VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Dhruva S Rao (1BM23CS092)

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
Aug-2025 to Dec-2025

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 **Dhruva S Rao (1BM23CS092),** 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.

Swathi Sridharan Assistant Professor Department of CSE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE

Index

Github Link:
github.com/DhruvaSRao64/AI-Lab

Program-01
Implement Tic Tac Toe Game

Algorithm:

Lab - 1

Tic - Tac - Toe Game

Algorithm:

~~Create board(char[][] board);~~

~~initialize board().~~

~~for(int~~

~~for i in range(0, n):~~

~~for j in range(0, n):~~

~~board~~

Step1: Create board of 2-dimension for storing 'O' and 'x' values of numbers from 0-8

Step 2: Initialize the board with empty space (or) '.' initially.

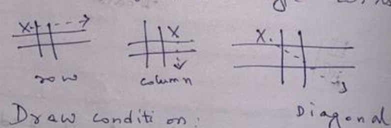
Step3: Win condition:

i). If any diagonal is filled with 'x' (or) 'o' successively, i.e, the diagonals i and (n-i-1) respectively, then that player wins

2). If any of the rows are filled continuously with 'x' (or) 'o', then that player with continuous value of same type wins.

3). If any of the columns are filled continuously with 'x' (or) 'o', then that player with continuous value of same type wins.

4).

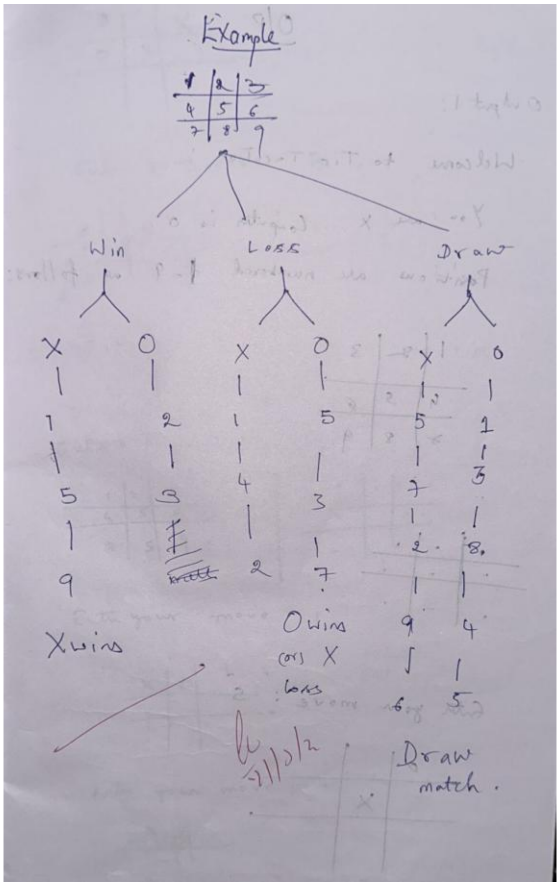


<u>Step4</u>: Draw condition:

If any of the above win conditions are not met, then it is a draw.

<u>Step5</u>: We use a two-pointer approach to solve this effectively and reduce time complexity to O(n).

<u>Step6</u>: Exit condition and 'play again' condition:



Code:

```
import random

grid = []
line = []
for i in range(3):
    for j in range(3):
        line.append(" ")
    grid.append(line)
    line = []

# grid printing
def print_grid():
    for i in range(3):
        print("|", end="")
```

```
        for j in range(3):
            print(grid[i][j], "|", end="")
        print("")

# player turn
def player_turn(turn_player1):
    if turn_player1 == True:
        turn_player1 = False
        print(f"It's {player2}'s turn")
    else:
        turn_player1 = True
        print(f"It's {player1}'s turn")
    return turn_player1

# choosing cell
def write_cell(cell, turn_player1):
    cell -= 1
    i = int(cell / 3)
    j = cell % 3
    if turn_player1 == True:
        grid[i][j] = player1_symbol
    else:
        grid[i][j] = player2_symbol
    return grid

# checking if cell is free
def free_cell(cell):
    cell -= 1
    i = int(cell / 3)
    j = cell % 3
    if grid[i][j] == player1_symbol or grid[i][j] == player2_symbol:
        print("This cell is not free")
        return False
    return True

# system turn (AI)
def system_turn():
```

```
    empty_cells = [i for i in range(1, 10) if free_cell(i)]
    if empty_cells:
        return random.choice(empty_cells)
    return None

# win check
def win_check(grid, player1_symbol, player2_symbol):
    full_grid = True
    player1_symbol_count = 0
    player2_symbol_count = 0
    # checking rows
    for i in range(3):
        for j in range(3):
            if grid[i][j] == player1_symbol:
                player1_symbol_count += 1
                player2_symbol_count = 0
                if player1_symbol_count == 3:
                    game = False
                    winner = player1
                    return game, winner
            if grid[i][j] == player2_symbol:
                player2_symbol_count += 1
                player1_symbol_count = 0
                if player2_symbol_count == 3:
                    game = False
                    winner = player2
                    return game, winner
            if grid[i][j] == " ":
                full_grid = False

        player1_symbol_count = 0
        player2_symbol_count = 0
    # checking columns
    player1_symbol_count = 0
    player2_symbol_count = 0
    for i in range(3):
        for j in range(3):
```

```
        for k in range(3):
            if i + k <= 2:
                if grid[i + k][j] == player1_symbol:
                    player1_symbol_count += 1
                    player2_symbol_count = 0
                    if player1_symbol_count == 3:
                        game = False
                        winner = player1
                        return game, winner
                if grid[i + k][j] == player2_symbol:
                    player2_symbol_count += 1
                    player1_symbol_count = 0
                    if player2_symbol_count == 3:
                        game = False
                        winner = player2
                        return game, winner
        if grid[i][j] == " ":
            full_grid = False

        player1_symbol_count = 0
        player2_symbol_count = 0
# checking diagonals
player1_symbol_count = 0
player2_symbol_count = 0
for i in range(3):
    for j in range(3):
        for k in range(3):
            if j + k <= 2 and i + k <= 2:
                if grid[i + k][j + k] == player1_symbol:
                    player1_symbol_count += 1
                    player2_symbol_count = 0
                    if player1_symbol_count == 3:
                        game = False
                        winner = player1
                        return game, winner
                if grid[i + k][j + k] == player2_symbol:
                    player2_symbol_count += 1
```

```
                    player1_symbol_count = 0
                    if player2_symbol_count == 3:
                        game = False
                        winner = player2
                        return game, winner
            if grid[i][j] == " ":
                full_grid = False

            player1_symbol_count = 0
            player2_symbol_count = 0

    player1_symbol_count = 0
    player2_symbol_count = 0
    for i in range(3):
        for j in range(3):
            for k in range(3):
                if j - k >= 0 and i + k <= 2:
                    if grid[i + k][j - k] == player1_symbol:
                        player1_symbol_count += 1
                        player2_symbol_count = 0
                        if player1_symbol_count == 3:
                            game = False
                            winner = player1
                            return game, winner
                    if grid[i + k][j - k] == player2_symbol:
                        player2_symbol_count += 1
                        player1_symbol_count = 0
                        if player2_symbol_count == 3:
                            game = False
                            winner = player2
                            return game, winner
            if grid[i][j] == " ":
                full_grid = False

            player1_symbol_count = 0
            player2_symbol_count = 0
```

```
    # full grid or not
    if full_grid == True:
        game = False
        winner = ""
        return game, winner
    else:
        game = True
        winner = ""
        return game, winner

# game mode selection
def game_mode_selection():
    print("Choose the game mode:")
    print("1. User vs User")
    print("2. User vs System")
    choice = input("Enter 1 or 2: ")
    if choice == "1":
        return "User vs User"
    elif choice == "2":
        return "User vs System"
    else:
        print("Invalid choice! Please enter 1 or 2.")
        return game_mode_selection()

# game opening
print("Welcome to Tic-Tac-Toe!")
mode = game_mode_selection()
print("")

# input player names and symbols
player1 = input("Please enter name of player 1: ")
player1_symbol = input(f"Please enter the symbol for {player1}: ")

if mode == "User vs User":
    player2 = input("Please enter name of player 2: ")
    player2_symbol = input(f"Please enter the symbol for {player2}: ")
else:
```

```
    player2 = "System"
    player2_symbol = "O" if player1_symbol == "X" else "X"  # Automatically set to the opposite symbol of player 1

game = True
full_grid = False
turn_player1 = True
winner = ""

# game loop
while game:
    turn_player1 = player_turn(turn_player1)
    free_box = False
    while free_box == False:
        if turn_player1:  # Player 1's turn
            cell = int(input(f"{player1}, enter a number (1 to 9): "))
        else:
            if mode == "User vs System":  # System's turn
                print(f"{player2}'s turn (System)")
                cell = system_turn()
                print(f"System chose cell {cell}")
            else:  # Player 2's turn (User vs User)
                cell = int(input(f"{player2}, enter a number (1 to 9): "))

        free_box = free_cell(cell)
    grid = write_cell(cell, turn_player1)
    print_grid()

    game, winner = win_check(grid, player1_symbol, player2_symbol)

# end of game
if winner == player1:
    print(f"Winner is {player1}!")
elif winner == player2:
    print(f"Winner is {player2}!")
else:
    print("It's a draw!")
```

Output:

```
Welcome to Tic-Tac-Toe!
Choose the game mode:
1. User vs User
2. User vs System
Enter 1 or 2: 1

Please enter name of player 1: dhanush
Please enter the symbol for dhanush: x
Please enter name of player 2: srujan
Please enter the symbol for srujan: o
It's srujan's turn
srujan, enter a number (1 to 9): 5
|   |   |   |
|   |o  |   |
|   |   |   |
It's dhanush's turn
dhanush, enter a number (1 to 9): 6
|   |   |   |
|   |o  |x  |
|   |   |   |
It's srujan's turn
srujan, enter a number (1 to 9): 7
|   |   |   |
|   |o  |x  |
|o  |   |   |
It's dhanush's turn
dhanush, enter a number (1 to 9): 3
|   |   |x  |
|   |o  |x  |
|o  |   |   |
It's srujan's turn
srujan, enter a number (1 to 9): 9
|   |   |x  |
|   |o  |x  |
|o  |   |o  |
It's dhanush's turn
dhanush, enter a number (1 to 9):
=== Session Ended. Please Run the code again ===
```

Program-02

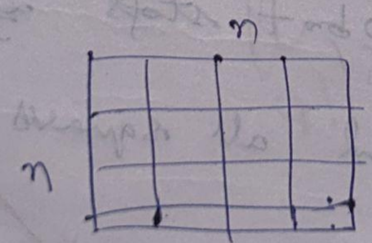
Implement Vacuum Cleaner

Algorithm:

Vacuum Cleaner

Algorithm: (4 - coordinates):

Step 1: Design a huge n×n grid for the robot to move and solve(or) clean.



