VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Sanjana Srinivas (1BM23CS301)

in partial fulfillment for the award of the degree of
BACHELOR OF ENGINEERING
in
COMPUTER SCIENCE AND ENGINEERING

B.M.S. COLLEGE OF ENGINEERING
(Autonomous Institution under VTU)
BENGALURU-560019
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B.M.S. College of Engineering,
Bull Temple Road, Bangalore 560019
(Affiliated To Visvesvaraya Technological University, Belgaum)
Department of Computer Science and Engineering

CERTIFICATE

This is to certify that the Lab work entitled "Artificial Intelligence (23CS5PCAIN)" carried out by **Sanjana Srinivas (1BM23CS301),** who is bonafide student of **B.M.S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements in respect of an Artificial Intelligence (23CS5PCAIN) work prescribed for the said degree.

Lab faculty Incharge Name Assistant Professor Department of CSE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE

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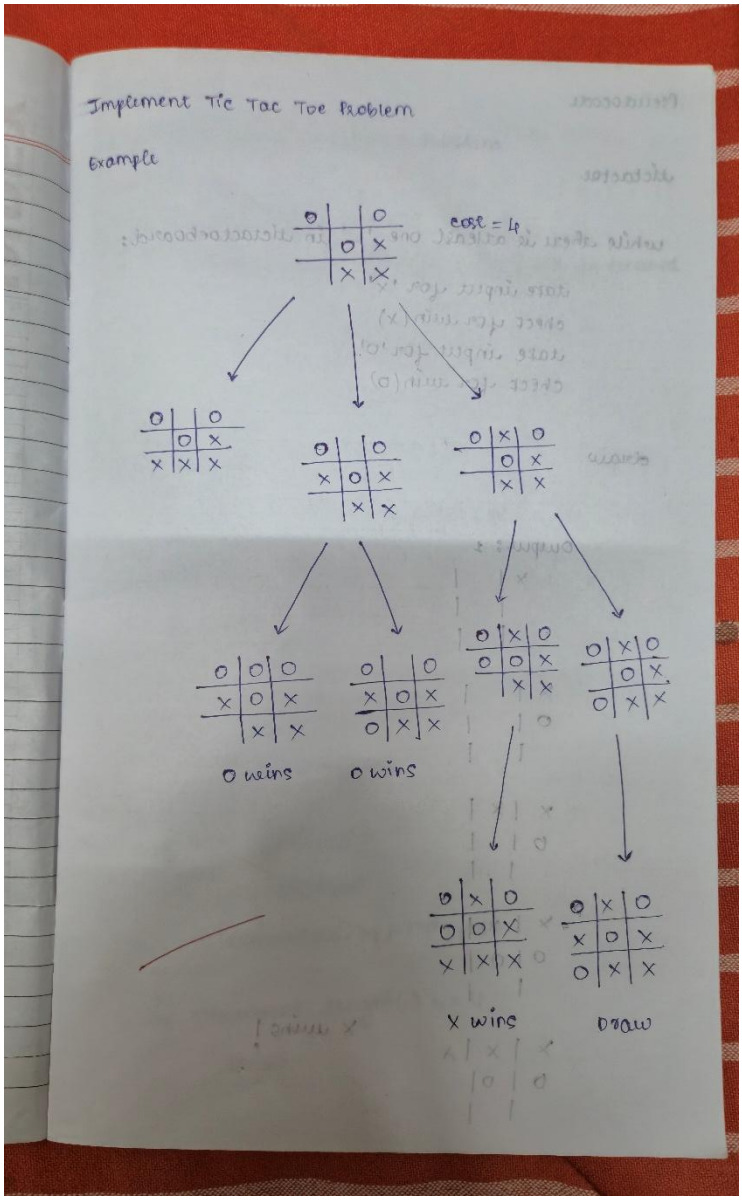
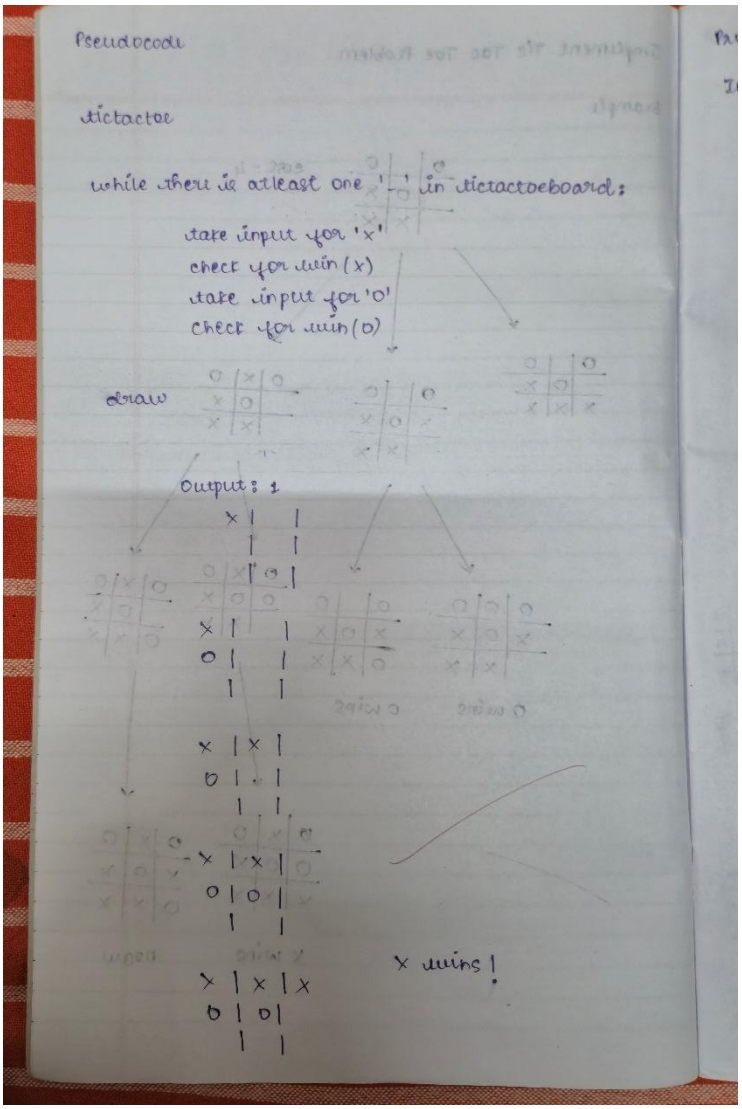
Github Link:
https://github.com/sanjanasrinivas22/1BM23CS301-AI

Program 1
Implement Tic –Tac –Toe Game

Algorithm:





Code:

```
print("Sanjana Srinivas-1BM23CS301")
def print_board(board):
    print("\n")
    for i in range(3):
        print(" | ".join(board[i*3:(i+1)*3]))
        if i < 2:
            print("-" * 10)
    print("\n")

def check_winner(board, player):
    win_conditions = [
        [0, 1, 2], [3, 4, 5], [6, 7, 8],
        [0, 3, 6], [1, 4, 7], [2, 5, 8],
        [0, 4, 8], [2, 4, 6]
    ]
```

```
    for combo in win_conditions:
        count=0
        for pos in combo:
            if board[pos]==player:
                count+=1
        if count==3:
            return True
    return False

board = [" "] * 9
current_player = "X"
print_board(board)

while True:
    while True:
        pos = int(input(f"Player {current_player}, enter your move (1-9): ")) - 1
        if 0 <= pos <= 8 and board[pos] == " ":
            board[pos] = current_player
            break
        else:
            print("Invalid move. Try again.")

    print_board(board)

    if check_winner(board, current_player):
        print(f"Player {current_player} wins!")
        break
    if " " not in board:
        print("It's a draw!")
        break

    # Switch players
    current_player = "O" if current_player == "X" else "X"
```

Output:

Sanjana Srinivas-1BM23CS301

```
  |  |
----------
  |  |
----------
  |  |


Player X, enter your move (1-9): 1
```

```
X |   |
----------
  |   |
----------
  |   |
```

Player O, enter your move (1-9): 2

```
X | O |
----------
  |   |
----------
  |   |
```

Player X, enter your move (1-9): 3

```
X | O | X
----------
  |   |
----------
  |   |
```

Player O, enter your move (1-9): 4

```
X | O | X
----------
O |   |
----------
  |   |
```

Player X, enter your move (1-9): 5

```
X | O | X
----------
O | X |
----------
  |   |
```

Player O, enter your move (1-9): 6
X | O | X

O | X | O

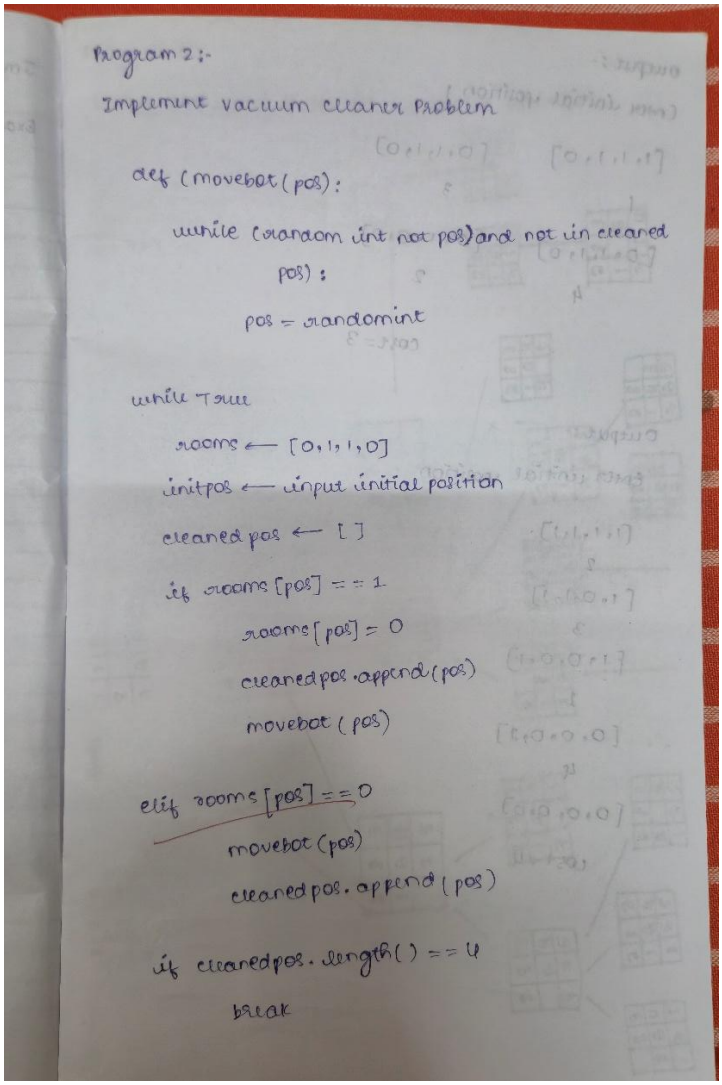
 | |
Player X, enter your move (1-9): 9

X | O | X

O | X | O

 | | X

Player X wins!
Implement vacuum cleaner agent



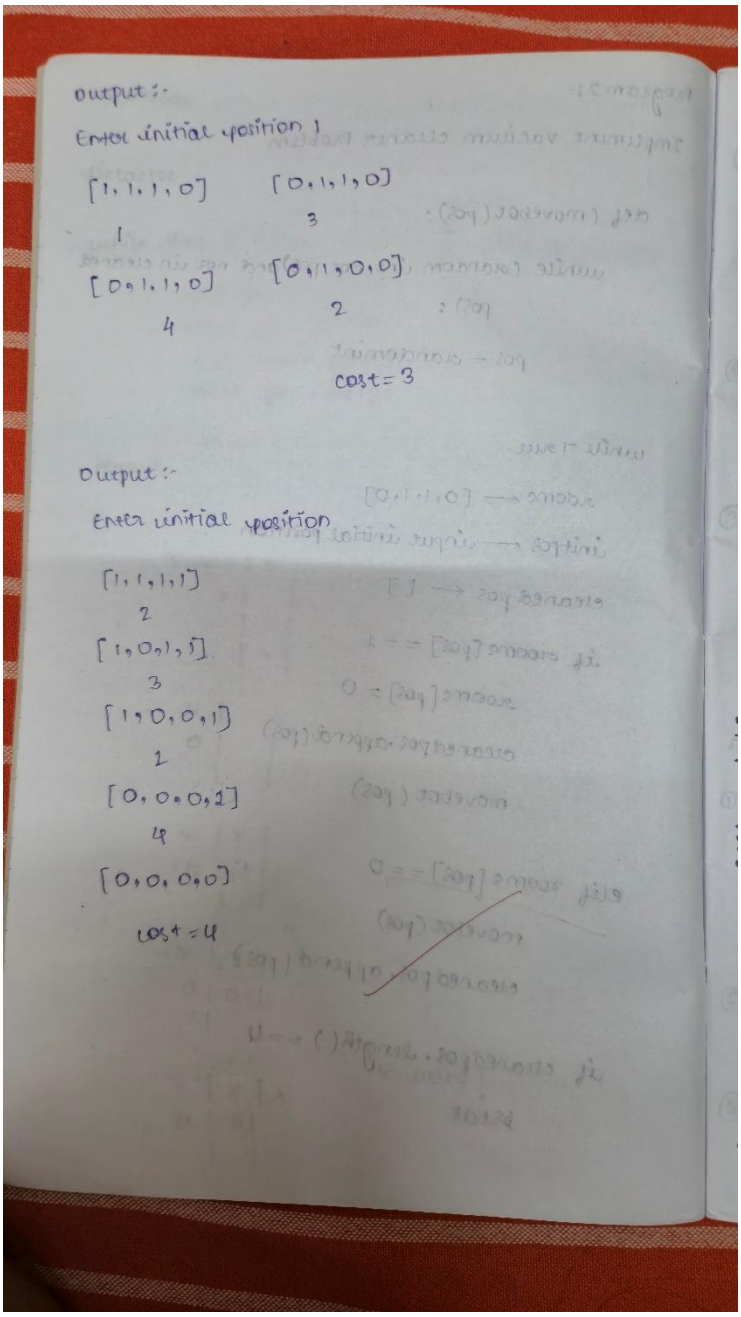
Program 2:-
Implement vacuum cleaner Problem

```
def (movebot(pos):
    while (random int not pos)and not in cleaned
            pos):
        pos = randomint

while True
    rooms ← [0,1,1,0]
    initpos ← input initial position
    cleaned pos ← [ ]
    if rooms[pos] == 1
        rooms[pos] = 0
        clearedpos.append(pos)
        movebot(pos)

elif rooms[pos] == 0
        movebot(pos)
        clearedpos.append(pos)

if clearedpos.length() == 4
        break
```



