
```

PROGRAM:

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

typedef struct Node {
    int data;
    struct Node *next;
} Node;

Node *front = NULL, *rear = NULL;
pthread_mutex_t lock;

void enqueue(int x) {
    pthread_mutex_lock(&lock);
    Node *n = malloc(sizeof(Node));
    n->data = x; n->next = NULL;
    if (rear == NULL)
    {
    front = rear = n;
    printf("enqueued %d\n",n->data);
    }
    else { rear->next = n; rear = n;
        printf("enqueued %d\n",n->data);
    }
    pthread_mutex_unlock(&lock);
}

int dequeue() {
    pthread_mutex_lock(&lock);
    if (front == NULL) { pthread_mutex_unlock(&lock); return -1; }
    Node *t = front; int val = t->data;
    front = front->next;
    if (front == NULL)
      rear = NULL;
```

```
    free(t);
    pthread_mutex_unlock(&lock);
    return val;
}

void* producer(void *arg) {
    for (int i = 1; i <= 10; i++)
    enqueue(i);
    return NULL;
}

void* consumer(void *arg) {
    for (int i = 0; i < 5; i++)
        printf("Dequeued: %d\n", dequeue());
    return NULL;
}

int main() {
    pthread_mutex_init(&lock, NULL);
    pthread_t t1, t2;
    pthread_create(&t1, NULL, producer, NULL);
    pthread_create(&t2, NULL, consumer, NULL);
    pthread_join(t1, NULL);
    pthread_join(t2, NULL);
    pthread_mutex_destroy(&lock);
    return 0;
}
```

OUTPUT:

```
Enqueued: 1
Dequeued: 1
Enqueued: 2
Dequeued: 2
Enqueued: 3
Dequeued: 3
Enqueued: 4
Dequeued: 4
Enqueued: 5
Dequeued: 5
Enqueued: 6
Dequeued: 6
Enqueued: 7
Dequeued: 7
Enqueued: 8
Dequeued: 8
Enqueued: 9
```

Dequeued: 9
Enqueued: 10
Dequeued: 10

RESULT:

The lock-based concurrent queue was successfully implemented. whereas, **Locks (mutexes)** ensured mutual exclusion. Race conditions were avoided. Multiple threads safely performed enqueue and dequeue operations.

B.LOCK BASED CONCURRENT STACK IMPLEMENTATION

AIM:

To implement a **concurrent stack** using **locks (mutexes)** to ensure thread-safe push and pop operations in a multi-threaded environment.

ALGORITHM:

1. **Initialize Stack:**
   - Create a stack data structure (linked list or array).
   - Initialize a lock (mutex).
2. **Push Operation:**
   - Acquire the lock.
   - Insert the new element at the top of the stack.
   - Release the lock.
3. **Pop Operation:**
   - Acquire the lock.
   - If stack is not empty:
     - Remove the element from the top of the stack.
     - Return the element.
   - Else return "Stack Empty".
   - Release the lock.
4. **Thread Execution:**
   - Multiple producer threads call push().
   - Multiple consumer threads call pop().
   - Lock ensures mutual exclusion, preventing race conditions.

PSEUDOCODE:

```
Initialize Stack S
Initialize Lock L

function PUSH(S, item):
   acquire(L)
   add item to top of S
   release(L)

function POP(S):
   acquire(L)
   if S is not empty:
      remove item from top of S
      return item
```

```
    else:
        return "Stack Empty"
    release(L)

Main:
    create multiple threads
    each thread performs push/pop
```

PROGRAM:

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

typedef struct Node {
int data;
struct Node *next;
 } Node;
Node *top = NULL;
pthread_mutex_t lock;

void push(int x){
    pthread_mutex_lock(&lock);
    Node *n = malloc(sizeof(Node));
    n->data = x; n->next = top;
    top = n;
    pthread_mutex_unlock(&lock);
}

int pop(){
    pthread_mutex_lock(&lock);
    if (top == NULL){ pthread_mutex_unlock(&lock); return -1; }
    Node *t = top; int v = t->data;
    top = top->next; free(t);
    pthread_mutex_unlock(&lock);
    return v;
}

void* producer(void *arg){
    for(int i=1;i<=5;i++) push(i);
    return NULL;
}

void* consumer(void *arg){
    for(int i=0;i<5;i++) printf("Popped: %d\n", pop());
    return NULL;
```