Step 2: Initialize the board with 0's.

Step 3: Consider a vacuum cleaner placed at $(0,0)^{th}$ coordinate.

Step4: There are 4 ways to move up, down, left and right.

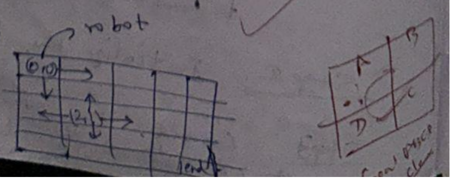
Step5: Initialize vertical as y and horizontal as x

Step6: So, the robot can move in 4 directions, i.e., $x-1$, ~~x+~~ (left), $(x+1)$ (right), $(y-1)$ (down), $(y+1)$ up

Step7: Call the recursion function again over these 4 values and check for boundary condition, $x < n-1$, $y < n-1$, $x \geq 0$ and $y \geq 0$.

Step8: The robot stops after reaching the end and all squares have been covered.

Diagram:



Code:

```
# Helper function: Check if all rooms are clean
def all_rooms_clean(environment):
    return all(status == "clean" for status in environment.values())

# Helper function: Clean a specific room
def clean_room(environment, room):
    print(f"Cleaning {room}")
    environment[room] = "clean"
```

```
# Helper function: Move to next room in the 2x2 grid
def move_to_next_room(current_room):
    # Predefined cyclic movement order
    if current_room == "room1":
        return "room2"
    elif current_room == "room2":
        return "room4"
    elif current_room == "room4":
        return "room3"
    elif current_room == "room3":
        return "room1"
```

```
# Vacuum cleaner agent function
def vacuum_cleaner_agent(environment):
    current_room = "room1"
    steps = 0

    print("Initial environment:", environment)
    print(f"Starting cleaning in {current_room}\n")

    while not all_rooms_clean(environment):
        if environment[current_room] == "dirty":
            clean_room(environment, current_room)
        else:
            print(f"{current_room} is already clean, moving on.")

        current_room = move_to_next_room(current_room)
        steps += 1
        print(f"Moved to {current_room}\n")

    print("All rooms cleaned!")
    print("Final environment:", environment)
    print(f"Total steps taken: {steps}")

# Initialize environment with all rooms dirty
environment = {
    "room1": "dirty",
    "room2": "dirty",
    "room3": "dirty",
    "room4": "dirty"
}

# Run the agent
vacuum_cleaner_agent(environment)
```

Output:

```
Vacuum Cleaner World
Commands: LEFT, RIGHT, CLEAN, EXIT

[R:dirty] [B:dirty]

Enter command: left
Already at the leftmost room!
[R:dirty] [B:dirty]

Enter command: right
[A:dirty] [R:dirty]

Enter command: clean
Cleaned B
[A:dirty] [R:clean]

Enter command: left
[R:dirty] [B:clean]

Enter command: clean
Cleaned A
[R:clean] [B:clean]

🏆 All rooms are clean!
```

Program-03

Implement 8 Puzzle

Algorithm:

Lab-2

8-Puzzles Program:

Algorithm:

Using ~~BFS~~ DFS (~~Breadth~~ Depth First Search).

Step 1: Create a 3 × 3 board with jumbled puzzle.

Step 2: Insert the puzzle (ex) use a random function to insert the puzzles. In this way it will form a 3×3 jumbled board.

Step 3: Initialize a pointer at (0,0) position.

Step 4: Set a variable goal at which position the puzzle would be solved.

Step 5: while the pointer is less than the number of rows and columns and move the pointer until it reaches the goal.

Step 6: on the way, check if the puzzle matches with the original puzzle (solution), if yes then break

Step 7: Return the solution if broke (or) if the pointer reaches the goal.

Step 8: Return the solved puzzle.

NOTE: The pointer can move and swap blocks in 4 directions, up, left, down and right.

Diagram:

original

1	2	3
4	5	7
9	8	0

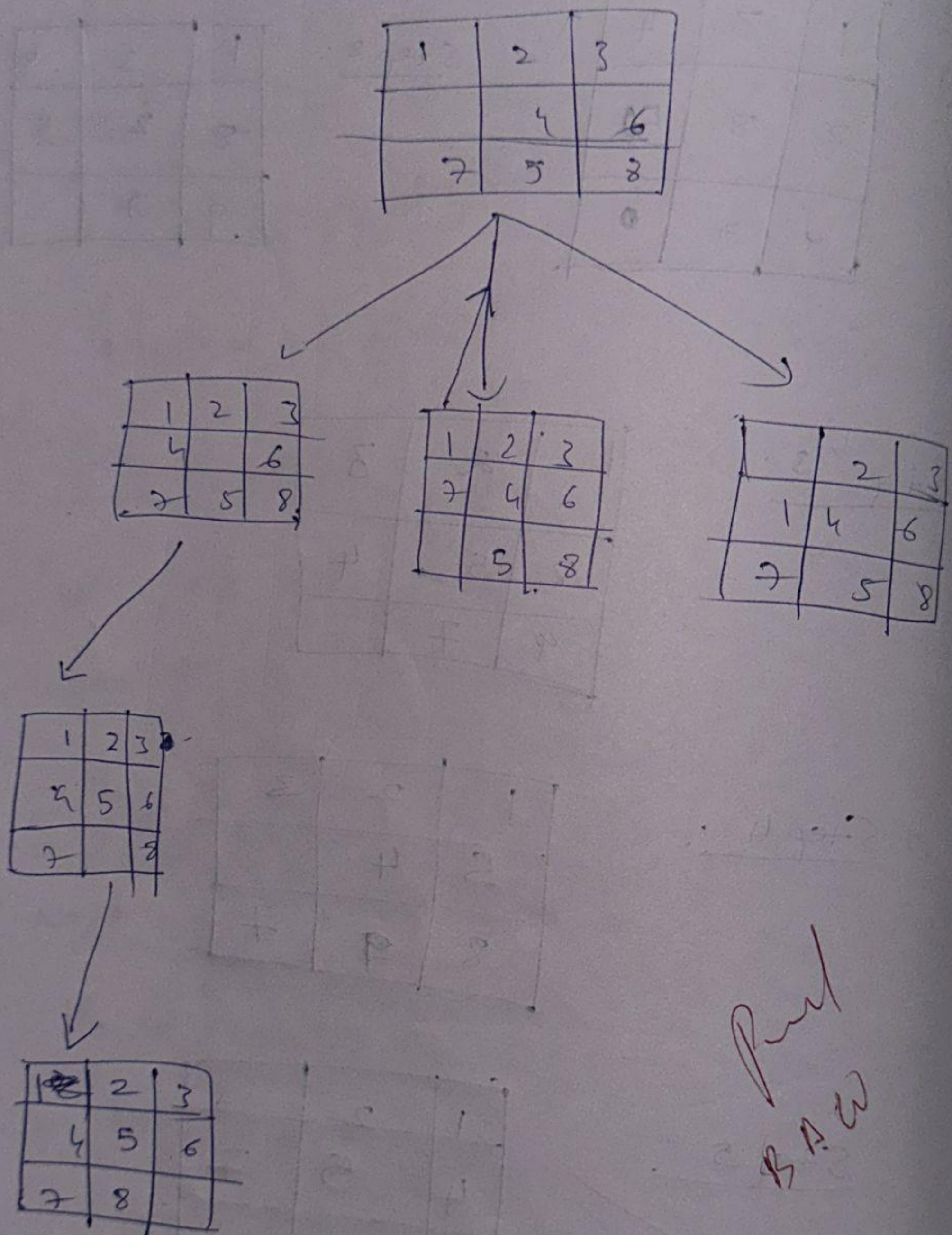
blank space

Jumbled

3	1	4
2	8	5
9	7	0

Example 2:

~~State~~ State - Space - Tree



Cost = 3

Code:

```
import heapq

# Goal state (target configuration)
GOAL_STATE = [[1, 2, 3],
              [4, 5, 6],
              [7, 8, 0]]

# Manhattan Distance Heuristic
def manhattan(state):
    distance = 0
    for i in range(3):
        for j in range(3):
            val = state[i][j]
            if val == 0:
                continue
            goal_x = (val - 1) // 3
            goal_y = (val - 1) % 3
```

```
distance += abs(goal_x - i) + abs(goal_y - j) return
distance

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

    # Find neighbors (possible moves from current state)
    def get_neighbors(state):
        neighbors = []
        # Find the position of the blank tile (0)
        x, y = [(ix, iy) for ix, row in enumerate(state) for iy, i in enumerate(row) if i ==
    0][0]
        # Possible moves for the blank tile: up, down, left, right
        moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]

        for dx, dy in moves:
            nx, ny = x + dx, y + dy
            if 0 <= nx < 3 and 0 <= ny < 3:
                new_state = [row[:] for row in state]  # Create a new state
                new_state[x][y], new_state[nx][ny] = new_state[nx][ny], new_state[x][y]
    # Swap blank with neighbor
                neighbors.append(new_state)
        return neighbors

    # A* search algorithm to solve the puzzle
    def solve_puzzle(start):
        # Priority queue to store the states (open set)
        heap = []
        # Push initial state into the priority queue with f(n) = g(n) + h(n)
        heapq.heappush(heap, (manhattan(start), 0, start, [])) # f(n), g(n), state, path to
    get there
        visited = set()  # Set to store visited states to avoid reprocessing

        while heap:
            est_total, cost, state, path = heapq.heappop(heap)  # Pop the state with
    lowest f(n)
            key = str(state)
```

```
        # Skip the state if it has already been visited
        if key in visited:
            continue
        visited.add(key)

        # If we reached the goal state, return the solution path
        if is_goal(state):
            return path + [state]

        # Explore the neighbors
        for neighbor in get_neighbors(state):
            # Push each neighbor to the priority queue
            heapq.heappush(heap, (cost + 1 + manhattan(neighbor), cost + 1,
neighbor, path + [state]))

    # If no solution found
    return None


def print_state(state):
    for row in state:
        print(row)
    print()
initial_state = [
    [1, 2, 3],
    [4, 0, 6],
    [7, 5, 8]
]

print("Initial State:")
print_state(initial_state)
solution = solve_puzzle(initial_state)
if solution:
    print("Solution found in {} steps:".format(len(solution) - 1))
    for step, state in enumerate(solution):
        print(f"Step {step}:")
```

```
        print_state(state)
else:
    print("No solution found.")
```