Code:

```
print("Sanjana Srinivas-1BM23CS301\n")

# Initial setup
rooms = [1, 1, 1, 1]   # 1 = dirty, 0 = clean
botpos = int(input("Enter Initial Position (1-4): ")) - 1
cost = 0
moves = 0

# Function to clean current room
```

```
def clean_room(pos):
    global cost
    if rooms[pos] == 1:
        rooms[pos] = 0
        cost += 1
        print(f"Cleaned room {pos+1}")
    else:
        print(f"Room {pos+1} already clean")

# Function to move bot
def move_bot(pos, direction):
    global moves
    # move right if direction=1 else left
    newpos = pos + direction
    moves += 1
    return newpos

# Main loop
direction = 1   # start moving right
while 1 in rooms:   # loop until all rooms are clean
    print("Rooms:", rooms, " Bot at:", botpos+1)
    clean_room(botpos)

    if 1 not in rooms:
        break

    # change direction if at edges
    if botpos == len(rooms)-1:
        direction = -1
    elif botpos == 0:
        direction = 1

    botpos = move_bot(botpos, direction)

print("\n All rooms cleaned!")
print("Cleaning Cost =", cost)
print("Total Moves =", moves)
```

Output:

Sanjana Srinivas-1BM23CS301

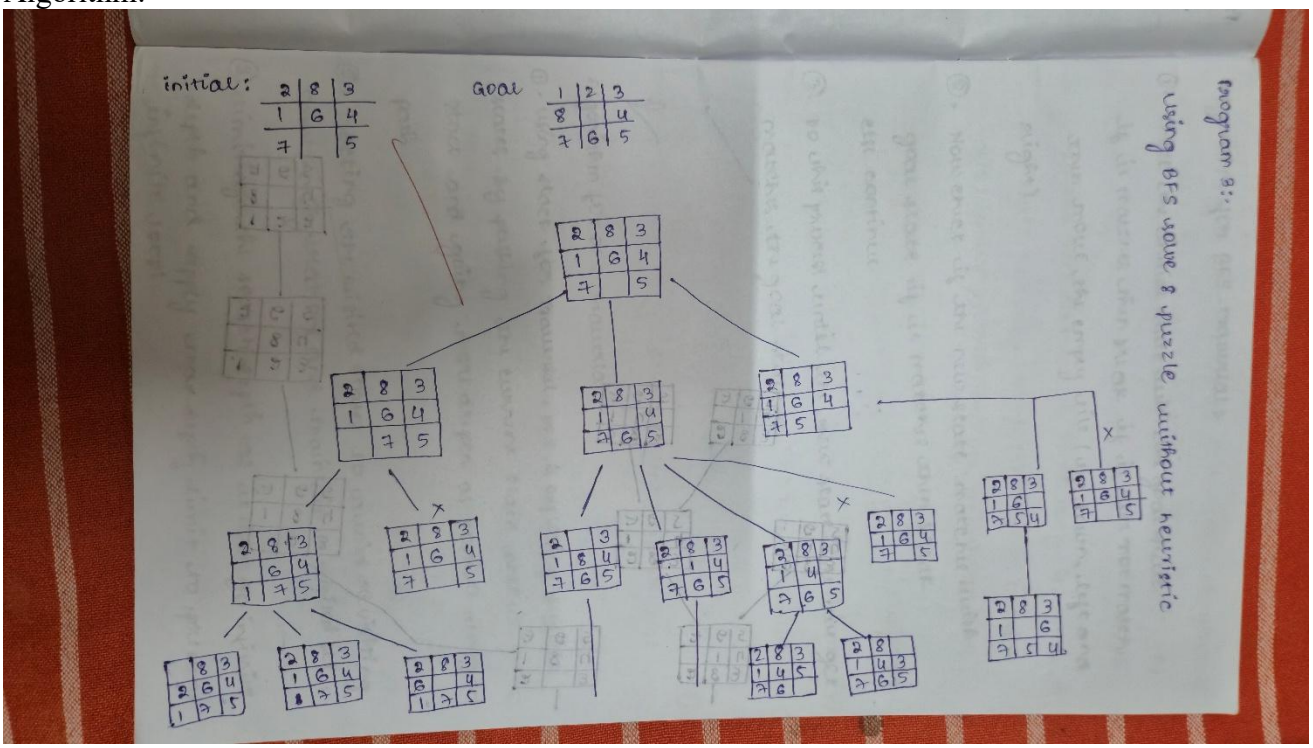
Enter Initial Position (1-4): 2
Rooms: [1, 1, 1, 1] Bot at: 2
Cleaned room 2
Rooms: [1, 0, 1, 1] Bot at: 3
Cleaned room 3

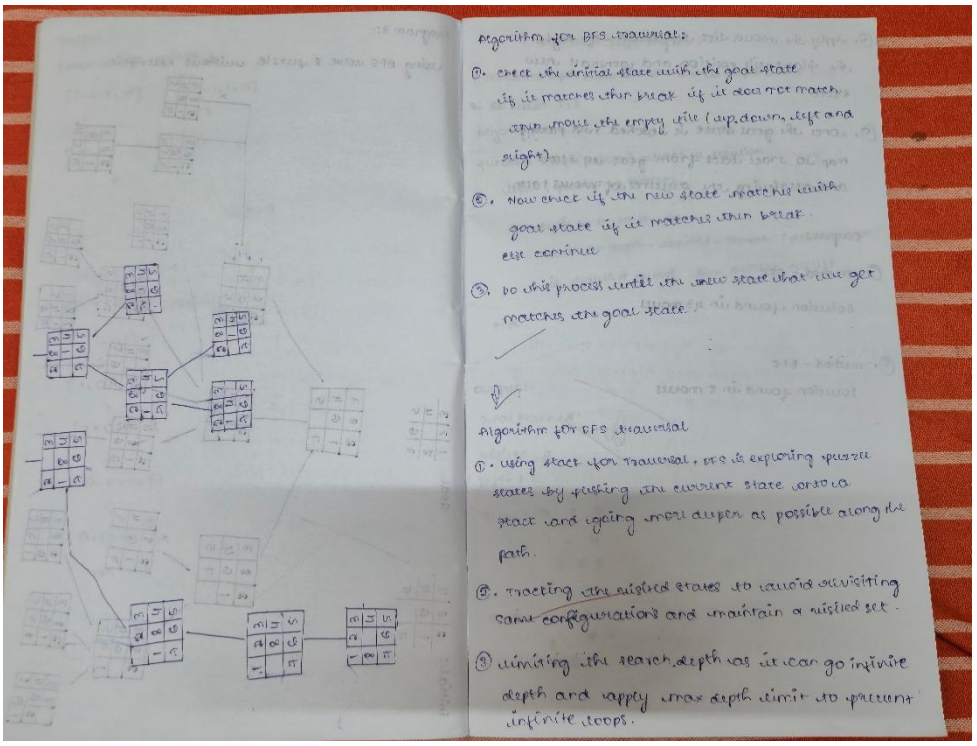
Rooms: [1, 0, 0, 1] Bot at: 4
Cleaned room 4
Rooms: [1, 0, 0, 0] Bot at: 3
Room 3 already clean
Rooms: [1, 0, 0, 0] Bot at: 2
Room 2 already clean
Rooms: [1, 0, 0, 0] Bot at: 1
Cleaned room 1

All rooms cleaned!
Cleaning Cost = 4
Total Moves = 5

Program 2
Implement 8 puzzle problems using Depth First Search (DFS)

Algorithm:



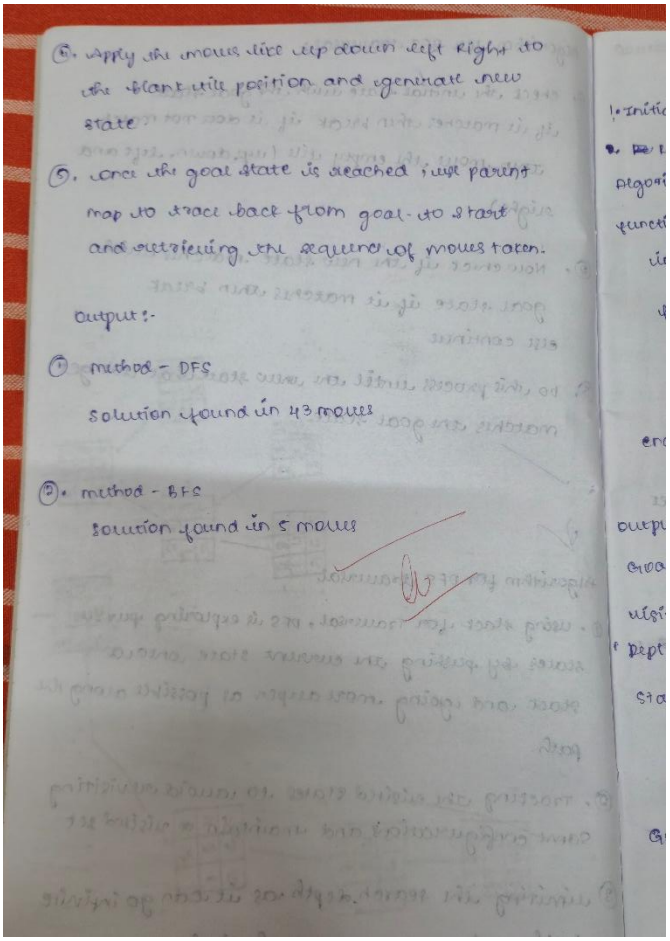


Algorithm for BFS traversal:

1. check the initial state with the goal state if it matches then break if it does not match then move the empty tile (up, down, left and right)
2. Now check if the new state matches with goal state if it matches then break else continue
3. Do this process until the new state that we get matches the goal state.

Algorithm for DFS traversal

1. Using stack for traversal, DFS is exploring puzzle states by pushing the current state onto a stack and going more deeper as possible along the path.
2. Tracking the visited states to avoid revisiting same configurations and maintain a visited set.
3. Limiting the search depth as it can go infinite depth and apply max depth limit to prevent infinite loops.



4. Apply the moves like up down left Right to the blank tile position and generate new state
5. Once the goal state is reached use parent map to trace back from goal to start and retrieving the sequence of moves taken.

Output:-

1. method - DFS
   solution found in 43 moves
2. method - BFS
   solution found in 5 moves

Code:

```
print("Sanjana Srinivas- 1BM23CS301")
from collections import deque
# Define possible moves
MOVES = {
    'Up': -3,
    'Down': 3,
    'Left': -1,
    'Right': 1
}

def is_valid_move(zero_index, move):
    if move == 'Left' and zero_index % 3 == 0:
        return False
    if move == 'Right' and zero_index % 3 == 2:
        return False
    if move == 'Up' and zero_index < 3:
        return False
    if move == 'Down' and zero_index > 5:
        return False
    return True

def move_tile(state, move):
    zero_index = state.index('0')
    if not is_valid_move(zero_index, move):
        return None
    new_index = zero_index + MOVES[move]
    state_list = list(state)
    state_list[zero_index], state_list[new_index] = state_list[new_index], state_list[zero_index]
    return ''.join(state_list)

def reconstruct_path(parent, move_record, end_state):
    path = []
    current = end_state
    while parent[current] is not None:
        path.append((move_record[current], current))
        current = parent[current]
    path.reverse()
    return path

# BFS implementation
def bfs(start_state, goal_state):
    queue = deque()
    visited = set()
    parent = {}
    move_record = {}
```

```
    queue.append(start_state)
    visited.add(start_state)
    parent[start_state] = None
    move_record[start_state] = None

    while queue:
        current = queue.popleft()

        if current == goal_state:
            return reconstruct_path(parent, move_record, current)

        for move in MOVES:
            new_state = move_tile(current, move)
            if new_state and new_state not in visited:
                visited.add(new_state)
                queue.append(new_state)
                parent[new_state] = current
                move_record[new_state] = move

    return None

# DFS implementation
def dfs(start_state, goal_state, max_depth=50):
    stack = [(start_state, 0)]
    visited = set()
    parent = {}
    move_record = {}

    parent[start_state] = None
    move_record[start_state] = None

    while stack:
        current, depth = stack.pop()

        if current == goal_state:
            return reconstruct_path(parent, move_record, current)

        if depth >= max_depth:
            continue

        visited.add(current)

        for move in reversed(list(MOVES)):  # Reverse for consistent DFS order
            new_state = move_tile(current, move)
            if new_state and new_state not in visited:
                stack.append((new_state, depth + 1))
                parent[new_state] = current
```

```
            move_record[new_state] = move

    return None

def print_puzzle(state):
    for i in range(0, 9, 3):
        row = state[i:i+3]
        print(' '.join(c if c != '0' else '_' for c in row))
    print()

def print_solution(start_state, goal_state, method='bfs'):
    print(f"\nStart State ({method.upper()}):")
    print_puzzle(start_state)
    print("Goal State:")
    print_puzzle(goal_state)

    if method == 'bfs':
        path = bfs(start_state, goal_state)
    elif method == 'dfs':
        path = dfs(start_state, goal_state)
    else:
        raise ValueError("Method must be 'bfs' or 'dfs'")

    if path is None:
        print("No solution found.")
        return

    print(f"\nSolution found in {len(path)} moves:")
    current = start_state
    for move, state in path:
        print(f"Move: {move}")
        print_puzzle(state)

def get_state_input(prompt):
    while True:
        raw = input(prompt).replace(" ", "").replace("_", "0")
        if len(raw) != 9 or not all(c in "0123456789" for c in raw):
            print("Invalid input. Enter 9 digits from 0-8 (0 for blank).")
            continue
        if sorted(raw) != list("012345678"):
            print("Invalid puzzle: must contain digits 0 through 8 exactly once.")
            continue
        return raw

# Main program
if __name__ == "__main__":
    print("8-Puzzle Solver (BFS and DFS)")
```

```
    print("Enter the puzzle state as 9 digits (0 = blank). Example: 123405678")

    start = get_state_input("Enter the initial state: ")
    goal = get_state_input("Enter the goal state: ")

    method = ''
    while method not in ['bfs', 'dfs']:
        method = input("Choose search method (bfs/dfs): ").strip().lower()

    print_solution(start, goal, method)
```