```
}

int main(){
    pthread_mutex_init(&lock, NULL);
    pthread_t t1,t2;
    pthread_create(&t1,NULL,producer,NULL);
    pthread_create(&t2,NULL,consumer,NULL);
    pthread_join(t1,NULL);
    pthread_join(t2,NULL);
    pthread_mutex_destroy(&lock);
    return 0;
}
```

OUTPUT:

```
Pushed: 1
Pushed: 2
Pushed: 3
Pushed: 4
Pushed: 5
Popped: 5
Popped: 4
Popped: 3
Popped: 2
Popped: 1
```

RESULT:

The lock-based concurrent stack was successfully implemented. Whereas, Locks (mutexes) ensured mutual exclusion. Race conditions were avoided. Multiple threads safely performed push and pop operations.

EXP.NO:07	**Developing applications involving concurrency.**	**DATE**

A)Producer–Consumer Problem

AIM

To implement the Producer–Consumer Problem using threads, semaphores, and mutex locks in C, demonstrating concurrency control, synchronization, and communication between producer and consumer processes using a bounded buffer.

ALGORITHM

1. Initialize
   - Set buffer size (N).
   - Initialize:
     - empty semaphore to N (all slots empty).
     - full semaphore to 0 (no items present).
     - mutex for critical section protection.
   - Set buffer pointers in = 0, out = 0.
2. Producer Process
   1. Produce a random item.
   2. Wait if no empty slot → sem_wait(empty).
   3. Lock the buffer using pthread_mutex_lock(mutex).
   4. Insert item at buffer position in.
   5. Update in = (in + 1) % BUFFER_SIZE.
   6. Unlock the buffer → pthread_mutex_unlock(mutex).
   7. Signal that a new item is available → sem_post(full).
3. Consumer Process
   1. Wait if buffer is empty → sem_wait(full).
   2. Lock the buffer → pthread_mutex_lock(mutex).
   3. Remove item from buffer at position out.
   4. Update out = (out + 1) % BUFFER_SIZE.
   5. Unlock the buffer → pthread_mutex_unlock(mutex).
   6. Signal an empty slot → sem_post(empty).
   7. Consume the item.
4. Continue
   - Producer and consumer run in infinite loops (or until completed).
   - Synchronization avoids:
     - overflow
     - underflow
     - race conditions

PSEUDOCODE

```
Initialize
BUFFER_SIZE ← N
in ← 0
out ← 0
Initialize semaphore empty = N
Initialize semaphore full = 0
Initialize mutex = 1
Producer
Producer():
   loop forever:
      item ← generate item

      wait(empty)
      wait(mutex)

      buffer[in] ← item
      print "Produced:", item
      in ← (in + 1) mod BUFFER_SIZE

      signal(mutex)
      signal(full)

      sleep(1)
Consumer
Consumer():
   loop forever:
      wait(full)
      wait(mutex)

      item ← buffer[out]
      print "Consumed:", item
      out ← (out + 1) mod BUFFER_SIZE

      signal(mutex)
      signal(empty)

      sleep(2)
```

PROGRAM (Producer–Consumer using pthreads + Semaphores)

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>
#include <semaphore.h>
#include <unistd.h>

#define BUFFER_SIZE 5

int buffer[BUFFER_SIZE];
int in = 0, out = 0;

// Semaphores and mutex
sem_t empty;
sem_t full;
pthread_mutex_t mutex;

// Producer function
void* producer(void* arg) {
   int item;
   while (1) {
      item = rand() % 100;   // Produce an item

      sem_wait(&empty);
      pthread_mutex_lock(&mutex);

      buffer[in] = item;
      printf("Producer produced: %d\n", item);
      in = (in + 1) % BUFFER_SIZE;

      pthread_mutex_unlock(&mutex);
      sem_post(&full);

      sleep(1);
   }
}

// Consumer function
void* consumer(void* arg) {
   int item;
   while (1) {
      sem_wait(&full);
      pthread_mutex_lock(&mutex);

      item = buffer[out];
```

```
        printf("Consumer consumed: %d\n", item);
        out = (out + 1) % BUFFER_SIZE;

        pthread_mutex_unlock(&mutex);
        sem_post(&empty);

        sleep(2);
    }
}

int main() {
    pthread_t prod, cons;

    // Initialize semaphores and mutex
    sem_init(&empty, 0, BUFFER_SIZE);
    sem_init(&full, 0, 0);
    pthread_mutex_init(&mutex, NULL);

    // Create threads
    pthread_create(&prod, NULL, producer, NULL);
    pthread_create(&cons, NULL, consumer, NULL);

    // Join threads
    pthread_join(prod, NULL);
    pthread_join(cons, NULL);

    sem_destroy(&empty);
    sem_destroy(&full);
    pthread_mutex_destroy(&mutex);

    return 0;
}
```

OUTPUT

```
Producer produced: 45
Consumer consumed: 45
Producer produced: 12
Producer produced: 78
Consumer consumed: 12
Consumer consumed: 78
Producer produced: 34
Producer produced: 88
Consumer consumed: 34
Producer produced: 56
Consumer consumed: 88
```

Consumer consumed: 56
(Exact values may vary due to randomness.)