Output:

```
Output
Initial State:
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]

Solution found in 2 steps:
Step 0:
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]

Step 1:
[1, 2, 3]
[4, 5, 6]
[7, 0, 8]

Step 2:
[1, 2, 3]
[4, 5, 6]
[7, 8, 0]
```

Program-04
Implement IDDFS

Algorithm:

Lab - 4

8-Puzzles using Misplaced Tiles and manhattan distance (using A^* algorithm)

Algorithm:

Step 1: Initialize OPEN with start state, CLOSED empty

Step 2: for each state n:

compute $f(n) = g(n) + h(n)$

- $g(n)$ = cost from start to n (number of moves so far)
- $h(n)$ = number of misplaced tiles

Step 3: Pick state with smallest f(n) from OPEN

Step 4: If it is goal → return solution

Step 5: Else expand n : generate children by moving the blank (up, down, left, right).

Step 6: For each child:

- If not in CLOSED, compute f and add to OPEN

Step 7: Move n to CLOSED

~~Step~~

Step 8: Repeat until goal is found.

Manhattan Distance: (A^* search):

Heuristic:

$h(n) = \sum |x_{current} - x_{goal}| + |y_{current} - y_{goal}|$ for all tiles.

Algorithm (A^*):

Same steps as above, but in step-2:

- Compute h(n) using manhattan distance instead of misplaced tiles.

8-Puzzle with (IDDFS) (Iterative Deepening Depth First Search)

Algorithm:

Step 1: Set depth limit $d = 0$.

Step 2: Perform Depth-Limited Search (DFS up to depth d).

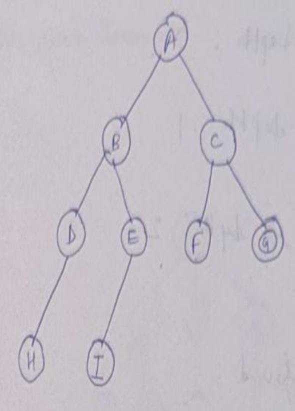
- If goal found → return solution.

Step 3: If not found, increase $d = d + 1$.

Step 4: Repeat Steps 2-3 until goal is found.

Step 5: Since IDDFS combines depth-first's low memory use + breadth-first's completeness, it will eventually find the optimal solution (but without heuristics)

Graph:



maxDepth = 3

Using IDDFS:

Let $d = 0$

Level-0 → A (Not found) $\Rightarrow d = d+1$

Level-1 → ABC (Not found) $\Rightarrow d = d+1$

Level-2 → ABDECFG (Goal found).

$\therefore d = 2$.

11-9-25

Example Problem: (A*)

Input:

1	2	3
4	5	6
7	8	0

→ Blank

Code:

Import modules

```
    'U': -3,
    'D': 3,
    'L': -1,
    'R': 1
}

def get_neighbors(state):
    neighbors = []
    zero_idx = state.index("0")

    for move, pos_change in moves.items():
        new_idx = zero_idx + pos_change


        if move == 'L' and zero_idx % 3 == 0:
            continue
        if move == 'R' and zero_idx % 3 == 2:
            continue
        if 0 <= new_idx < 9:
            new_state = list(state)

            new_state[zero_idx], new_state[new_idx] = new_state[new_idx], new_state[zero_idx]
            neighbors.append(("".join(new_state), move))
    return neighbors


def depth_limited_search(state, goal, limit, path, visited):
    if state == goal:
        return path

    if limit <= 0:
        return None

    visited.add(state)
    for neighbor, move in get_neighbors(state):
        if neighbor not in visited:
            new_path = depth_limited_search(neighbor, goal, limit - 1, path + [move], visited.copy())
            if new_path:
                return new_path
    return None
def iterative_deepening_search(start, goal, max_depth=30):
    for depth in range(max_depth + 1):
```

```
print(f"\n🔍 Searching with depth limit = {depth}")
path = depth_limited_search(start, goal, depth, [], set())
if path:
    print(f"✅ Goal found at depth {depth}! Moves: {' -> '.join(path)}")
```

```
        return path
    print(f"+ Goal not found within depth {max_depth}")
    return None


start_state = "724506831"
goal_state  = "012345678"

iterative_deepening_search(start_state, goal_state, max_depth=20)
```

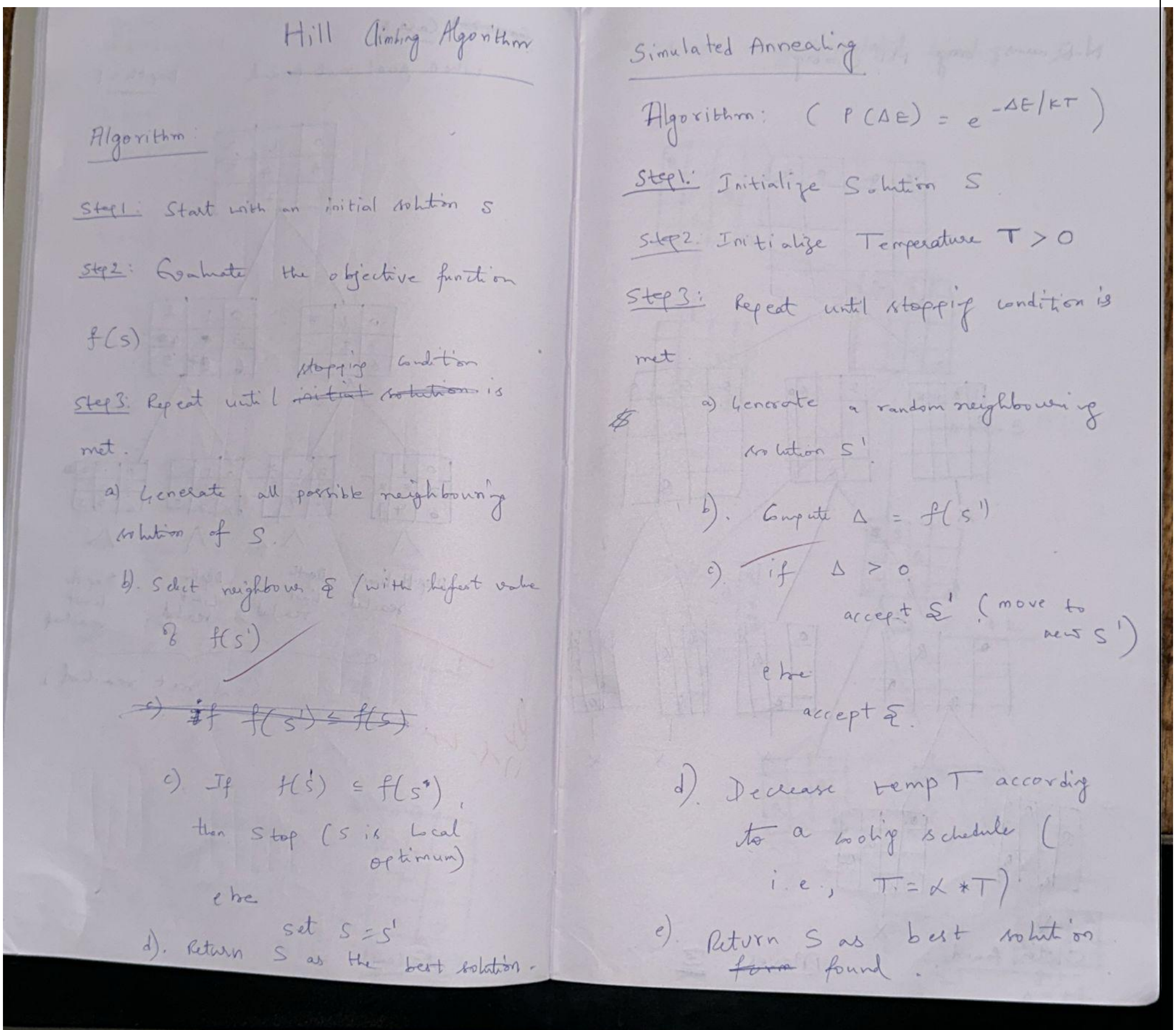
Output:

```
🔎 Searching with depth limit = 0
🔎 Searching with depth limit = 1
🔎 Searching with depth limit = 2
🔎 Searching with depth limit = 3
🔎 Searching with depth limit = 4
🔎 Searching with depth limit = 5
🔎 Searching with depth limit = 6
🔎 Searching with depth limit = 7
🔎 Searching with depth limit = 8
🔎 Searching with depth limit = 9
🔎 Searching with depth limit = 10
🔎 Searching with depth limit = 11
🔎 Searching with depth limit = 12
```

Program-05

Implement Hill climbing algorithm using N- Queens

Algorithm:



Hill Climbing Algorithm

Algorithm

Step1: Start with an initial solution S

Step2: Evaluate the objective function f(S)

Step3: Repeat until ~~initial solution~~ stopping condition is met.

a) Generate all possible neighbouring solution of S.

b). Select neighbour S' with highest value of f(s')

~~c) if f(s') ≤ f(s)~~

c) If $f(s') \le f(s^*)$, then Stop (S is Local optimum)

else set $S = S'$

d). Return S as the best solution.