Output:

```
Sanjana Srinivas- 1BM23CS301
8-Puzzle Solver (BFS and DFS)
Enter the puzzle state as 9 digits (0 = blank). Example: 123405678
Enter the initial state: 283164705
Enter the goal state: 123804765
Choose search method (bfs/dfs): dfs

Start State (DFS):
2 8 3
1 6 4
7 _ 5

Goal State:
1 2 3
8 _ 4
7 6 5


Solution found in 43 moves:
Move: Up
2 8 3
1 _ 4
7 6 5

Move: Up
2 _ 3
1 8 4
7 6 5

Move: Left
_ 2 3
1 8 4
7 6 5

Move: Down
```

1 2 3
_ 8 4
7 6 5

Move: Down
1 2 3
7 8 4
_ 6 5

Move: Right
1 2 3
7 8 4
6 _ 5

Move: Up
1 2 3
7 _ 4
6 8 5

Move: Up
1 _ 3
7 2 4
6 8 5

Move: Left
_ 1 3
7 2 4
6 8 5

Move: Down
7 1 3
_ 2 4
6 8 5

Move: Down
7 1 3
6 2 4
_ 8 5

Move: Right
7 1 3
6 2 4
8 _ 5

Move: Up
7 1 3
6 _ 4

8 2 5

Move: Up
7 _ 3
6 1 4
8 2 5

Move: Left
_ 7 3
6 1 4
8 2 5

Move: Down
6 7 3
_ 1 4
8 2 5

Move: Down
6 7 3
8 1 4
_ 2 5

Move: Right
6 7 3
8 1 4
2 _ 5

Move: Up
6 7 3
8 _ 4
2 1 5

Move: Up
6 _ 3
8 7 4
2 1 5

Move: Left
_ 6 3
8 7 4
2 1 5

Move: Down
8 6 3
_ 7 4
2 1 5

Move: Down
8 6 3
2 7 4
_ 1 5

Move: Right
8 6 3
2 7 4
1 _ 5

Move: Up
8 6 3
2 _ 4
1 7 5

Move: Up
8 _ 3
2 6 4
1 7 5

Move: Left
_ 8 3
2 6 4
1 7 5

Move: Down
2 8 3
_ 6 4
1 7 5

Move: Right
2 8 3
6 _ 4
1 7 5

Move: Down
2 8 3
6 7 4
1 _ 5

Move: Left
2 8 3
6 7 4
_ 1 5

Move: Up
2 8 3

_ 7 4
6 1 5

Move: Right
2 8 3
7 _ 4
6 1 5

Move: Down
2 8 3
7 1 4
6 _ 5

Move: Left
2 8 3
7 1 4
_ 6 5

Move: Up
2 8 3
_ 1 4
7 6 5

Move: Up
_ 8 3
2 1 4
7 6 5

Move: Right
8 _ 3
2 1 4
7 6 5

Move: Down
8 1 3
2 _ 4
7 6 5

Move: Left
8 1 3
_ 2 4
7 6 5

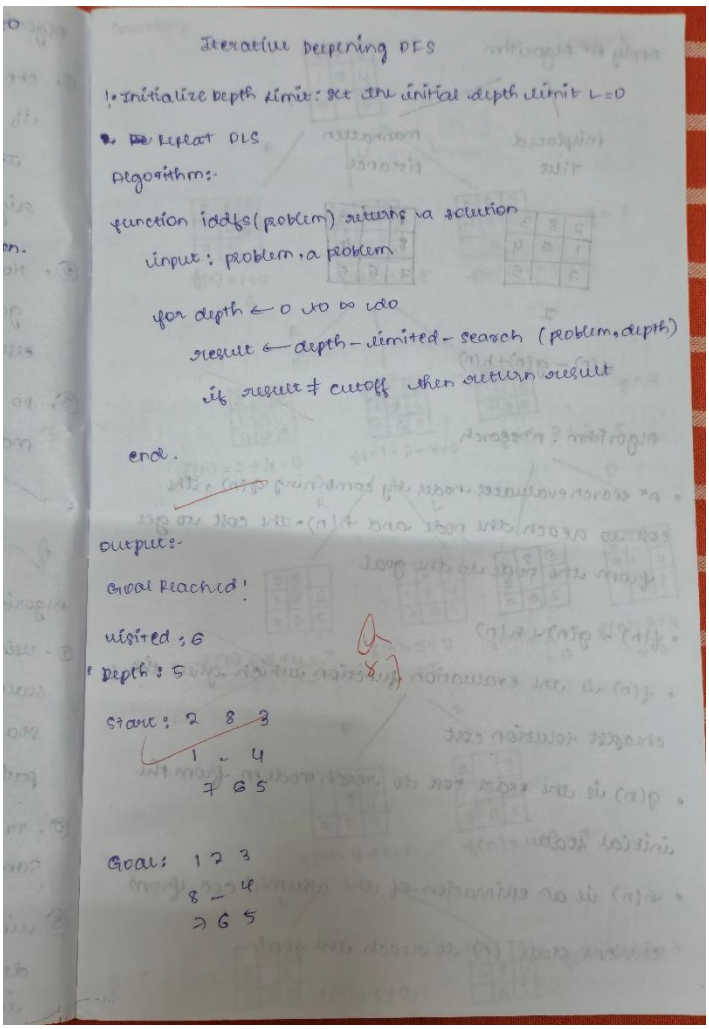
Move: Up
_ 1 3
8 2 4
7 6 5

Move: Right
1 _ 3
8 2 4
7 6 5

Move: Down
1 2 3
8 _ 4
7 6 5

Implement Iterative deepening search algorithm

Algorithm:



Code:

```
import copy

print("Sanjana Srinivas-1BM23CS301\n")
# Goal state
goal_state = [[1, 2, 3],
              [8, 0, 4],
              [7, 6, 5]]

# Moves: Up, Down, Left, Right
moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]

# Find the position of the blank tile (0)
def find_blank(state):
    for i in range(3):
        for j in range(3):
            if state[i][j] == 0:
                return i, j

# Check if the current state is the goal state
def is_goal(state):
    return state == goal_state

# Get all possible neighbors (states) by moving the blank tile
def get_neighbors(state):
    neighbors = []
    x, y = find_blank(state)
    for dx, dy in moves:
        nx, ny = x + dx, y + dy
        if 0 <= nx < 3 and 0 <= ny < 3:
            new_state = copy.deepcopy(state)
            new_state[x][y], new_state[nx][ny] = new_state[nx][ny], new_state[x][y]
            neighbors.append(new_state)
    return neighbors

# Convert the state into a tuple for hashing in the visited set
def state_to_tuple(state):
    return tuple(tuple(row) for row in state)

# Print the current state in a readable format
def print_state(state):
    for row in state:
        print(" ".join(str(num) if num != 0 else "_" for num in row))
    print("----------")
```

```
# Depth-limited DFS
def dfs_limited(state, path, depth, limit, visited):
    if depth == limit:  # If we reached the depth limit, stop exploring
        return None

    # Print the current state (optional, can be commented out for cleaner output)
    print_state(state)

    if is_goal(state):
        return path + [state]  # Return the solution path if goal is found

    visited.add(state_to_tuple(state))  # Mark current state as visited

    for neighbor in get_neighbors(state):
        key = state_to_tuple(neighbor)
        if key not in visited:
            result = dfs_limited(neighbor, path + [state], depth + 1, limit, visited)
            if result:
                return result  # If a valid solution is found, return it

    return None  # No solution found at this depth

# Iterative Deepening DFS
def iddfs(start_state, max_depth=50):
    for limit in range(max_depth + 1):
        print(f"=== Iteration with depth limit {limit} ===")
        visited = set()  # Set to track visited states
        path = dfs_limited(start_state, [], 0, limit, visited)  # Start DFS with depth 0
        if path:
            print("Goal reached!")
            print("Visited:", len(visited))
            print("Solution depth:", len(path) - 1)
            print("Steps:")
            for step in path:
                print_state(step)  # Print the path from start to goal
            return  # Solution found, exit the function
    print("No solution found within depth limit.")  # No solution found after max_depth

# Example usage
start_state = [[2, 8, 3],
               [1, 6, 4],
               [7, 0, 5]]

iddfs(start_state, max_depth=20)  # Start the search with a max depth of 20
```

Output:

Sanjana Srinivas-1BM23CS301

=== Iteration with depth limit 0 ===
=== Iteration with depth limit 1 ===
2 8 3
1 6 4
7 _ 5

=== Iteration with depth limit 2 ===
2 8 3
1 6 4
7 _ 5
---
2 8 3
1 _ 4
7 6 5
---
2 8 3
1 6 4
_ 7 5
---
2 8 3
1 6 4
7 5 _

=== Iteration with depth limit 3 ===
2 8 3
1 6 4
7 _ 5
---
2 8 3
1 _ 4
7 6 5
---
2 _ 3
1 8 4
7 6 5
---
2 8 3
_ 1 4
7 6 5
---
2 8 3
1 4 _
7 6 5
---
2 8 3
1 6 4

_ 7 5
----
2 8 3
_ 6 4
1 7 5
----
2 8 3
1 6 4
7 5 _
----
2 8 3
1 6 _
7 5 4

=== Iteration with depth limit 4 ===
2 8 3
1 6 4
7 _ 5
----
2 8 3
1 _ 4
7 6 5
----
2 _ 3
1 8 4
7 6 5

_ 2 3
1 8 4
7 6 5
----
2 3 _
1 8 4
7 6 5
----
2 8 3
_ 1 4
7 6 5

_ 8 3
2 1 4
7 6 5
----
2 8 3
7 1 4
_ 6 5
----

2 8 3
1 4 _
7 6 5
---
2 8 _
1 4 3
7 6 5
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2 8 3
1 4 5
7 6 _
---
2 8 3
1 6 4
_ 7 5
---
2 8 3
_ 6 4
1 7 5

_ 8 3
2 6 4
1 7 5
---
2 8 3
6 _ 4
1 7 5
---
2 8 3
1 6 4
7 5 _
---
2 8 3
1 6 _
7 5 4
---
2 8 _
1 6 3
7 5 4
---
2 8 3
1 _ 6
7 5 4

=== Iteration with depth limit 5 ===
2 8 3
1 6 4

7 _ 5
---
2 8 3
1 _ 4
7 6 5
---
2 _ 3
1 8 4
7 6 5

_ 2 3
1 8 4
7 6 5
---
1 2 3
_ 8 4
7 6 5
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2 3 _
1 8 4
7 6 5
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2 3 4
1 8 _
7 6 5
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2 8 3
_ 1 4
7 6 5

_ 8 3
2 1 4
7 6 5
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8 _ 3
2 1 4
7 6 5
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2 8 3
7 1 4
_ 6 5
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2 8 3
7 1 4
6 _ 5
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2 8 3

1 4 _
7 6 5
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2 8 _
1 4 3
7 6 5
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2 _ 8
1 4 3
7 6 5
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2 8 3
1 4 5
7 6 _
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2 8 3
1 4 5
7 _ 6
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2 8 3
1 6 4
_ 7 5
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2 8 3
_ 6 4
1 7 5

_ 8 3
2 6 4
1 7 5
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8 _ 3
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2 8 3
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7 5 4
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2 _ 3
1 8 6
7 5 4
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2 8 3
1 5 6
7 _ 4
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2 8 3
_ 1 6
7 5 4