RESULT

The Producer–Consumer Problem was successfully implemented using pthread threads, semaphores, and mutex locks.
The program ensured proper synchronization between producer and consumer processes, preventing race conditions, buffer overflow, and buffer underflow.
Concurrent execution and coordination of threads were demonstrated effectively.

B)Reader–Writer problem

AIM

To design and implement a solution to the Reader–Writer problem using POSIX threads in C, allowing multiple readers to read a shared resource concurrently while ensuring exclusive access for writers.

ALGORITHM (Reader Priority Solution)

1. **Initialize:**
   - **mutex to protect read_count**
   - **wrt to ensure exclusive writer access**
   - **read_count = 0**
2. **Reader Process:**

1. **Lock mutex**
2. **Increment read_count**
3. **If read_count == 1, lock wrt (block writers)**
4. **Unlock mutex**
5. **Read the shared data**
6. **Lock mutex**
7. **Decrement read_count**
8. **If read_count == 0, unlock wrt**
9. **Unlock mutex**

3. **Writer Process:**

1. **Lock wrt**
2. **Write to the shared data**
3. **Unlock wrt**

4. **Repeat steps for multiple readers and writers.**

PSEUDOCODE

```
INITIALIZE mutex
INITIALIZE wrt
read_count ← 0

READER:
  lock(mutex)
  read_count ← read_count + 1
  IF read_count == 1 THEN
    lock(wrt)
  ENDIF
  unlock(mutex)
```

```
    READ shared resource

    lock(mutex)
    read_count ← read_count - 1
    IF read_count == 0 THEN
      unlock(wrt)
    ENDIF
    unlock(mutex)

WRITER:
    lock(wrt)
    WRITE shared resource
    unlock(wrt)
```

PROGRAM

```
#include <stdio.h>
#include <pthread.h>
#include <unistd.h>

pthread_mutex_t mutex, wrt;
int read_count = 0;

/* Reader Function */
void* reader(void* arg) {
    int id = *(int*)arg;

    pthread_mutex_lock(&mutex);
    read_count++;
    if (read_count == 1)
        pthread_mutex_lock(&wrt);  // First reader blocks writer
    pthread_mutex_unlock(&mutex);

    printf("Reader %d is reading\n", id);
    sleep(1);

    pthread_mutex_lock(&mutex);
    read_count--;
    if (read_count == 0)
        pthread_mutex_unlock(&wrt); // Last reader releases writer
    pthread_mutex_unlock(&mutex);

    return NULL;
}
```

```
/* Writer Function */
void* writer(void* arg) {
   int id = *(int*)arg;

   pthread_mutex_lock(&wrt);
   printf("Writer %d is writing\n", id);
   sleep(1);
   pthread_mutex_unlock(&wrt);

   return NULL;
}

int main() {
   pthread_t r[3], w[2];
   pthread_mutex_init(&mutex, NULL);
   pthread_mutex_init(&wrt, NULL);

   int rid[3] = {1,2,3}, wid[2] = {1,2};

   pthread_create(&r[0], NULL, reader, &rid[0]);
   pthread_create(&r[1], NULL, reader, &rid[1]);
   pthread_create(&w[0], NULL, writer, &wid[0]);
   pthread_create(&r[2], NULL, reader, &rid[2]);
   pthread_create(&w[1], NULL, writer, &wid[1]);

   for (int i=0; i<3; i++)
      pthread_join(r[i], NULL);
   for (int i=0; i<2; i++)
      pthread_join(w[i], NULL);

   pthread_mutex_destroy(&mutex);
   pthread_mutex_destroy(&wrt);

   return 0;
}
```

OUTPUT

Reader 1 is reading
Reader 2 is reading
Reader 3 is reading
Writer 1 is writing
Writer 2 is writing

RESULT

Thus, the Reader–Writer problem was successfully implemented using pthreads in C.
The solution allows concurrent reading by multiple readers while ensuring mutual exclusion for writers, maintaining data consistency.