Simulated Annealing

Algorithm: ($P(\Delta E) = e^{-\Delta E/KT}$)

Step1: Initialize Solution S

Step2: Initialize Temperature $T > 0$

Step3: Repeat until stopping condition is met

a) Generate a random neighbouring solution S'

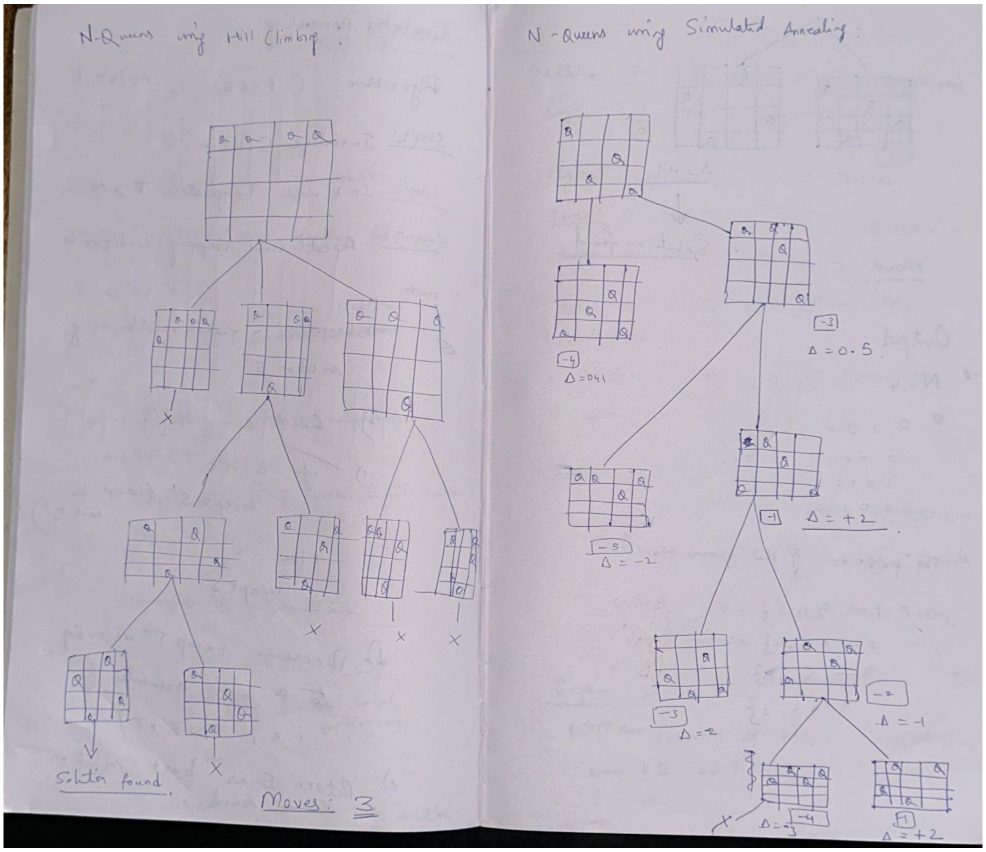
b). Compute $\Delta = f(s')$

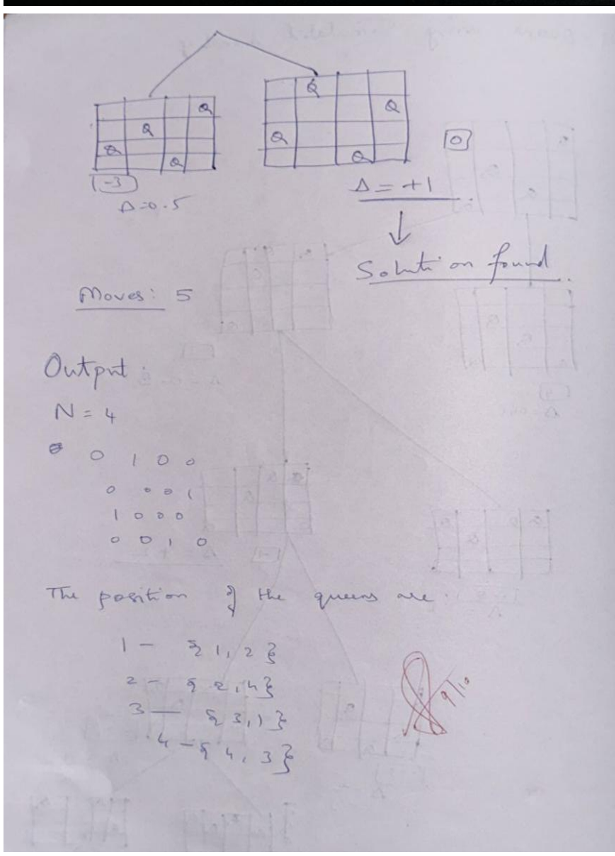
c). if $\Delta > 0$ accept S' (move to new S')

else accept S.

d). Decrease temp T according to a cooling schedule (i.e., $T = \alpha * T$)

e). Return S as best solution ~~form~~ found.


N-Queens using Hill Climbing.
Solution found.
Moves: 3
N - Queens using Simulated Annealing
-4
Δ = 0.41
-3
Δ = 0.5
-1
Δ = +2
-5
Δ = -2
-3
Δ = -2
-2
Δ = -1
-4
Δ = -3
-1
Δ = +2


-3
Δ = 0.5
0
Δ = +1
Solution found.
Moves: 5
Output
N = 4
0 1 0 0
0 0 0 1
1 0 0 0
0 0 1 0
The position of the queens are
1 — {1, 2}
2 — {2, 4}
3 — {3, 1}
4 — {4, 3}
9/10

Code:

```
from random import randint

def configureUserInput(board, state, N):
    while True:
        try:
            initial_positions = input(f"Enter the initial row positions for queens
(space-separated, 0 to {N-1}): ")
            initial_positions = list(map(int, initial_positions.split()))
            if len(initial_positions) == N and all(0 <= x < N for x in
initial_positions):
                for i in range(N):
                    state[i] = initial_positions[i]
```

```
                board[state[i]][i] = 1
            break
        else:
            print(f"Please enter exactly {N} valid row positions between 0 and
{N-1}.")
    except ValueError:
        print("Invalid input. Please enter integers.")

def printBoard(board):
    for row in board:
        print(*row)

def compareStates(state1, state2):
    return state1 == state2

def fill(board, value):
    for i in range(len(board)):
        for j in range(len(board)):
            board[i][j] = value

def calculateObjective(board, state, N):
    attacking = 0
    for i in range(N):
        row = state[i]
        col = i
        for j in range(i+1, N):
            other_row = state[j]
            other_col = j
            if other_row == row or abs(other_row - row) == abs(other_col - col):
                attacking += 1
    return attacking

def generateBoard(board, state, N):
    fill(board, 0)
    for i in range(N):
        board[state[i]][i] = 1
```

```
def copyState(state1, state2):
    for i in range(len(state2)):
        state1[i] = state2[i]

def getNeighbour(board, state, N):
    opState = state[:]
    generateBoard(board, opState, N)
    opObjective = calculateObjective(board, opState, N)

    for col in range(N):
        for row in range(N):
            if row != state[col]:
                tempState = state[:]
                tempState[col] = row
                generateBoard(board, tempState, N)
                tempObjective = calculateObjective(board, tempState, N)
                if tempObjective < opObjective:
                    opObjective = tempObjective
                    opState = tempState[:]
    copyState(state, opState)
    generateBoard(board, state, N)

def hillClimbing(board, state, N):
    neighbourState = state[:]
    generateBoard(board, neighbourState, N)

    while True:
        print("\nCurrent state:")
        printBoard(board)
        print(f"Number of attacking pairs: {calculateObjective(board, state, N)}")

        copyState(state, neighbourState)
        generateBoard(board, state, N)

        getNeighbour(board, neighbourState, N)

        if compareStates(state, neighbourState):
```

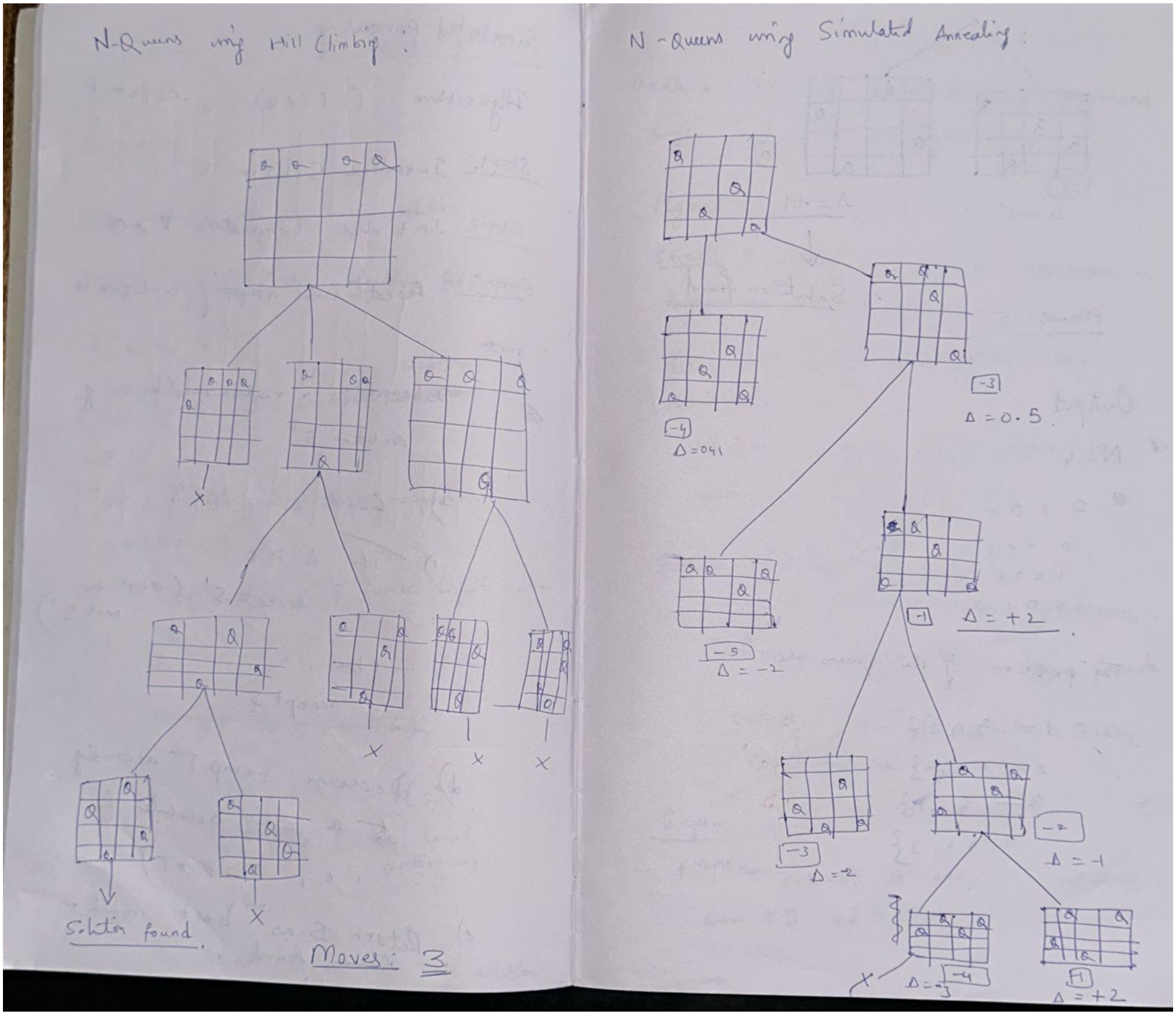
```
            print("\nFinal board with minimum conflicts:")
            printBoard(board)
            print(f"Number of attacking pairs: {calculateObjective(board, state, N)}")
            break

def main():
    N = int(input("Enter number of queens (N): "))
    board = [[0 for _ in range(N)] for _ in range(N)]
    state = [0] * N

    print("Enter initial positions for queens ")
    configureUserInput(board, state, N)

    hillClimbing(board, state, N)

if _name___== "_main_":
    main()
```