=== Iteration with depth limit 6 ===
2 8 3
1 6 4
7 _ 5
---
2 8 3
1 _ 4
7 6 5
---
2 _ 3
1 8 4

```
7 6 5
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_ 2 3
1 8 4
7 6 5
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1 2 3
_ 8 4
7 6 5
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1 2 3
7 8 4
_ 6 5
----------
1 2 3
8 _ 4
7 6 5
----------
Goal reached!
Visited: 6
Solution depth: 5
Steps:
2 8 3
1 6 4
7 _ 5
----------
2 8 3
1 _ 4
7 6 5
----------
2 _ 3
1 8 4
7 6 5
----------
_ 2 3
1 8 4
7 6 5
----------
1 2 3
_ 8 4
7 6 5
----------
1 2 3
8 _ 4
7 6 5
```
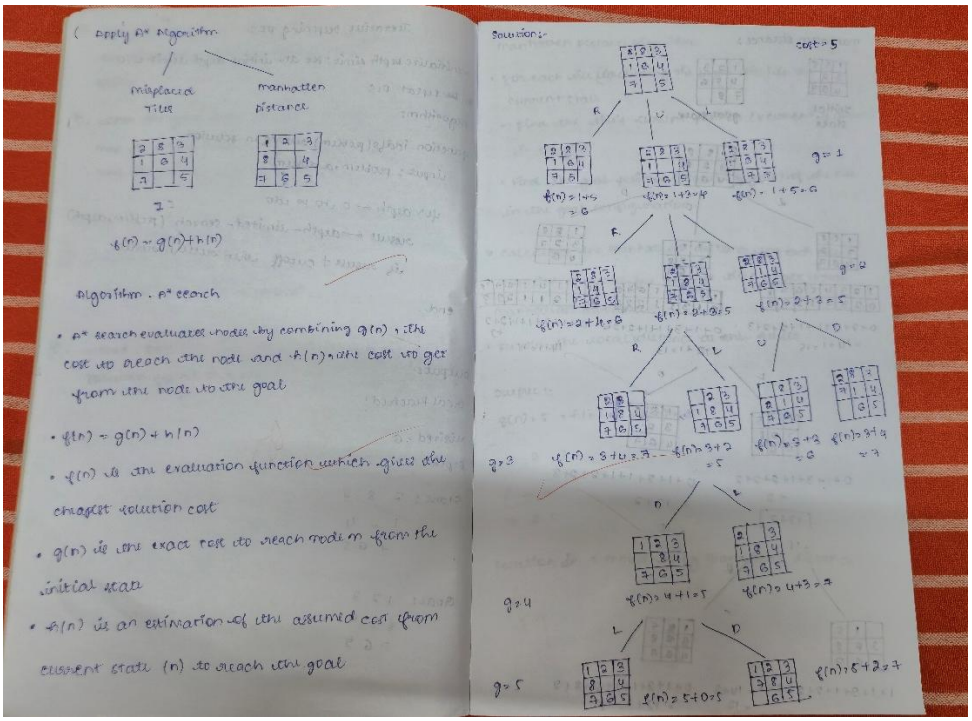
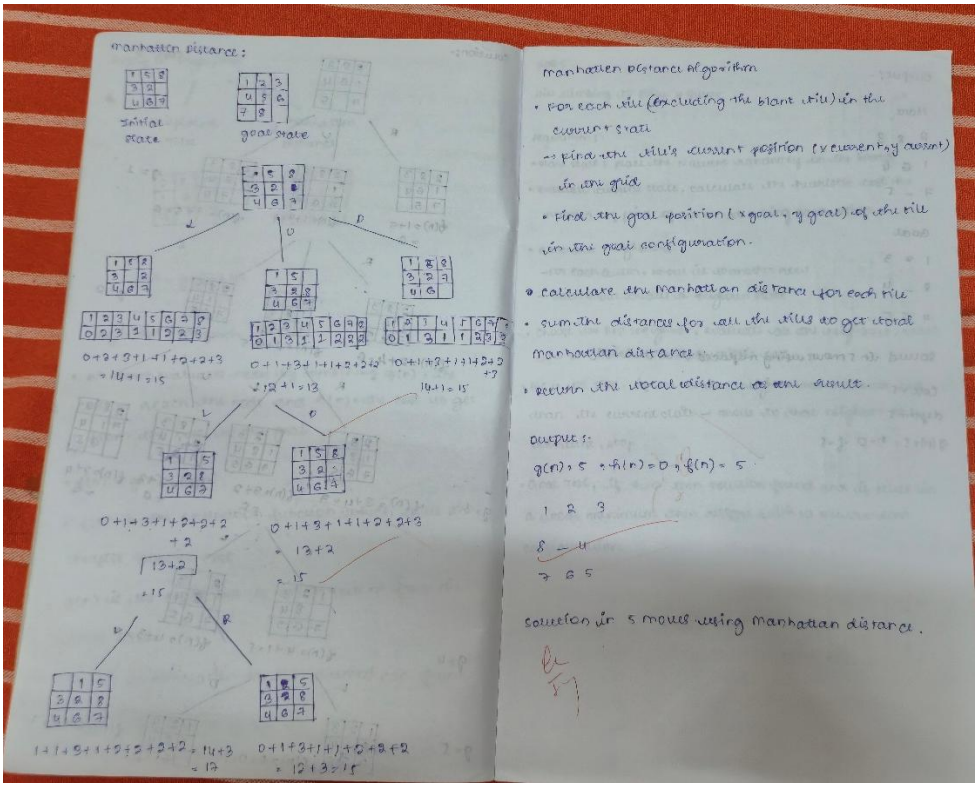
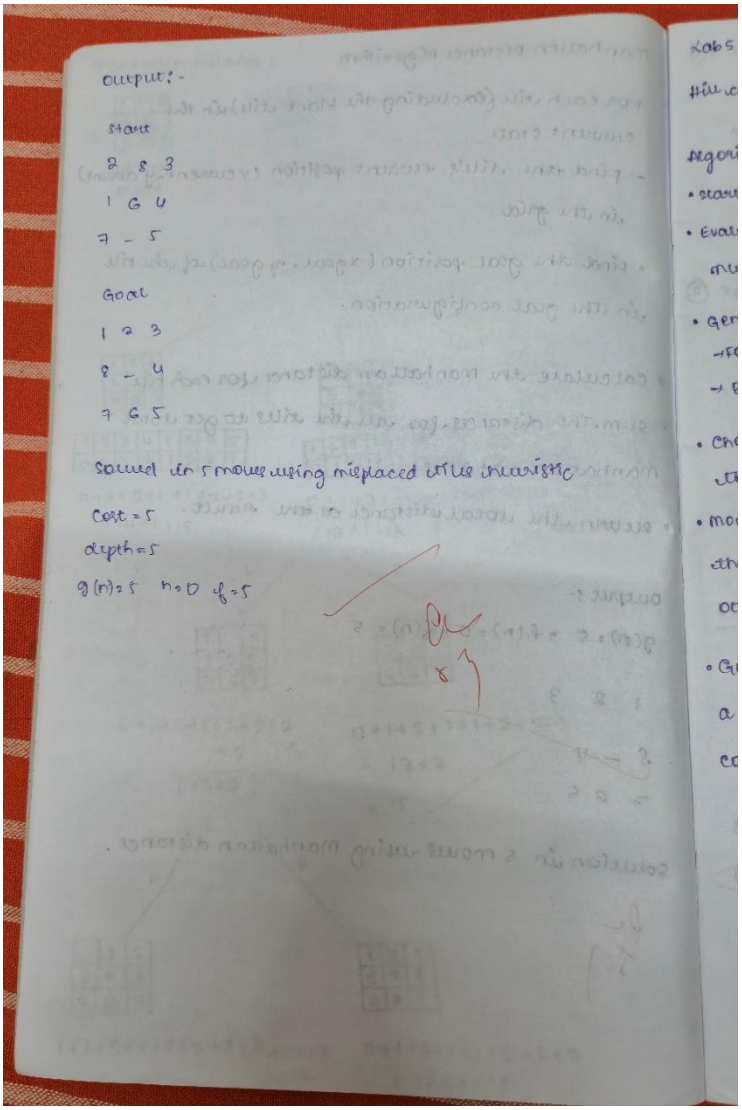

Program 3

Implement A* search algorithm

Algorithm:







Code:

```
print("Sanjana Srinivas-1BM23CS301")

from heapq import heappush, heappop

GOAL = (1, 2, 3,
        8, 0, 4,
        7, 6, 5)  # 0 = blank

GOAL_POS = {v: (i // 3, i % 3) for i, v in enumerate(GOAL)}

def manhattan_distance(state):
    dist = 0
    for i, v in enumerate(state):
        if v != 0:  # skip blank
            r, c = divmod(i, 3)  # current position (row, col)
```

```
            gr, gc = GOAL_POS[v]  # goal position (row, col)
            dist += abs(r - gr) + abs(c - gc)
    return dist

# Inversion parity (checking solvability)
def inversion_parity(state):
    arr = [v for v in state if v != 0]
    inv = 0
    for i in range(len(arr)):
        for j in range(i + 1, len(arr)):
            if arr[i] > arr[j]:
                inv += 1
    return inv % 2

def is_solvable(start, goal):
    """General solvability: start and goal must have same inversion parity."""
    return inversion_parity(start) == inversion_parity(goal)

# Moves: (name, row_delta, col_delta)
MOVES = [
    ("up",    -1,  0),
    ("down",   1,  0),
    ("left",   0, -1),
    ("right",  0,  1),
]

def neighbors(state):
    """Generate (next_state, action) pairs by sliding a tile into the blank."""
    zero = state.index(0)
    zr, zc = divmod(zero, 3)

    for name, dr, dc in MOVES:
        nr, nc = zr + dr, zc + dc
        if 0 <= nr < 3 and 0 <= nc < 3:
            nidx = nr * 3 + nc
            new_state = list(state)
            new_state[zero], new_state[nidx] = new_state[nidx], new_state[zero]
            yield tuple(new_state), name

# ---------- A* search ----------
def a_star(start):
    if not is_solvable(start, GOAL):
        raise ValueError("This puzzle configuration is not solvable.")

    counter = 0
    h0 = manhattan_distance(start)
    frontier = []
```

```
    heappush(frontier, (h0, counter, start))

    g = {start: 0}  # g(n): cost to reach the current state from the start
    parent = {start: None}
    action_to = {start: None}

    while frontier:
        f, _, s = heappop(frontier)

        if s == GOAL:
            # Reconstruct path
            actions, states = [], []
            cur = s
            while cur is not None:
                states.append(cur)
                actions.append(action_to[cur])
                cur = parent[cur]
            actions = actions[-2::-1]  # drop None, reverse
            states = states[::-1]
            return actions, states, g

        for ns, act in neighbors(s):
            tentative_g = g[s] + 1  # g(n) = g(parent) + 1
            if ns not in g or tentative_g < g[ns]:
                g[ns] = tentative_g
                parent[ns] = s
                action_to[ns] = act
                counter += 1
                heappush(frontier, (tentative_g + manhattan_distance(ns), counter, ns))

    raise ValueError("No path found (should not happen for solvable states).")

def print_state(state):
    for r in range(3):
        row = state[3*r:3*r+3]
        print(" ".join(str(x) if x != 0 else "·" for x in row))
    print()

if __name__ == "__main__":
    start = (2, 8, 3,
             1, 6, 4,
             7, 0, 5)

    print("Start:")
    print_state(start)
    print("Goal:")
    print_state(GOAL)
```

```
    try:
        actions, states, g = a_star(start)
        print(f"Solved in {len(actions)} moves using Manhattan distance heuristic.\n")

        # Printing the costs during the search path
        for i, (a, st) in enumerate(zip(actions, states[1:]), start=1):
            g_cost = g[st]  # g(n): cost to reach this state from the start
            h_cost = manhattan_distance(st)  # h(n): Manhattan distance heuristic
            f_cost = g_cost + h_cost  # f(n) = g(n) + h(n)
            print(f"Move {i}: {a}")
            print(f"g(n) = {g_cost}, h(n) = {h_cost}, f(n) = {f_cost}")
            print_state(st)
    except ValueError as e:
        print(e)

print("Sanjana Srinivas-1BM23CS301\n")
from heapq import heappush, heappop

# ---------- Problem setup ----------
GOAL = (1, 2, 3,
        8, 0, 4,
        7, 6, 5)  # 0 = blank

# Heuristic: misplaced tiles
def misplaced_tiles(state):
    return sum(1 for i, v in enumerate(state) if v != 0 and v != GOAL[i])

# Inversion count
def inversion_parity(state):
    arr = [v for v in state if v != 0]
    inv = 0
    for i in range(len(arr)):
        for j in range(i + 1, len(arr)):
            if arr[i] > arr[j]:
                inv += 1
    return inv % 2

def is_solvable(start, goal):
    """General solvability: start and goal must have same inversion parity."""
    return inversion_parity(start) == inversion_parity(goal)

# Moves: (name, row_delta, col_delta)
MOVES = [
    ("up",    -1,  0),
    ("down",   1,  0),
    ("left",   0, -1),
```

```
    ("right",  0,  1),
]

def neighbors(state):
    """Generate (next_state, action) pairs by sliding a tile into the blank."""
    zero = state.index(0)
    zr, zc = divmod(zero, 3)

    for name, dr, dc in MOVES:
        nr, nc = zr + dr, zc + dc
        if 0 <= nr < 3 and 0 <= nc < 3:
            nidx = nr * 3 + nc
            new_state = list(state)
            new_state[zero], new_state[nidx] = new_state[nidx], new_state[zero]
            yield tuple(new_state), name

# ---------- A* search ----------
def a_star(start):
    if not is_solvable(start, GOAL):
        raise ValueError("This puzzle configuration is not solvable.")

    counter = 0
    h0 = misplaced_tiles(start)
    frontier = []
    heappush(frontier, (h0, counter, start))

    g = {start: 0}
    parent = {start: None}
    action_to = {start: None}

    while frontier:
        f, _, s = heappop(frontier)

        if s == GOAL:
            # Reconstruct path
            actions, states = [], []
            cur = s
            while cur is not None:
                states.append(cur)
                actions.append(action_to[cur])
                cur = parent[cur]
            actions = actions[-2::-1]  # drop None, reverse
            states = states[::-1]
            return actions, states, g

        for ns, act in neighbors(s):
            tentative_g = g[s] + 1
```

```
            if ns not in g or tentative_g < g[ns]:
                g[ns] = tentative_g
                parent[ns] = s
                action_to[ns] = act
                counter += 1
                heappush(frontier, (tentative_g + misplaced_tiles(ns), counter, ns))

    raise ValueError("No path found (should not happen for solvable states).")

# ---------- Pretty printing ----------
def print_state(state):
    for r in range(3):
        row = state[3*r:3*r+3]
        print(" ".join(str(x) if x != 0 else "·" for x in row))
    print()

# ---------- Example ----------
if __name__ == "__main__":
    start = (2, 8, 3,
             1, 6, 4,
             7, 0, 5)

    print("Start:")
    print_state(start)
    print("Goal:")
    print_state(GOAL)

    try:
        actions, states, g = a_star(start)
        print(f"Solved in {len(actions)} moves using misplaced-tiles heuristic.\n")
        for i, (a, st) in enumerate(zip(actions, states[1:]), start=1):
            g_cost = g[st]
            h_cost = misplaced_tiles(st)
            f_cost = g_cost + h_cost
            print(f"Move {i}: {a}")
            print(f"g={g_cost}, h={h_cost}, f={f_cost}")
            print_state(st)
    except ValueError as e:
        print(e)
```

Output:

```
Sanjana Srinivas-1BM23CS301
Start:
2 8 3
1 6 4
7 · 5
```

Goal:
1 2 3
8 · 4
7 6 5

Solved in 5 moves using Manhattan distance heuristic.

Move 1: up
g(n) = 1, h(n) = 4, f(n) = 5
2 8 3
1 · 4
7 6 5

Move 2: up
g(n) = 2, h(n) = 3, f(n) = 5
2 · 3
1 8 4
7 6 5

Move 3: left
g(n) = 3, h(n) = 2, f(n) = 5
· 2 3
1 8 4
7 6 5

Move 4: down
g(n) = 4, h(n) = 1, f(n) = 5
1 2 3
· 8 4
7 6 5

Move 5: right
g(n) = 5, h(n) = 0, f(n) = 5
1 2 3
8 · 4
7 6 5

Sanjana Srinivas-1BM23CS301

Start:
2 8 3
1 6 4
7 · 5

Goal:
1 2 3
8 · 4

7 6 5

Solved in 5 moves using misplaced-tiles heuristic.