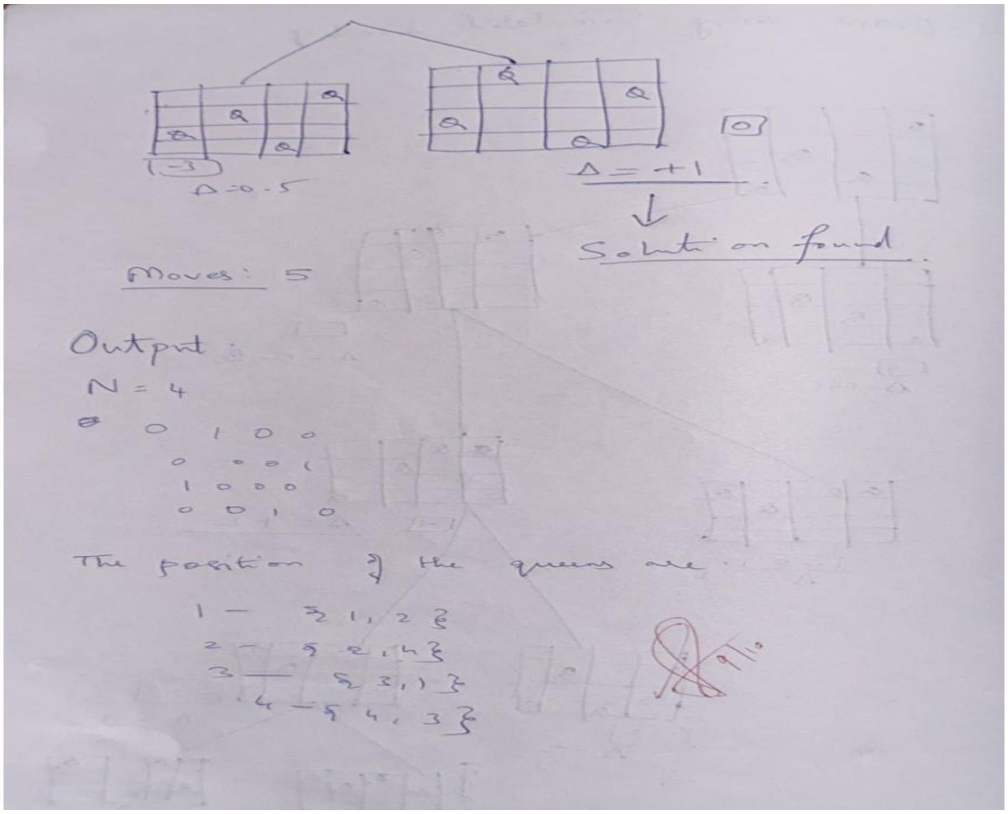
Output:

```
Initial board:
. . . .
. Q . .
. . . .
Q . Q Q

Initial heuristic (attacking pairs): 4

Step 0: h = 4
. . . .
. Q . .
. . . .
Q . Q Q

Step 1: h = 2
. . . Q
. Q . .
. . . .
Q . Q .

Step 2: h = 1
. . . Q
. Q . .
Q . . .
. . Q .

Final board:
. . . Q
. Q . .
Q . . .
. . Q .

Final heuristic: 1
⚠ Local minimum reached (no solution from this start).
```

Program-06
Implement Simulated Annealing

Algorithm:





Code:

```
import random
import math

class SimulatedAnnealing:
    def __init__(self, N, initial_temp=10000, cooling_rate=0.999):
        self.N = N  # Size of the board
        self.initial_temp = initial_temp  # Initial temperature
        self.cooling_rate = cooling_rate  # Cooling rate
        self.state = self.random_state()  # Initial state

    def random_state(self):
        """ Generate a random state with one queen per column. """
        return [random.randint(0, self.N - 1) for _ in range(self.N)]

    def calculate_conflicts(self, state):
```

```
        """ Calculate the number of pairs of queens that are attacking each
other. """
        conflicts = 0
        for i in range(self.N):
            for j in range(i + 1, self.N):
                if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                    conflicts += 1
        return conflicts

    def get_neighbors(self, state):
        """ Generate neighboring states by moving one queen to a random
new position. """
        neighbors = []
        for i in range(self.N):
            new_state = state[:]
            new_pos = random.randint(0, self.N - 1)
            while new_pos == new_state[i]:  # Prevent moving the queen to
the same row
                new_pos = random.randint(0, self.N - 1)
            new_state[i] = new_pos
            neighbors.append(new_state)
        return neighbors

    def acceptance_probability(self, current_conflicts,
neighbor_conflicts, temp):
        """ Calculate the probability of accepting a worse solution. """
        if neighbor_conflicts < current_conflicts:
            return 1.0
        else:
            return math.exp((current_conflicts - neighbor_conflicts) / temp)

    def simulated_annealing(self):
        """ Perform the simulated annealing process. """
        current_state = self.state
        current_conflicts = self.calculate_conflicts(current_state)
        temp = self.initial_temp

        print(f"Initial State: {current_state}")
```

```
        print(f"Initial Conflicts: {current_conflicts}")

        while temp > 1:
            neighbors = self.get_neighbors(current_state)
            next_state = random.choice(neighbors)
            next_conflicts = self.calculate_conflicts(next_state)

            # If the next state is better or with some probability, accept the
worse state
            if self.acceptance_probability(current_conflicts, next_conflicts,
temp) > random.random():
                current_state = next_state
                current_conflicts = next_conflicts

            # Cooling the system down
            temp *= self.cooling_rate

            print(f"Temp: {temp:.4f} | Conflicts: {current_conflicts} |
State: {current_state}")

            # If we have found a solution (0 conflicts), stop the process
            if current_conflicts == 0:
                print("Solution found!")
                break

        return current_state, current_conflicts


# Driver code
if __name__ == "__main__":
    try:
        N = int(input("Enter the number of queens (N): "))
        sa = SimulatedAnnealing(N)

        final_state, final_conflicts = sa.simulated_annealing()
        print(f"\nFinal State: {final_state}")
        print(f"Final Conflicts: {final_conflicts}")
```

```
    except ValueError:
        print("Please enter a valid number for N.")
```

Output:

```
Final board:
. . . . . . Q .
. . Q . . . . .
. . . . . . . Q
. Q . . . . . .
. . . . Q . . .
Q . . . . . . .
. . . . . Q . .
. . . Q . . . .

Final heuristic (attacking pairs): 0
✅ Solution found!
```

Program-07

Creative knowledge based using prepositional knowledge and show the given query entries a knowledge based or not

Algorithm:

Lab - 6

Create a knowledge base using propositional logic and test entailment

Algorithm.

Step 1: Identify all atomic propositions in ~~KB was~~ KB and Query

Goal: 1) KB using propositional logic sentences

2). Given a query check whether the query is entailed by KB.

Step 3: Input.

KB = propositional logic sentences.

Query = propositional logic formula.

Output: True if KB entails Query, else failure

Begin

props ← extract all atomic propositions from KB and Query.

All assignments ← generate all combinations of truth values of query.

For assignment in all assignments do
evaluate all sentences in KB ~~[illegible]~~
under this assignment. If all
sentences in KB are true
Evaluate query under this assignment
if Query false
return false
end if
end if
end for
return true
true
end

O/P:

Q	P	R	Q→P	P→~Q	Q∨R	KB_True
0	0	0	1	1	0	0
0	0	1	1	1	1	1
0	1	0	1	1	0	0
0	1	1	1	1	1	1
1	0	0	0	1	1	0
1	0	1	0	1	1	0
1	1	0	1	0	1	0
1	1	1	1	0	1	0

Models when KB is True:

Q = False, P = False, R = True

Q = false, P = True, R = True

Question 2 :- Construct a table (truth table) that shows the value of each sentence in KB & indicate the models in which the KB.

Truth table

~~P Q R Q→P~~
~~F F F~~

1) $Q \rightarrow P$
2) $P \rightarrow \sim Q$
3) $Q \vee R$

(i) Truth table
(ii) KB entail R ?
(iii) KB entail $R \rightarrow P$?
(iv) KB entail $Q \rightarrow R$?

Solution

Truth table

only when P is F, it will be F

P	Q	R	Q → P
F	F	F	T
F	F	T	T
F	T	F	F
F	T	T	F
T	F	F	T
T	F	T	T
T	T	F	T
T	T	T	T

2) and 3)

P	Q	R	P→~Q	Q ∨ R	KB
F	F	F	T	F	F
F	F	T	T	T	T
F	T	F	T	T	F
F	T	T	T	T	F
T	F	F	T	F	F
T	F	T	T	T	F
T	T	F	F	T	F
T	T	T	F	T	F

(ii) True, because KB is true which imposes R to be True.