Move 1: up
g=1, h=3, f=4
2 8 3
1 · 4
7 6 5

Move 2: up
g=2, h=3, f=5
2 · 3
1 8 4
7 6 5

Move 3: left
g=3, h=2, f=5
· 2 3
1 8 4
7 6 5

Move 4: down
g=4, h=1, f=5
1 2 3
· 8 4
7 6 5

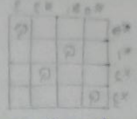
Move 5: right
g=5, h=0, f=5
1 2 3
8 · 4
7 6 5

Program 4
Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm:

Lab 5

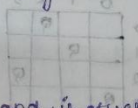
Hill climbing to solve 4 Queens



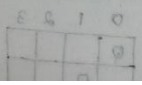
Algorithm:-

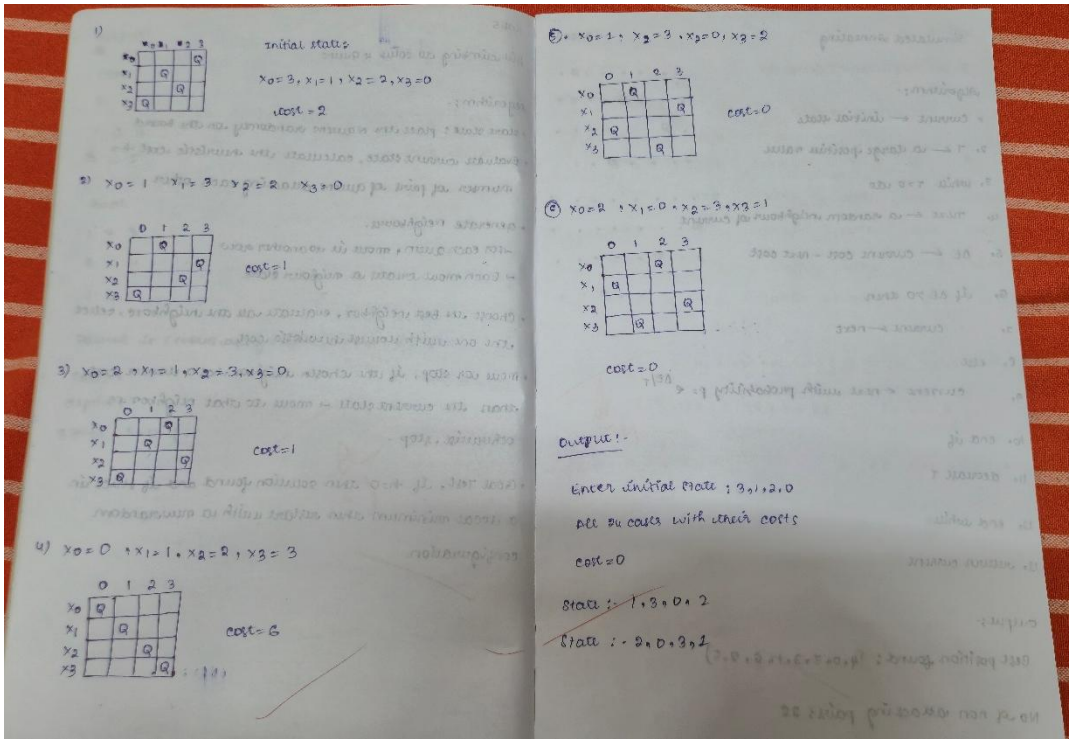
- Start state: place the N queens randomly on the board.
- Evaluate current state, calculate the heuristic cost h = number of pairs of queens attacking each other
- Generate Neighbours.
  - → For each queen, move it to another row
  - → Each move create a neighbour state

- Choose the Best neighbor, evaluate all the neighbors, select the one with lowest heuristic cost.
- Move or stop, if the chosen neighbor has a lower cost than the current state → move to that neighbor or otherwise, stop.



- Goal Test, if $h=0$ then solution found and if stuck in a local minimum then restart with a new random configuration





Code:

```
from itertools import permutations
print("Sanjana Srinivas-1BM23CS301\n")
def compute_cost(state):
    conflicts = 0
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            if abs(state[i] - state[j]) == abs(i - j):
                conflicts += 1
    return conflicts

def format_board(state):
    n = len(state)
    board_lines = []
    for row in range(n):
        row_str = " ".join("Q" if state[col] == row else "-" for col in range(n))
        board_lines.append(row_str)
    return "\n".join(board_lines)

def is_valid_permutation(state):
    return sorted(state) == list(range(len(state)))

def main():
    n = 4
    all_states = list(permutations(range(n)))
    costs = []

    print(f"Total possible permutations: {len(all_states)}\n")

    # Calculate costs for all states
    for state in all_states:
        cost = compute_cost(state)
        costs.append((state, cost))

    # Find minimum cost
    min_cost = min(costs, key=lambda x: x[1])[1]
    best_solutions = [state for state, cost in costs if cost == min_cost]

    # Print all states with their costs
    print("All permutations with their costs:\n")
    for idx, (state, cost) in enumerate(costs, 1):
        print(f"Case {idx}: {state} | Conflicts = {cost}")
        print(format_board(state))
        print("-" * 40)

    # Print best solution(s)
```

```
    print(f"\nLowest cost = {min_cost}")
    print("Best solution(s):\n")
    for state in best_solutions:
        print(f"State: {state} | Conflicts = {min_cost}")
        print(format_board(state))
        print("-" * 40)

if __name__ == "__main__":
    main()
```

Output:

Sanjana Srinivas-1BM23CS301

Total possible permutations: 24

All permutations with their costs:

Case 1: (0, 1, 2, 3) | Conflicts = 6
Q - - -
- Q - -
- - Q -
- - - Q

Case 2: (0, 1, 3, 2) | Conflicts = 2
Q - - -
- Q - -
- - - Q
- - Q -

Case 3: (0, 2, 1, 3) | Conflicts = 2
Q - - -
- - Q -
- Q - -
- - - Q

Case 4: (0, 2, 3, 1) | Conflicts = 1
Q - - -
- - - Q
- Q - -
- - Q -

Case 5: (0, 3, 1, 2) | Conflicts = 1
Q - - -
- - Q -
- - - Q
- Q - -

Case 6: (0, 3, 2, 1) | Conflicts = 4
Q - - -
- - - Q
- - Q -
- Q - -

Case 7: (1, 0, 2, 3) | Conflicts = 2
- Q - -
Q - - -
- - Q -
- - - Q

Case 8: (1, 0, 3, 2) | Conflicts = 4
- Q - -
Q - - -
- - - Q
- - Q -

Case 9: (1, 2, 0, 3) | Conflicts = 1
- - Q -
Q - - -
- Q - -
- - - Q

Case 10: (1, 2, 3, 0) | Conflicts = 4
- - - Q
Q - - -
- Q - -
- - Q -

Case 11: (1, 3, 0, 2) | Conflicts = 0
- - Q -
Q - - -
- - - Q
- Q - -

Case 12: (1, 3, 2, 0) | Conflicts = 1
- - - Q
Q - - -
- - Q -
- Q - -

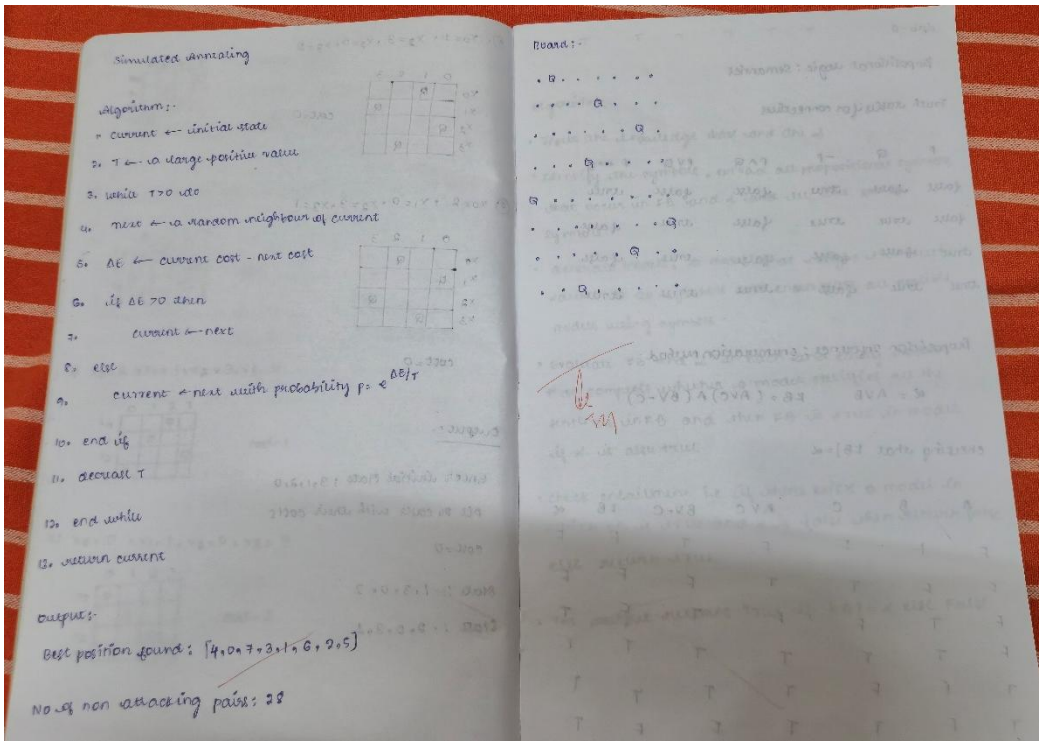
Case 13: (2, 0, 1, 3) | Conflicts = 1
- Q - -
- - Q -
Q - - -
- - - Q

```
----------------------------------------
Case 14: (2, 0, 3, 1) | Conflicts = 0
- Q - -
- - - Q
Q - - -
- - Q -
----------------------------------------
Case 15: (2, 1, 0, 3) | Conflicts = 4
- - Q -
- Q - -
Q - - -
- - - Q
----------------------------------------
Case 16: (2, 1, 3, 0) | Conflicts = 1
- - - Q
- Q - -
Q - - -
- - Q -
----------------------------------------
Case 17: (2, 3, 0, 1) | Conflicts = 4
- - Q -
- - - Q
Q - - -
- Q - -
----------------------------------------
Case 18: (2, 3, 1, 0) | Conflicts = 2
- - - Q
- - Q -
Q - - -
- Q - -
----------------------------------------
Case 19: (3, 0, 1, 2) | Conflicts = 4
- Q - -
- - Q -
- - - Q
Q - - -
----------------------------------------
Case 20: (3, 0, 2, 1) | Conflicts = 1
- Q - -
- - - Q
- - Q -
Q - - -
----------------------------------------
Case 21: (3, 1, 0, 2) | Conflicts = 1
- - Q -
- Q - -
- - - Q
```

```
Q - - -
----------------------------------------
Case 22: (3, 1, 2, 0) | Conflicts = 2
- - - Q
- Q - -
- - Q -
Q - - -
----------------------------------------
Case 23: (3, 2, 0, 1) | Conflicts = 2
- - Q -
- - - Q
- Q - -
Q - - -
----------------------------------------
Case 24: (3, 2, 1, 0) | Conflicts = 6
- - - Q
- - Q -
- Q - -
Q - - -
----------------------------------------

Lowest cost = 0
Best solution(s):

State: (1, 3, 0, 2) | Conflicts = 0
- - Q -
Q - - -
- - - Q
- Q - -
----------------------------------------
State: (2, 0, 3, 1) | Conflicts = 0
- Q - -
- - - Q
Q - - -
- - Q -
----------------------------------------
```

Program 5
Simulated Annealing to Solve 8-Queens problem

Algorithm:



Code:

```
print("Sanjana Srinivas-1BM23CS301\n")
import random
import math

def cost(state):
    """Calculate number of attacking pairs in the state."""
    attacks = 0
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                attacks += 1
    return attacks

def get_neighbor(state):
    """Generate a neighbor by swapping two random positions."""
    neighbor = state[:]
    i, j = random.sample(range(len(state)), 2)
    neighbor[i], neighbor[j] = neighbor[j], neighbor[i]
    return neighbor

def simulated_annealing(n=8, max_iter=10000, temp=100.0, cooling=0.95):
    """Perform simulated annealing to solve N-Queens."""
    current = list(range(n))
    random.shuffle(current)
```

```
    current_cost = cost(current)

    temperature = temp
    cooling_rate = cooling

    best = current[:]
    best_cost = current_cost

    for _ in range(max_iter):
        if temperature <= 0 or best_cost == 0:
            break

        neighbor = get_neighbor(current)
        neighbor_cost = cost(neighbor)
        delta = current_cost - neighbor_cost

        if delta > 0 or random.random() < math.exp(delta / temperature):
            current, current_cost = neighbor, neighbor_cost
            if neighbor_cost < best_cost:
                best, best_cost = neighbor[:], neighbor_cost

        temperature *= cooling_rate

    return best, best_cost

def print_board(state):
    """Print the board in a readable format."""
    n = len(state)
    for row in range(n):
        line = " ".join("Q" if state[col] == row else "." for col in range(n))
        print(line)
    print()

if __name__ == "__main__":
    n = 8
    solution, cost_val = simulated_annealing(n, max_iter=20000)

    print("Best position found:", solution)
    print(f"Number of non-attacking pairs: {n*(n-1)//2 - cost_val}")
    print("\nBoard:")
    print_board(solution)
```

Output:

Sanjana Srinivas-1BM23CS301

Best position found: [4, 0, 7, 3, 1, 6, 2, 5]
Number of non-attacking pairs: 28

Board:
. Q . . . . . .
. . . . Q . . .
. . . . . . Q .
. . . Q . . . .
Q . . . . . .
. . . . Q
. . . . . Q . .
. . Q . . . . .

Program 6
Create a knowledge base using propositional logic and show that the given query entails the knowledge base or not.

Algorithm:

Code:
```
print("Sanjana Srinivas-1BM23CS301")
from itertools import product

# --- Utility to parse logical expressions safely ---
def eval_formula(expr, model):
    # Replace propositional symbols with model values
    for sym, val in model.items():
        expr = expr.replace(sym, str(val))

    # Replace logical operators with Python equivalents
    expr = expr.replace("¬", " not ")
    expr = expr.replace("∧", " and ")
    expr = expr.replace("∨", " or ")
    expr = expr.replace("→", " <= ")   # A → B ≡ (not A) or B
    expr = expr.replace("↔", " == ")   # A ↔ B ≡ (A == B)

    return eval(expr)

# --- Main program ---
print("Available logical operators you can use in input formulas:")
print("  Negation (NOT):        ¬")
print("  Conjunction (AND):     ∧")
print("  Disjunction (OR):      ∨")
print("  Implication (IMPLIES): →")
print("  Biconditional (IFF):   ↔")
print("-" * 50)

symbols = input("Enter symbols separated by space (e.g., P Q R): ").split()
```

```
kb_expr = input("Enter Knowledge Base formula (e.g., (P ∧ Q) → R): ")
query_expr = input("Enter Query formula α (e.g., R): ")

print("\nKnowledge Base (KB):", kb_expr)
print("Query (α):", query_expr, "\n")

# Function to print truth table
def print_truth_table(kb_expr, query_expr, symbols):
    header = symbols + ["KB", "α"]
    print(" | ".join(f"{h:^5}" for h in header))
    print("-" * (7 * len(header)))

    for values in product([False, True], repeat=len(symbols)):
        model = dict(zip(symbols, values))
        kb_val = eval_formula(kb_expr, model)
        q_val = eval_formula(query_expr, model)
        row = [model[s] for s in symbols] + [kb_val, q_val]
        print(" | ".join(f"{str(r):^5}" for r in row))

# Entailment check
def entails(kb_expr, query_expr, symbols):
    for values in product([True, False], repeat=len(symbols)):
        model = dict(zip(symbols, values))
        if eval_formula(kb_expr, model):   # KB true
            if not eval_formula(query_expr, model):  # Query false → not entailed
                return False
    return True

# Run
print_truth_table(kb_expr, query_expr, symbols)
result = entails(kb_expr, query_expr, symbols)
print("\nDoes KB entail Query (α)? :", result)
```

Output:

```
Sanjana Srinivas-1BM23CS301
Available logical operators you can use in input formulas:
  Negation (NOT):       ¬
  Conjunction (AND):    ∧
  Disjunction (OR):     ∨
  Implication (IMPLIES): →
  Biconditional (IFF):  ↔
--------------------------------------------------
Enter symbols separated by space (e.g., P Q R): A B C
Enter Knowledge Base formula (e.g., (P ∧ Q) → R): (A∨C) ∧ (B∨¬C)
Enter Query formula α (e.g., R):  A ∨ B

Knowledge Base (KB): (A∨C) ∧ (B∨¬C)
```

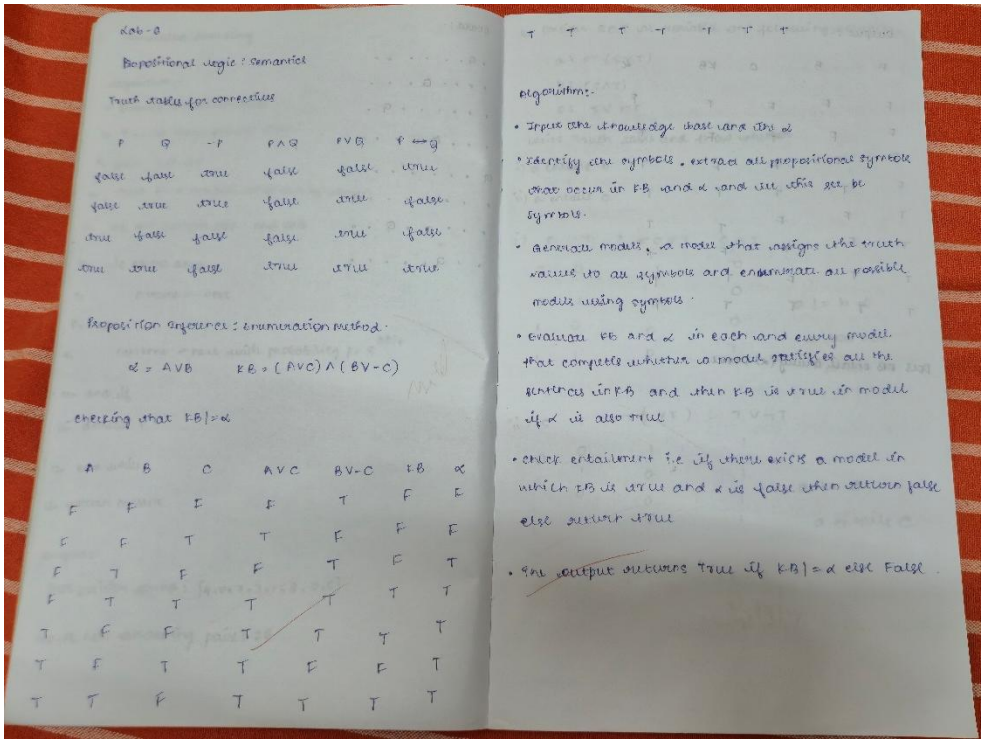
Query (α): A ∨ B

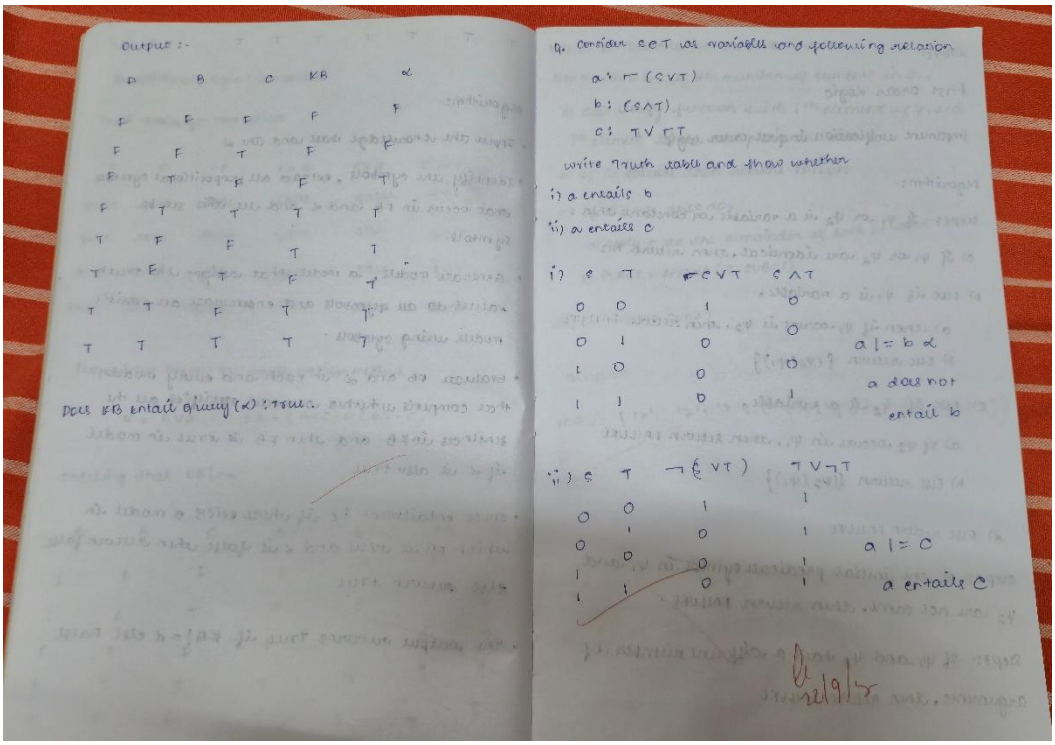
A	B	C	KB	α
False	False	False	False	False
False	False	True	False	False
False	True	False	False	True
False	True	True	True	True
True	False	False	True	True
True	False	True	False	True
True	True	False	True	True
True	True	True	True	True

Does KB entail Query (α)? : True

Program 7
Implement unification in first order logic

Algorithm:





Code:

```
print("Sanjana Srinivas-1BM23CS301")
def unify(x, y, substitutions=None):
    if substitutions is None:
        substitutions = {}

    if x == y:
        return substitutions

    # If x is a variable
    if is_variable(x):
        return unify_var(x, y, substitutions)

    # If y is a variable
    if is_variable(y):
        return unify_var(y, x, substitutions)

    # If both are compound terms (like f(a), g(X), etc.)
    if isinstance(x, tuple) and isinstance(y, tuple):
        if x[0] != y[0] or len(x[1]) != len(y[1]):
            return None
        for xi, yi in zip(x[1], y[1]):
            substitutions = unify(apply(substitutions, xi), apply(substitutions, yi), substitutions)
            if substitutions is None:
                return None
```

```
        return substitutions
    return None


def unify_var(var, x, substitutions):
    if var in substitutions:
        return unify(substitutions[var], x, substitutions)
    elif occurs_check(var, x, substitutions):
        return None
    else:
        substitutions[var] = x
        return substitutions


def occurs_check(var, x, substitutions):
    if var == x:
        return True
    elif isinstance(x, tuple):
        return any(occurs_check(var, xi, substitutions) for xi in x[1])
    elif isinstance(x, str) and x in substitutions:
        return occurs_check(var, substitutions[x], substitutions)
    return False


def apply(substitutions, expr):
    if isinstance(expr, str):
        return substitutions.get(expr, expr)
    elif isinstance(expr, tuple):
        return (expr[0], [apply(substitutions, e) for e in expr[1]])
    else:
        return expr


def is_variable(x):
    # A variable is a single lowercase letter (e.g., x, y, z)
    return isinstance(x, str) and len(x) == 1 and x.islower()


def parse(expr):
    expr = expr.replace(" ", "")
    if '(' not in expr:
        return expr
    functor = expr.split('(')[0]
    args = expr[len(functor) + 1:-1]
    parts, depth, start = [], 0, 0
    for i, c in enumerate(args):
        if c == ',' and depth == 0:
```

```
            parts.append(args[start:i])
            start = i + 1
        elif c == '(':
            depth += 1
        elif c == ')':
            depth -= 1
    parts.append(args[start:])
    return (functor, [parse(p) for p in parts])


# -------- TEST CASES --------
tests = [
    ("p(b,x,f(g(z)))", "p(z,f(y),f(y))"),  # fixed the extra parenthesis
    ("Q(a,g(x,a),f(y))", "Q(a,g(f(b),a),x)"),
    ("p(f(a),g(Y))", "p(X,X)"),
    ("prime(11)", "prime(y)"),
    ("knows(John,x)", "knows(y,mother(y))"),
    ("knows(John,x)", "knows(y,Bill)")
]

print(" UNIFICATION RESULTS \n")
for i, (a, b) in enumerate(tests, start=1):
    e1 = parse(a)
    e2 = parse(b)
    result = unify(e1, e2)
    print(f"Q{i}: {a}  AND  {b}")
    if result is None:
        print("MGU = FAIL\n")
    else:
        print("MGU =", result, "\n")
```

Output:

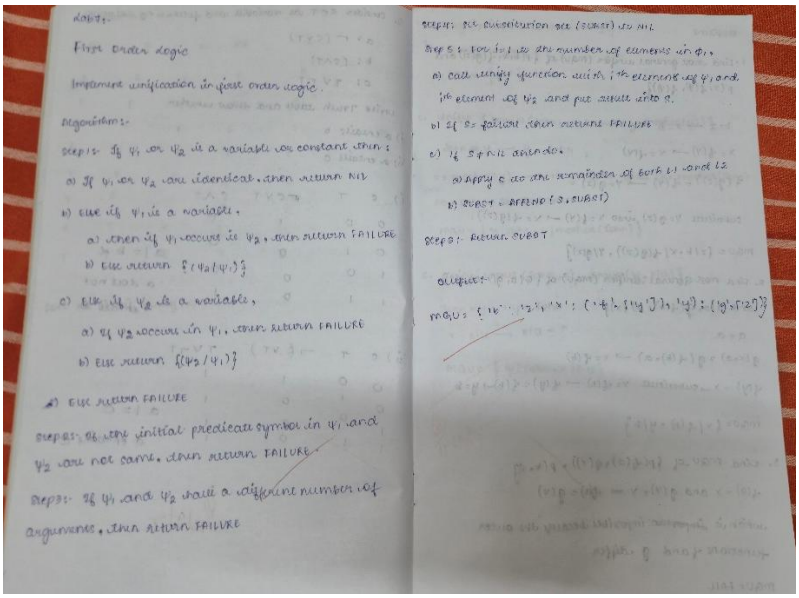
```
Sanjana Srinivas-1BM23CS301
 UNIFICATION RESULTS

Q1: p(b,x,f(g(z)))  AND  p(z,f(y),f(y))
MGU = {'b': 'z', 'x': ('f', ['y']), 'y': ('g', ['z'])}

Q2: Q(a,g(x,a),f(y))  AND  Q(a,g(f(b),a),x)
MGU = {'x': ('f', ['b']), 'y': 'b'}

Q3: p(f(a),g(Y))  AND  p(X,X)
MGU = FAIL

Q4: prime(11)  AND  prime(y)
MGU = {'y': '11'}
```

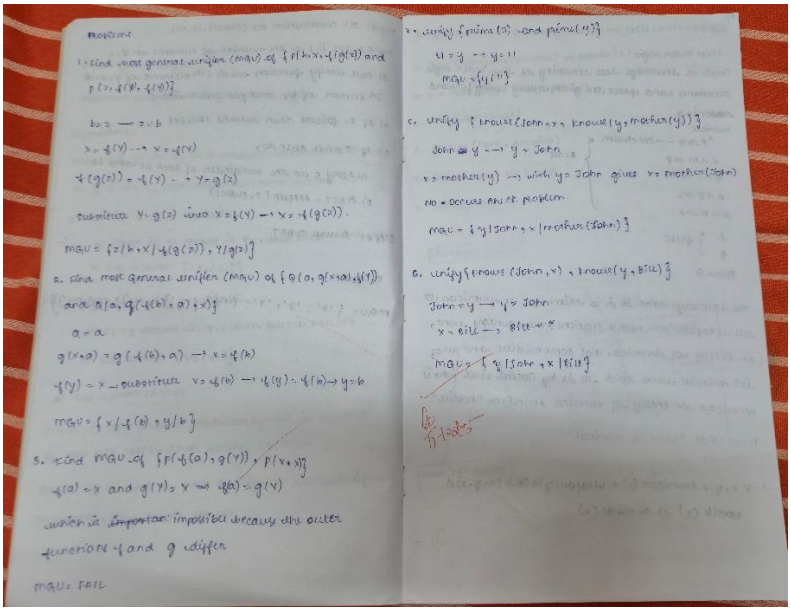
Q5: knows(John,x) AND knows(y,mother(y))
MGU = {'y': 'John', 'x': ('mother', ['John'])}

Q6: knows(John,x) AND knows(y,Bill)
MGU = {'y': 'John', 'x': 'Bill'}

Program 8
Create a knowledge base consisting of first order logic statements and prove the given query using forward reasoning.