(iii) False, since KB true makes $R \rightarrow P$ false

(iv) True, since KB true makes $Q \rightarrow R$ true (ii).

KB $\rightarrow$ R		~~KB → R~~
F	F	
T	T	
F	F	
F	T	
F	F	
T	T	
F	F	
F	T	

TF condition is not there.

So KB entails R

(iii). KB R→P

KB	R→P
F	T
T	F x
F	T
F	F
F	T
T	T
F	T
F	T

KB doesnt entails R→P

(iv) KB Q→R.

KB	Q→R
F	T
T	T ✓
F	F
F	T
F	T
T	T ✓
F	F
F	T

KB entails Q→R

16/10

O/P:

~~A B C A~~

=)

Code:

```
import itertools

# ----- Helper: evaluate propositional logic sentence -----
def pl_true(expr, model):
    if isinstance(expr, str):
        return model[expr]

    op = expr[0]

    if op == 'not':
        return not pl_true(expr[1], model)
    elif op == 'and':
        return pl_true(expr[1], model) and pl_true(expr[2], model)
    elif op == 'or':
        return pl_true(expr[1], model) or pl_true(expr[2], model)
    elif op == 'implies':
        return (not pl_true(expr[1], model)) or pl_true(expr[2], model)
    else:
        raise ValueError("Unknown operator: " + op)


# ----- Truth table entailment algorithm -----
def tt_entails(KB, query, symbols):
    for values in itertools.product([False, True], repeat=len(symbols)):
        model = dict(zip(symbols, values))

        # If KB is true but query is false -> Not entailed
        if all(pl_true(sentence, model) for sentence in KB):
            if not pl_true(query, model):
                print("Counterexample model:", model)
                return False

    return True


# ----- Define your KB -----
```

```
KB = [
    ('implies', 'Q', 'P'),             # Q → P
    ('implies', 'P', ('not', 'Q')),    # P → ¬Q
    ('or', 'Q', 'R')                   # Q ∨ R
]

symbols = ['P', 'Q', 'R']

# ----- Define queries -----
queries = {
    "R": 'R',
    "R → P": ('implies', 'R', 'P'),
    "Q → R": ('implies', 'Q', 'R')
}

# ----- Run entailment tests -----
for name, q in queries.items():
    result = tt_entails(KB, q, symbols)
    print(f"KB entails {name}: {result}")
```

Output:

```
=== Propositional Logic Entailment Checker ===

Enter number of formulas in KB: 3
Formula 1 (use ~ for NOT, & for AND, | for OR, -> for IMPLIES, <-> for IFF): Q->P
Formula 2 (use ~ for NOT, & for AND, | for OR, -> for IMPLIES, <-> for IFF): P->-Q
Formula 3 (use ~ for NOT, & for AND, | for OR, -> for IMPLIES, <-> for IFF): Q|R

Enter the query formula (alpha): Q

Truth Table:
--------------------------------------------------
P | Q | R | Q->P | P->-Q | Q|R | Q
--------------------------------------------------
True | True | True | True | False | True | True
True | True | False | True | False | True | True
True | False | True | True | False | True | False
True | False | False | True | False | False | False
False | True | True | False | False | True | True
False | True | False | False | False | True | True
False | False | True | True | True | True | False

❌ Counterexample found: {'P': False, 'Q': False, 'R': True}
False | False | False | True | True | False | False
--------------------------------------------------

❌ KB does NOT entail Q
```

Program-08

Implement unification in first order logic

Algorithm:

Step2. Repeat until E is empty.

Pick an equation (p, q) from E

Step3: Simplify the equation;

If p = q:

Remove it from E (its already unified)

Step4: Variable case

2. If p is a variable:
   - If p occurs in q' FAIL (occurs check)
   - Else, substitute p with q everywhere (in E and σ)
   - Add substitution p/q to σ
3. Else if q is a variable:
   - Do the same steps as above (swap roles of p and q)

Step5: Function/Compound case

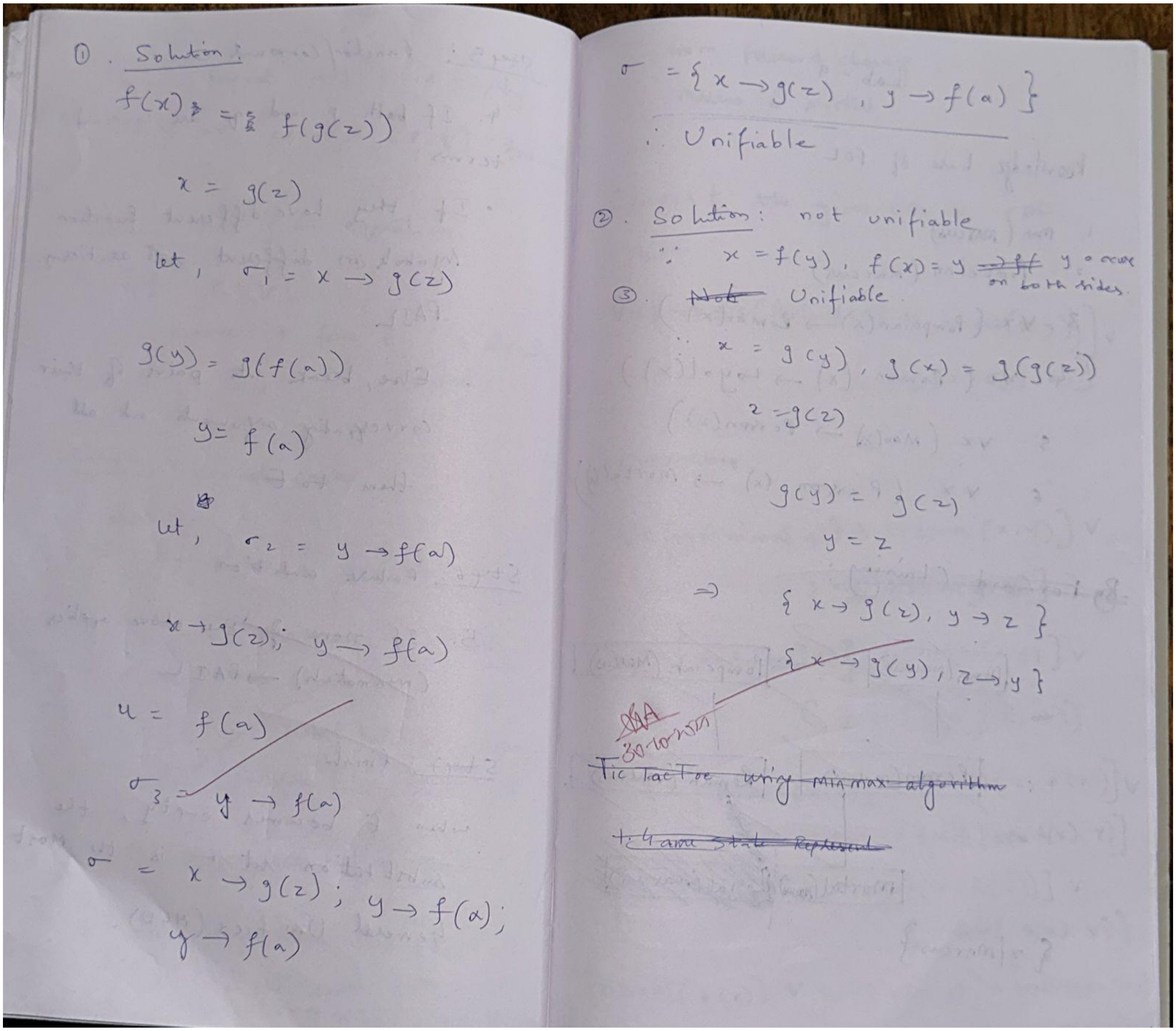
4. If both p and q are compound terms:
   - If they have different function symbols or different ~~act~~ arities → FAIL
   - Else, break into pairs of their corresponding arguments and add them to E

Step6: Failure condition

5. If none of the above applies (mismatch) → FAIL

Step7: Finish

When E becomes empty, the substitution set σ is the Most General Unifier (MGU).



1. Solution:

$f(x) = f(g(z))$

$x = g(z)$

let, $\sigma_1 = x \to g(z)$

$g(y) = g(f(a))$

$y = f(a)$

let, $\sigma_2 = y \to f(a)$

$x \to g(z); \; y \to f(a)$

$u = f(a)$

$\sigma_3 = y \to f(a)$

$\sigma = x \to g(z); \; y \to f(a);$

$y \to f(a)$

$\sigma = \{x \to g(z), \; y \to f(a)\}$

∴ Unifiable

2. Solution: not unifiable

∵ $x = f(y)$, $f(x) = y$ y occurs on both sides.

3. ~~Not~~ Unifiable

∵ $x = g(y)$, $g(x) = g(g(z))$

$z = g(z)$

$g(y) = g(z)$

$y = z$

$\Rightarrow \{x \to g(z), \; y \to z\}$

$\{x \to g(y), \; z \to y\}$

~~Tic Tac Toe using min max algorithm~~

~~Game State Represent~~

Code:

```
def unify(x, y, theta=None):
    if theta is None:
        theta = {}
    if x == y:
        return theta
    elif is_variable(x):
        return unify_var(x, y, theta)
    elif is_variable(y):
        return unify_var(y, x, theta)
    elif is_compound(x) and is_compound(y):
```

```
        for xi, yi in zip(x[1], y[1]):
            theta = unify(xi, yi, theta)
            if theta is None:
                return None
        return theta
    else:
        return None

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

def is_variable(x):
    return isinstance(x, str) and x.islower()

def is_compound(x):
    return isinstance(x, tuple) and len(x) == 2

def occurs_check(var, x, theta):
    """Check if var occurs inside x (to avoid infinite recursion)"""
    if var == x:
        return True
    elif is_variable(x) and x in theta:
        return occurs_check(var, theta[x], theta)
    elif is_compound(x):
        return any(occurs_check(var, arg, theta) for arg in x[1])
    else:
        return False
expr1 = ('f', ('x', ('g', ('y',))))
expr2 = ('f', (('g', ('z',)), ('g', ('a',))))

theta = unify(expr1, expr2, {})
print("Substitution θ:", theta)
```