Algorithm:





Code:

```
import re

def match_pattern(pattern, fact):
    pat_pred, pat_args = re.match(r'(\w+)', pattern).groups()
    fact_pred, fact_args = re.match(r'(\w+)', fact).groups()

    # Predicate names must match
    if pat_pred != fact_pred:
        return None

    pat_args = [a.strip() for a in pat_args.split(",")]
    fact_args = [a.strip() for a in fact_args.split(",")]

    if len(pat_args) != len(fact_args):
        return None

    subst = {}
    for p_arg, f_arg in zip(pat_args, fact_args):
        # Variables are lowercase identifiers (e.g., p, x, y)
        if re.fullmatch(r'[a-z]\w*', p_arg):
            subst[p_arg] = f_arg
        elif p_arg != f_arg:
            return None
    return subst


def apply_substitution(expr, subst):

    for var, val in subst.items():
        expr = re.sub(rf'\b{var}\b', val, expr)
    return expr


rules = [
    (["American(p)", "Weapon(q)", "Sells(p,q,r)", "Hostile(r)"], "Criminal(p)"),
    (["Missile(x)"], "Weapon(x)"),
    (["Enemy(x, America)"], "Hostile(x)"),
    (["Missile(x)", "Owns(A, x)"], "Sells(Robert, x, A)")
]

facts = {
    "American(Robert)",
    "Enemy(A, America)",
    "Owns(A, T1)",
    "Missile(T1)"
```

```
}

goal = "Criminal(Robert)"

def forward_chain(rules, facts, goal):
    added = True
    while added:
        added = False
        for premises, conclusion in rules:
            possible_substs = []

            # Check each premise of the rule
            for p in premises:
                matched = False
                for f in facts:
                    subst = match_pattern(p, f)
                    if subst:
                        possible_substs.append(subst)
                        matched = True
                        break
                if not matched:
                    break  # one premise fails → skip rule
            else:
                # Combine substitutions into one dictionary
                combined = {}
                for s in possible_substs:
                    combined.update(s)

                new_fact = apply_substitution(conclusion, combined)

                if new_fact not in facts:
                    facts.add(new_fact)
                    print(f"Inferred: {new_fact}")
                    added = True
                    if new_fact == goal:
                        return True
    return goal in facts

print("Goal achieved:", forward_chain(rules, facts, goal))
```

Output:

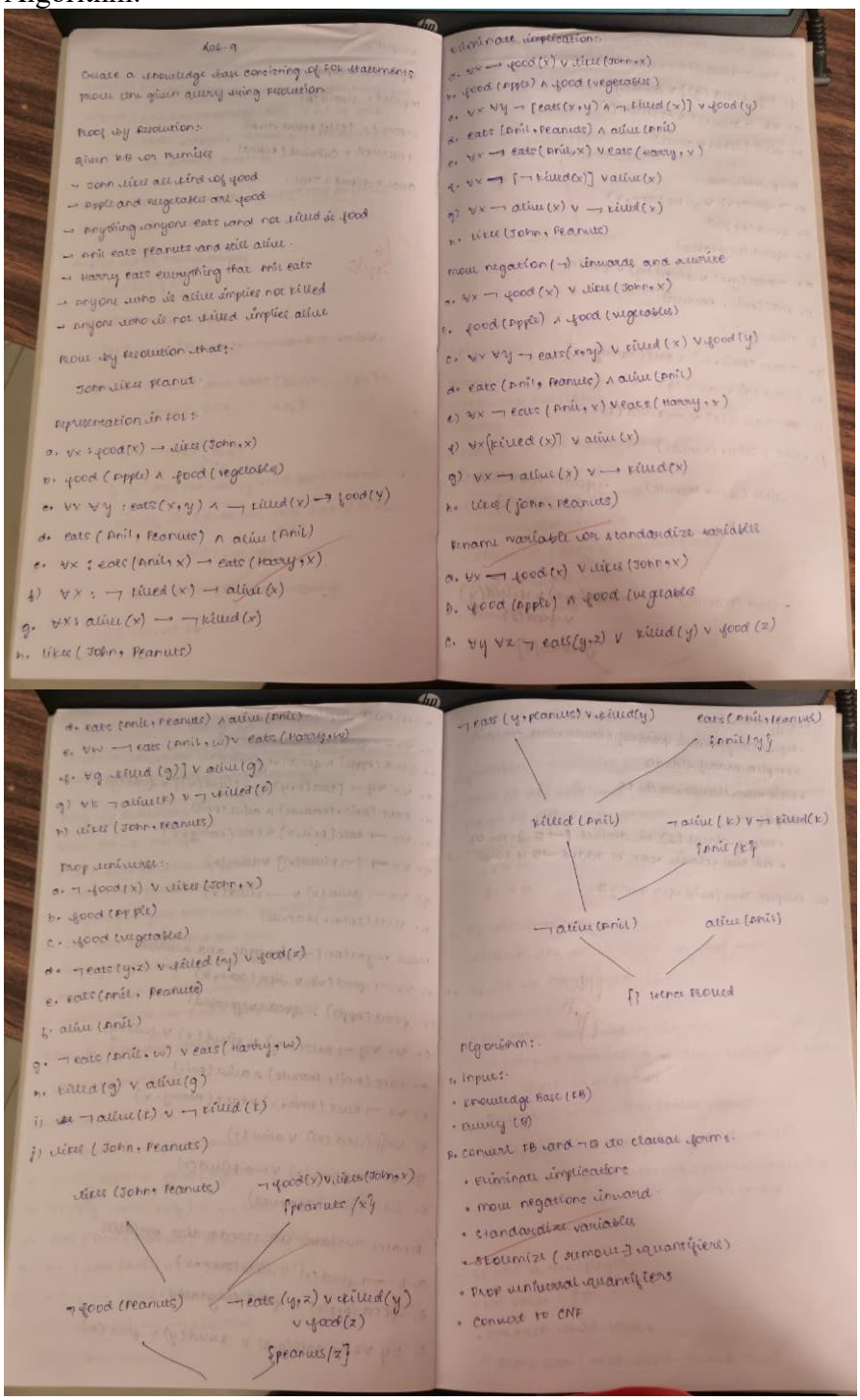
```
Sanjana Srinivas-1BM23CS301
Inferred: Weapon(T1)
Inferred: Hostile(A)
Inferred: Sells(Robert, T1, A)
Inferred: Criminal(Robert)
```

Goal achieved: True

Program 9

Create a knowledge base consisting of first order logic statements and prove the given query using Resolution

Algorithm:



3. Apply Resolution:
   - Repeatedly resolve pairs of clauses that contain complementary literals
   - Add new clauses to the KB
   - Stop if:
     - Empty clause ($\perp$) is derived $\rightarrow$ Q is true or
     - No new clauses can be added $\rightarrow$ Q is false

4. Output True / False for query Q.

Code:

```
print("Sanjana Srinivas-1BM23CS301")
import re
import copy

def __init__(self, predicate_string):
        self.predicate_string = predicate_string.strip()
        self.name, self.arguments, self.negative = self.parse_predicate(self.predicate_string)

    def parse_predicate(self, predicate_string):

        s = predicate_string.strip()
        neg = False
        while s.startswith('~'):
            neg = not neg
            s = s[1:].strip()
        m = re.match(r"^([A-Za-z_][A-Za-z0-9_]*)$", s)
        if not m:
            raise ValueError(f"Invalid predicate: {predicate_string}")
        name, args = m.groups()
        args = [a.strip() for a in args.split(",") if a.strip() != ""]
        return name, args, neg

    def negate(self):
        self.negative = not self.negative
        self.predicate_string = ("~" if self.negative else "") + self.name + "(" + ",".join(self.arguments) +
")"

    def unify_with_predicate(self, other):
        if self.name != other.name or len(self.arguments) != len(other.arguments):
            return False
        subs = {}

        def is_var(x):
            return len(x) > 0 and x[0].islower()

        for a, b in zip(self.arguments, other.arguments):
            if a == b:
                continue
            if is_var(a) and is_var(b):
                if a in subs and subs[a] != b:
                    return False
                if b in subs and subs[b] != a:
                    return False
                subs[a] = b
```

```
            elif is_var(a):
                if a in subs and subs[a] != b:
                    return False
                subs[a] = b
            elif is_var(b):
                if b in subs and subs[b] != a:
                    return False
                subs[b] = a
            else:
                return False
        return subs

    def substitute(self, subs):
        self.arguments = [subs.get(a, a) for a in self.arguments]
        self.predicate_string = ("~" if self.negative else "") + self.name + "(" + ",".join(self.arguments) +
")"

    def __repr__(self):
        return self.predicate_string

    def __eq__(self, other):
        return isinstance(other, Predicate) and self.name == other.name and self.arguments ==
other.arguments and self.negative == other.negative

    def __hash__(self):
        return hash((self.name, tuple(self.arguments), self.negative))

class Statement:
    def __init__(self, statement_string):
        self.statement_string = statement_string.strip()
        self.predicate_set = self.parse_statement(self.statement_string)

    def parse_statement(self, statement_string):
        parts = [p.strip() for p in statement_string.split('|') if p.strip() != '']
        predicates = [Predicate(p) for p in parts]
        return frozenset(predicates)

    def add_statement_to_KB(self, KB, KB_HASH):
        if self in KB:
            return
        KB.add(self)
        for predicate in self.predicate_set:
            key = predicate.name
            if key not in KB_HASH:
                KB_HASH[key] = set()
            KB_HASH[key].add(self)
```

```
    def get_resolving_clauses(self, KB_HASH):
        resolving_clauses = set()
        for predicate in self.predicate_set:
            key = predicate.name
            if key in KB_HASH:
                resolving_clauses |= KB_HASH[key]
        return resolving_clauses

    def resolve(self, other):
        new_statements = set()
        for p1 in self.predicate_set:
            for p2 in other.predicate_set:
                if p1.name == p2.name and p1.negative != p2.negative:
                    subs = p1.unify_with_predicate(p2)
                    if subs is False:
                        continue
                    new_pred_set = set()
                    for pred in (set(self.predicate_set) | set(other.predicate_set)):
                        if pred == p1 or pred == p2:
                            continue
                        pred_copy = copy.deepcopy(pred)
                        pred_copy.substitute(subs)
                        new_pred_set.add(pred_copy)
                    if not new_pred_set:
                        return False  # contradiction (empty clause)
                    sorted_preds = sorted([str(p) for p in new_pred_set])
                    new_stmt = Statement('|'.join(sorted_preds))
                    new_statements.add(new_stmt)
        return new_statements

    def __repr__(self):
        sorted_preds = sorted([str(p) for p in self.predicate_set])
        return '|'.join(sorted_preds)

    def __eq__(self, other):
        return isinstance(other, Statement) and self.predicate_set == other.predicate_set

    def __hash__(self):
        return hash(self.predicate_set)

def fol_to_cnf_clauses(sentence):

    sentence = sentence.replace(' ', '')
    if '=>' in sentence:
        lhs, rhs = sentence.split('=>')
        parts = [p for p in lhs.split('&') if p != '']
        negated_lhs = []
```

```
        for p in parts:
            if p.startswith('~'):
                negated_lhs.append(p[1:])
            else:
                negated_lhs.append('~' + p)
        disjunction = '|'.join(negated_lhs + [rhs])
        return [disjunction]
    if '&' in sentence:
        return [c for c in sentence.split('&') if c != '']
    return [sentence]

KILL_LIMIT = 8000

def prepare_knowledgebase(fol_sentences):
    KB = set()
    KB_HASH = {}
    for sentence in fol_sentences:
        clauses = fol_to_cnf_clauses(sentence)
        for clause in clauses:
            stmt = Statement(clause)
            stmt.add_statement_to_KB(KB, KB_HASH)
    return KB, KB_HASH

def FOL_Resolution(KB, KB_HASH, query, verbose=True):
    KB = set(KB)
    KB_HASH = {k: set(v) for k, v in KB_HASH.items()}

    query.add_statement_to_KB(KB, KB_HASH)
    if verbose:
        print("\nInitial KB clauses (including negated query):")
        for s in KB:
            print("  ", s)

    iterations = 0
    while True:
        iterations += 1
        if len(KB) > KILL_LIMIT:
            if verbose:
                print("Reached KILL_LIMIT, stopping.")
            return False
        new_statements = set()
        kb_list = list(KB)
        for s1 in kb_list:
            for s2 in s1.get_resolving_clauses(KB_HASH):
                if s1 == s2:
                    continue
                resolvents = s1.resolve(s2)
```

```
            if resolvents is False:
                if verbose:
                    print(f"\nCONTRADICTION derived by resolving:\n   {s1}\n   {s2}\n=> empty clause (proof found).")
                return True
            new_statements |= resolvents
        if new_statements.issubset(KB):
            if verbose:
                print("\nNo new clauses derived. Resolution failed (query not proved).")
            return False
        added = new_statements - KB
        if verbose and added:
            print(f"\nIteration {iterations}: Derived {len(added)} new clause(s):")
            for st in sorted(added, key=lambda x: str(x)):
                print("   ", st)
        for st in added:
            st.add_statement_to_KB(KB, KB_HASH)

def main():
    fol_sentences = [
        "Food(x) => Likes(John,x)",
        "Food(Apple)",
        "Food(Vegetables)",
        "Eats(p,y)&~Killed(y) => Food(y)",
        "Eats(Anil,Peanuts)",
        "Alive(Anil)",
        "Eats(Anil,y) => Eats(Harry,y)",
        "Alive(x) => ~Killed(x)",
        "~Killed(x) => Alive(x)"
    ]

    goal = "Likes(John,Peanuts)"

    KB, KB_HASH = prepare_knowledgebase(fol_sentences)

    neg_goal_pred = Predicate(goal)
    neg_goal_pred.negate()
    neg_goal_stmt = Statement(str(neg_goal_pred))

    proved = FOL_Resolution(KB, KB_HASH, neg_goal_stmt, verbose=True)

    print("\nResult: Query 'John likes peanuts' is", "TRUE (proved)" if proved else "FALSE (not proved)")

if __name__ == "__main__":
    main()
```