Output:

```
Substitution θ: {'x': ('g', ('z',)), 'y': 'a'}


=== Code Execution Successful ===
```

Program-09

Implement Alpha Beta and Minima Maxima Using tic tac toe Game

Code:

```
import math, random

# Initialize the board
board = [" " for _ in range(9)]  # 0-8
positions

def print_board():
    print()
    for i in range(3):
        row = "|".join(board[i*3:(i+1)*3])
        print(" " + row)
        if i < 2:
            print(" ------ ")
    print()

def is_winner(brd, player):
    win_positions = [
        [0, 1, 2], [3, 4, 5], [6, 7, 8],  # Rows
        [0, 3, 6], [1, 4, 7], [2, 5, 8],  #
Columns
        [0, 4, 8], [2, 4, 6]              #
Diagonals
    ]
    return any(all(brd[pos] == player for
pos in line) for line in win_positions)

def is_full(brd):
    return all(cell != " " for cell in brd)

def minimax(brd, depth, is_maximizing):
    if is_winner(brd, "O"):
        return 1
```

```
    elif is_winner(brd, "X"):
        return -1
    elif is_full(brd):
        return 0

    if is_maximizing:
        best_score = -math.inf
        for i in range(9):
            if brd[i] == " ":
                brd[i] = "O"
                score = minimax(brd, depth +
1, False)
                brd[i] = " "
                best_score = max(best_score,
score)
        return best_score
    else:
        best_score = math.inf
        for i in range(9):
            if brd[i] == " ":
                brd[i] = "X"
                score = minimax(brd, depth +
1, True)
                brd[i] = " "
                best_score = min(best_score,
score)
        return best_score

def best_move():
    # 70% of the time AI plays a random
(bad) move
    if random.random() < 0.7:
        available = [i for i in range(9) if
board[i] == " "]
        return random.choice(available)
    # 30% of the time AI plays optimally
    best_score = -math.inf
    move = None
```

```
    for i in range(9):
        if board[i] == " ":
            board[i] = "O"
            score = minimax(board, 0, False)
            board[i] = " "
            if score > best_score:
                best_score = score
                move = i
    return move

def play_game():
    print("Welcome to Tic Tac Toe (You
= X, AI = O)")
    print("Hint: You can win easily 😏")
    print_board()

    while True:
        # Human move
        while True:
            try:
                move = int(input("Enter your
move (1-9): ")) - 1
                if 0 <= move <= 8 and
board[move] == " ":
                    board[move] = "X"
                    break
                else:
                    print("Invalid move, try
again.")
            except ValueError:
                print("Please enter a number
from 1 to 9.")

        print_board()

        if is_winner(board, "X"):
            print("🎉 You win! (AI made
mistakes)")
```

```
            break
        if is_full(board):
            print(" It's a draw!")
            break

        # AI move
        print("AI is thinking...")
        ai = best_move()
        board[ai] = "O"
        print_board()

        if is_winner(board, "O"):
            print(" AI wins (rarely)!")
            break
        if is_full(board):
            print(" It's a draw!")
            break

# Run the game
if __name__ == "__main__":
    play_game()
```

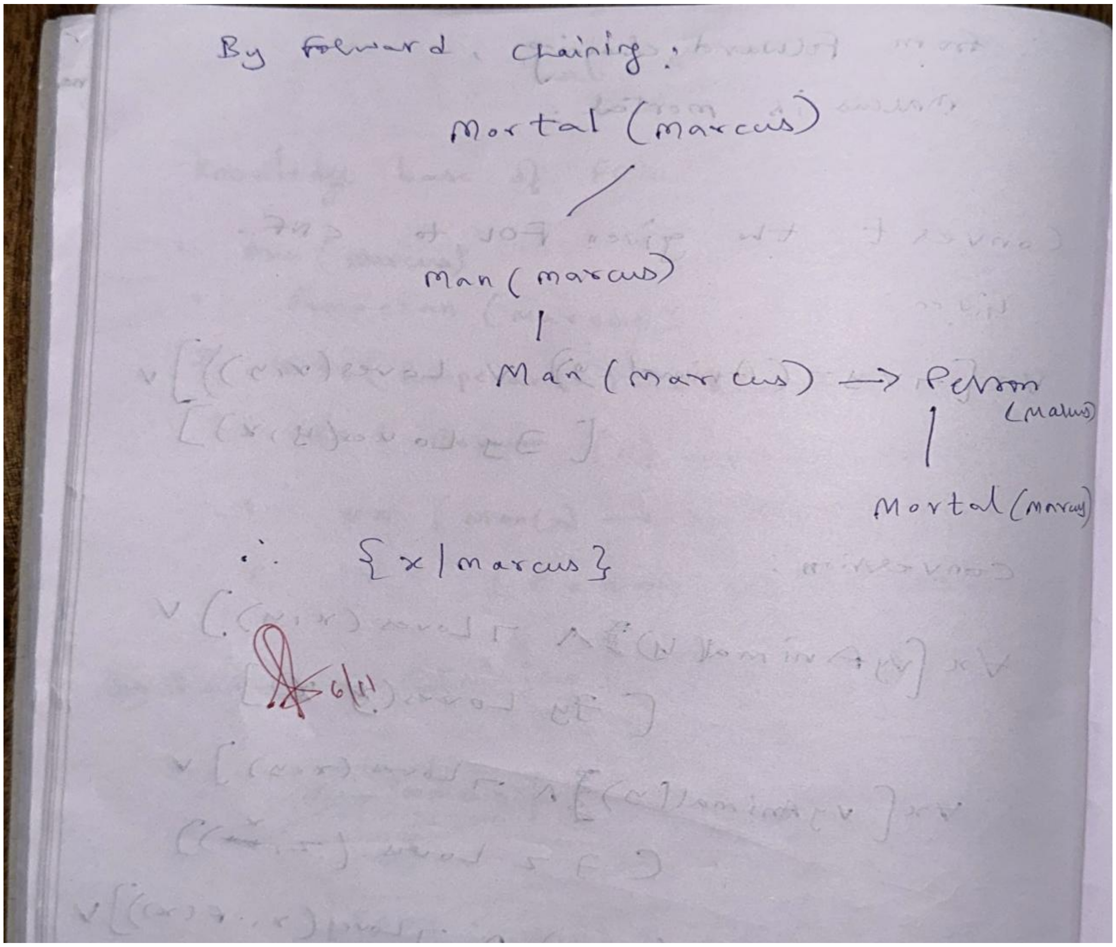
Output:

```
Welcome to Tic-Tac-Toe!
Choose the game mode:
1. User vs User
2. User vs System
Enter 1 or 2: 1

Please enter name of player 1: dhanush
Please enter the symbol for dhanush: x
Please enter name of player 2: srujan
Please enter the symbol for srujan: o
It's srujan's turn
srujan, enter a number (1 to 9): 5
|  |  |  |
|  |o |  |
|  |  |  |
It's dhanush's turn
dhanush, enter a number (1 to 9): 6
|  |  |  |
|  |o |x |
|  |  |  |
It's srujan's turn
srujan, enter a number (1 to 9): 7
|  |  |  |
|  |o |x |
|o |  |  |
It's dhanush's turn
dhanush, enter a number (1 to 9): 3
|  |  |x |
|  |o |x |
|o |  |  |
It's srujan's turn
srujan, enter a number (1 to 9): 9
|  |  |x |
|  |o |x |
|o |  |o |
It's dhanush's turn
dhanush, enter a number (1 to 9):
=== Session Ended. Please Run the code again ===
```

Program-10

Create a knowledge base For the first order logic statement and prove the given query using Forward reasoning

Algorithm:



Code:

```
facts = {
    "Man(Marcus)",
    "Pompeian(Marcus)"
```

```
}

rules = [
    ("Pompeian(x)", "Roman(x)"),
    ("Roman(x)", "Loyal(x)"),
    ("Man(x)", "Person(x)"),
    ("Person(x)", "Mortal(x)")
]

query = "Mortal(Marcus)"



def match(statement, fact):
    """
    Match a statement pattern like 'Pompeian(x)' to a fact like
'Pompeian(Marcus)'.
    Returns the substitution (x -> Marcus) if they match.
    """
    if "(" not in statement or "(" not in fact:
        return None
    pred1, arg1 = statement[:-1].split("(")
    pred2, arg2 = fact[:-1].split("(")
    if pred1.strip() != pred2.strip():
        return None
    if arg1.strip().islower():  # variable like x
        return {arg1.strip(): arg2.strip()}
    elif arg1.strip() == arg2.strip():
        return {}
    else:
        return None


def substitute(statement, subs):
    for var, val in subs.items():
        statement = statement.replace(var, val)
    return statement
```

```
def forward_chain(facts, rules, query):
    inferred = set()
    while True:
        new_facts = set(facts)
        for antecedent, consequent in rules:
            for fact in facts:
                subs = match(antecedent, fact)
                if subs is not None:
                    new_fact = substitute(consequent, subs)
                    if new_fact not in facts:
                        print(f"Inferred: {new_fact} (from {fact} using rule {antecedent} → {consequent})")
                        new_facts.add(new_fact)
        # If no new facts, stop
        if new_facts == facts:
            break
        facts = new_facts
    return query in facts, facts


result, all_facts = forward_chain(facts, rules, query)

print("\n--- Final Facts ---")
for f in sorted(all_facts):
    print(f)

print("\n--- Result ---")
if result:
    print(f" The query '{query}' is TRUE based on forward reasoning.")
else:
    print(f"+ The query '{query}' cannot be proven from the given knowledge base.")
```