Output:

Sanjana Srinivas-1BM23CS301

Initial KB clauses (including negated query):

```
Alive(x)|Killed(x)
~Alive(x)|~Killed(x)
~Likes(John,Peanuts)
Food(Apple)
Alive(Anil)
Eats(Anil,Peanuts)
Food(Vegetables)
Likes(John,x)|~Food(x)
Eats(Harry,y)|~Eats(Anil,y)
Food(y)|Killed(y)|~Eats(p,y)
```

Iteration 1: Derived 13 new clause(s):

```
Alive(x)|~Alive(x)
Eats(Harry,Peanuts)
Food(Peanuts)|Killed(Peanuts)
Food(x)|~Alive(x)|~Eats(p,x)
Food(y)|Killed(y)|~Eats(Anil,y)
Food(y)|~Alive(y)|~Eats(p,y)
Killed(x)|Likes(John,x)|~Eats(p,x)
Killed(x)|~Killed(x)
Killed(y)|Likes(John,y)|~Eats(p,y)
Likes(John,Apple)
Likes(John,Vegetables)
~Food(Peanuts)
~Killed(Anil)
```

Iteration 2: Derived 23 new clause(s):

```
Alive(x)
Food(Anil)|~Eats(Anil,Anil)
Food(Anil)|~Eats(p,Anil)
Food(Peanuts)|~Alive(Peanuts)
Food(x)|Killed(x)|~Eats(Anil,x)
Food(x)|Killed(x)|~Eats(p,x)
Food(x)|~Alive(x)|~Eats(Anil,x)
Food(x)|~Eats(p,x)
Food(y)|~Alive(y)|~Eats(Anil,y)
Killed(Peanuts)
Killed(Peanuts)|Likes(John,Peanuts)
Killed(Peanuts)|~Eats(Anil,Peanuts)
Killed(Peanuts)|~Eats(p,Peanuts)
Killed(x)
Killed(x)|Likes(John,x)|~Eats(Anil,x)
Killed(y)|Likes(John,y)|~Eats(Anil,y)
```

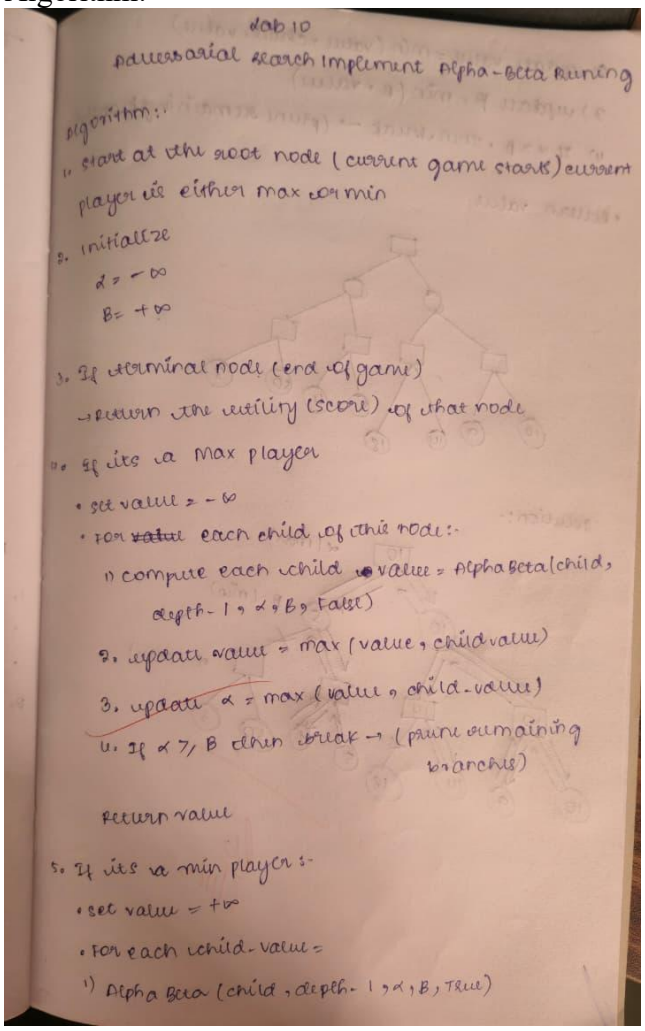
Likes(John,Anil)|~Eats(p,Anil)
Likes(John,x)|~Alive(x)|~Eats(p,x)
Likes(John,x)|~Eats(p,x)
Likes(John,y)|~Alive(y)|~Eats(p,y)
~Alive(Peanuts)|~Eats(p,Peanuts)
~Alive(x)
~Killed(x)

CONTRADICTION derived by resolving:
Killed(x)
Killed(x)|~Killed(x)
=> empty clause (proof found).

Result: Query 'John likes peanuts' is TRUE (proved)

Program 10
Implement Alpha-Beta Pruning.

Algorithm:

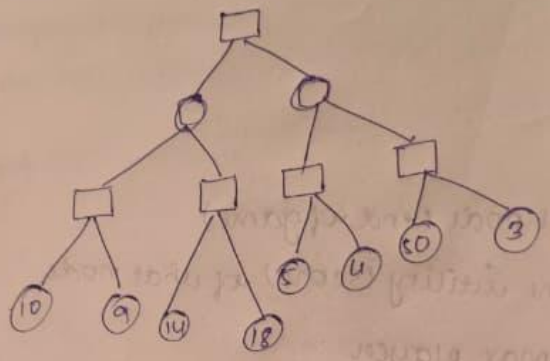

Lab 10
Adversarial search implement Alpha-Beta Pruning
Algorithm:-
1. Start at the root node (current game state) current player is either max or min
2. Initialize
α = −∞
β = +∞
3. If terminal node (end of game)
→ Return the utility (score) of that node
4. If its a max player
• set value = −∞
• For each child of this node:-
1) compute each child value = AlphaBeta(child, depth-1, α, β, False)
2. update value = max(value, child value)
3. update α = max(value, child-value)
4. If α ≥ β then break → (prune remaining branches)
Return value
5. If its a min player :-
• set value = +∞
• For each child-value =
1) AlphaBeta(child, depth-1, α, β, True)

2) update value = min (value, child.value)

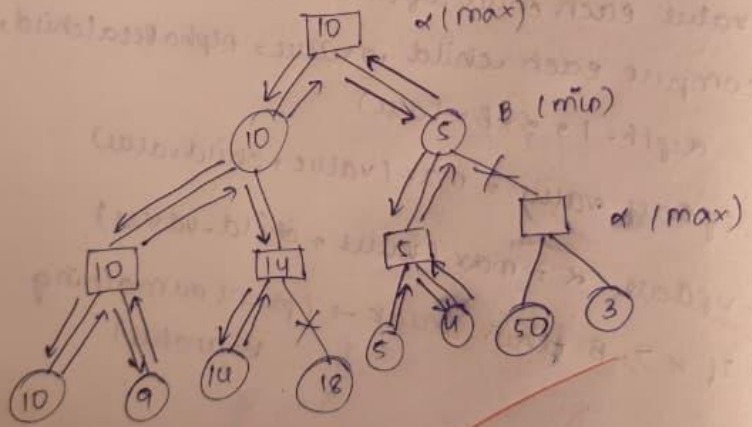
3) update β = min (β, value)

4) if α ≥ β, then break → (prune remaining branches)

• Return value.



solution:-



6/11/23

Code:

```
print("Sanjana Srinivas-1BM23CS301")
from typing import List, Optional, Tuple
import math

class Node:
    def __init__(self, name: str, children: Optional[List["Node"]] = None, value: Optional[int] = None):
        self.name = name
        self.children = children or []
        self.value = value

    def is_leaf(self):
        return self.value is not None

    def __repr__(self):
        if self.is_leaf():
            return f"{self.name}({self.value})"
        return f"{self.name}"
EXPANSION_ORDER: List[str] = []
PRUNED_SUBTREES: List[Tuple[str, List[str]]] = []

def alpha_beta(node: Node,
               alpha: float,
               beta: float,
               maximizing_player: bool,
               path: Optional[List[str]] = None) -> Tuple[float, List[str]]:
    if path is None:
        path = []
    path = path + [node.name]
    if node.is_leaf():
        EXPANSION_ORDER.append(node.name)
        return node.value, path

    EXPANSION_ORDER.append(node.name)

    if maximizing_player:
        value = -math.inf
        best_path: List[str] = []
        for child in node.children:
            if value >= beta:
                PRUNED_SUBTREES.append((child.name, path + [child.name]))
                continue

            child_val, child_path = alpha_beta(child, alpha, beta, False, path)
            if child_val > value:
                value = child_val
                best_path = child_path
```

```
            alpha = max(alpha, value)
        return value, best_path
    else:
        value = math.inf
        best_path: List[str] = []
        for child in node.children:
            if value <= alpha:
                PRUNED_SUBTREES.append((child.name, path + [child.name]))
                continue

            child_val, child_path = alpha_beta(child, alpha, beta, True, path)
            if child_val < value:
                value = child_val
                best_path = child_path
            beta = min(beta, value)
        return value, best_path
def build_example_tree() -> Node:
    L_D1 = Node("D1", value=3)
    L_D2 = Node("D2", value=5)
    L_E1 = Node("E1", value=6)
    L_E2 = Node("E2", value=9)

    L_F1 = Node("F1", value=1)
    L_F2 = Node("F2", value=2)
    L_G1 = Node("G1", value=0)
    L_G2 = Node("G2", value=-1)

    L_I1 = Node("I1", value=4)
    L_I2 = Node("I2", value=7)
    L_J1 = Node("J1", value=8)
    L_J2 = Node("J2", value=-2)

    D = Node("D", children=[L_D1, L_D2])   # 5
    E = Node("E", children=[L_E1, L_E2])   # 9

    F = Node("F", children=[L_F1, L_F2])   # 2
    G = Node("G", children=[L_G1, L_G2])   # 0

    I = Node("I", children=[L_I1, L_I2])   # 7
    J = Node("J", children=[L_J1, L_J2])   # 8

    B = Node("B", children=[D, E])         # min(5,9)=5
    C = Node("C", children=[F, G])         # min(2,0)=0
    H = Node("H", children=[I, J])         # min(7,8)=7

    A = Node("A", children=[B, C, H])      # MAX root
    return A
```

```
def evaluate_child_without_polluting_trace(child: Node, root_name: str) -> float:

    global EXPANSION_ORDER, PRUNED_SUBTREES
    saved_exp = EXPANSION_ORDER.copy()
    saved_pruned = PRUNED_SUBTREES.copy()

    # Clear globals for a clean evaluation
    EXPANSION_ORDER.clear()
    PRUNED_SUBTREES.clear()
    val, _ = alpha_beta(child, alpha=-math.inf, beta=math.inf, maximizing_player=False,
path=[root_name])
    EXPANSION_ORDER.clear()
    EXPANSION_ORDER.extend(saved_exp)
    PRUNED_SUBTREES.clear()
    PRUNED_SUBTREES.extend(saved_pruned)

    return val
def run_demo():
    global EXPANSION_ORDER, PRUNED_SUBTREES
    EXPANSION_ORDER = []
    PRUNED_SUBTREES = []

    root = build_example_tree()
    child_values = []
    for child in root.children:
        val = evaluate_child_without_polluting_trace(child, root.name)
        child_values.append((child.name, val))
    best_child_name, best_child_val = max(child_values, key=lambda x: x[1])
    print(f"Best move for MAX: {best_child_name} (value = {best_child_val})\n")
    EXPANSION_ORDER = []
    PRUNED_SUBTREES = []
    root_value, best_path = alpha_beta(root, alpha=-math.inf, beta=math.inf, maximizing_player=True)

    print("Alpha-Beta Pruning Demo (root is MAX):\n")
    print(f"Root value computed: {root_value}")
    print(f"Best path from root to leaf (names): {' -> '.join(best_path)}")

    print("\nNodes expanded in visit order:")
    print("  ", " , ".join(EXPANSION_ORDER))

    if PRUNED_SUBTREES:
        print("\nPruned subtrees (roots and their path from root):")
        for name, path in PRUNED_SUBTREES:
            print(f"  Pruned subtree root: {name}, path: {' -> '.join(path)}")
    else:
        print("\nNo pruning occurred for this ordering.")
```

```
    # Also display per-child values (useful to see why that child was chosen)
    print("\nImmediate child values at root (MIN nodes evaluated):")
    for name, val in child_values:
        print(f"  Child {name}: {val}")

if __name__ == "__main__":
    run_demo()
```

Output:

```
Sanjana Srinivas-1BM23CS301
Best move for MAX: H (value = 7)

Alpha-Beta Pruning Demo (root is MAX):

Root value computed: 7
Best path from root to leaf (names): A -> H -> I -> I2

Nodes expanded in visit order:
   A , B , D , D1 , D2 , E , E1 , C , F , F1 , F2 , H , I , I1 , I2 , J , J1

Pruned subtrees (roots and their path from root):
  Pruned subtree root: E2, path: A -> B -> E -> E2
  Pruned subtree root: G, path: A -> C -> G
  Pruned subtree root: J2, path: A -> H -> J -> J2

Immediate child values at root (MIN nodes evaluated):
  Child B: 5
  Child C: 0
  Child H: 7
```