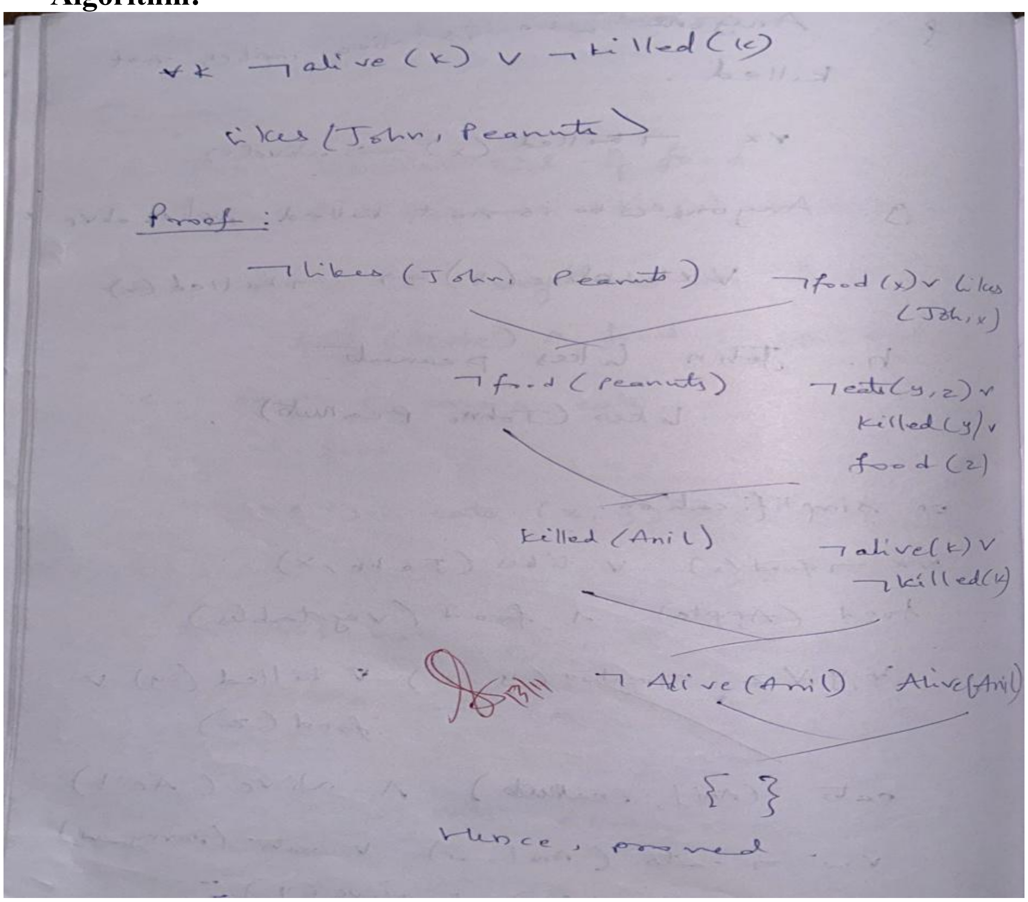
Output:

```
All inferred facts:
Hostile(A)
Criminal(Robert)
Weapon(T1)
Sells(Robert, T1, A)

✅ Robert is a criminal
```

Program-11

Convert the given first order logic statement to conjunctive normal form (CNF)

Algorithm:



Code:

```
import copy

# Utility for deep substitution
def substitute(term, var, replacement):
    """Replace variable var with replacement inside a term."""
    if isinstance(term, str):
        return replacement if term == var else term
    elif isinstance(term, tuple):
        return tuple(substitute(t, var, replacement) for t in term)
    else:
        return term


# 1️⃣ Remove negations using equivalences
def eliminate_negations(expr):
    """Apply ¬∀y¬P(y) ≡ ∃y P(y) and ¬∃y P(y) ≡ ∀y ¬P(y)."""
    if isinstance(expr, tuple):
        op = expr[0]
        if op == 'not':
            sub = expr[1]
            if isinstance(sub, tuple) and sub[0] == 'forall':
                var, inner = sub[1], sub[2]
                return ('exists', var, eliminate_negations(('not', inner)))
            elif isinstance(sub, tuple) and sub[0] == 'exists':
                var, inner = sub[1], sub[2]
                return ('forall', var, eliminate_negations(('not', inner)))
            elif isinstance(sub, tuple) and sub[0] == 'not':
                return eliminate_negations(sub[1])
            else:
                return ('not', eliminate_negations(sub))
        elif op in ['and', 'or']:
            return (op, eliminate_negations(expr[1]), eliminate_negations(expr[2]))
        elif op in ['forall', 'exists']:
            return (op, expr[1], eliminate_negations(expr[2]))
    return expr
```

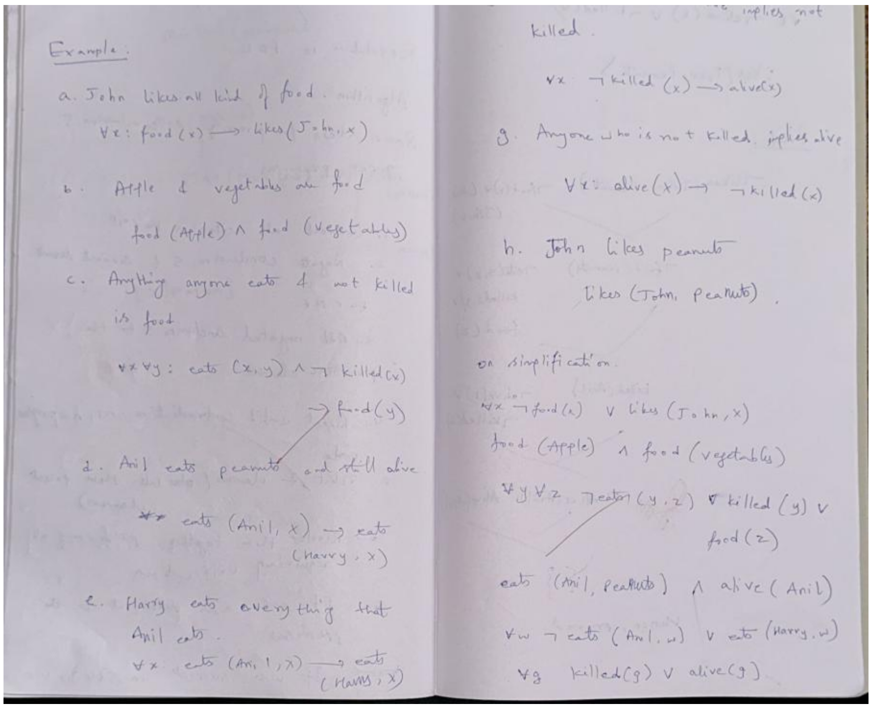
```python
#   Move quantifiers to front (Prenex form)
def move_quantifiers(expr):
    if isinstance(expr, tuple):
        op = expr[0]
        if op in ['and', 'or']:
            left = move_quantifiers(expr[1])
            right = move_quantifiers(expr[2])
            # If quantifiers exist in left or right, move them out
            if isinstance(left, tuple) and left[0] in ['forall', 'exists']:
                return (left[0], left[1], move_quantifiers((op, left[2], right)))
            elif isinstance(right, tuple) and right[0] in ['forall', 'exists']:
                return (right[0], right[1], move_quantifiers((op, left, right[2])))
            else:
                return (op, left, right)
        elif op in ['forall', 'exists']:
            return (op, expr[1], move_quantifiers(expr[2]))
    return expr


# 3️⃣ Skolemization
def skolemize(expr, scope_vars=None):
    """Remove existential quantifiers using Skolem functions."""
    if scope_vars is None:
        scope_vars = []
    if isinstance(expr, tuple):
        op = expr[0]
        if op == 'forall':
            return ('forall', expr[1], skolemize(expr[2], scope_vars + [expr[1]]))
        elif op == 'exists':
            func_name = f"f_{expr[1]}"
            skolem_func = func_name + "(" + ",".join(scope_vars) + ")" if scope_vars else func_name
            return skolemize(substitute(expr[2], expr[1], skolem_func), scope_vars)
        elif op in ['and', 'or']:
            return (op, skolemize(expr[1], scope_vars), skolemize(expr[2], scope_vars))
    return expr
```

```
# Drop universal quantifiers
def drop_universal(expr):
    if isinstance(expr, tuple) and expr[0] == 'forall':
        return drop_universal(expr[2])
    elif isinstance(expr, tuple) and expr[0] in ['and', 'or']:
        return (expr[0], drop_universal(expr[1]), drop_universal(expr[2]))
    return expr


# Distribute ∨ over ∧ to get
CNF def
distribute_or_over_and(expr):
    if not isinstance(expr, tuple):
        return expr
    op = expr[0]
    if op == 'or':
        a, b = expr[1], expr[2]
        if isinstance(a, tuple) and a[0] == 'and':
            return ('and',
                    distribute_or_over_and(('or', a[1], b)),
                    distribute_or_over_and(('or', a[2], b)))
        elif isinstance(b, tuple) and b[0] == 'and':
            return ('and',
                    distribute_or_over_and(('or', a, b[1])),
                    distribute_or_over_and(('or', a, b[2])))
        else:
            return ('or', distribute_or_over_and(a), distribute_or_over_and(b))
    elif op == 'and':
        return ('and', distribute_or_over_and(expr[1]), distribute_or_over_and(expr[2]))
    else:
        return expr


def to_cnf(expr):
    expr = eliminate_negations(expr)
    expr = move_quantifiers(expr)
```

```
    expr = skolemize(expr)


    expr = drop_universal(expr)
    expr = distribute_or_over_and(expr)
    return expr


expr = ('forall', 'x',
        ('or',
            ('not', ('forall', 'y', ('not', ('or', ('Animal', 'y'), ('Loves', 'x', 'y'))))),
            ('exists', 'y', ('Loves', 'y', 'x'))
        )
)

cnf = to_cnf(expr)
print("Final CNF Structure:\n", cnf)
```

Program 12
Create knowledge piece using prepositional logic and prove the given query using resolution

Algorithm:



Example:

a. John likes all kind of food.

$\forall x: food(x) \rightarrow likes(John, x)$

b. Apple & vegetables are food

$food(Apple) \wedge food(vegetables)$

c. Anything anyone eats & not killed is food

$\forall x \forall y: eats(x, y) \wedge \neg killed(x) \rightarrow food(y)$

d. Anil eats peanuts and still alive

$eats(Anil, x) \rightarrow eats(Harry, x)$

e. Harry eats everything that Anil eats.

$\forall x \; eats(Anil, x) \rightarrow eats(Harry, x)$

implies not killed.

$\forall x \; \neg killed(x) \rightarrow alive(x)$

g. Anyone who is not killed implies alive

$\forall x: alive(x) \rightarrow \neg killed(x)$

h. John likes peanuts

$likes(John, Peanuts)$.

on simplification

$\forall x \; \neg food(x) \vee likes(John, x)$

$food(Apple) \wedge food(vegetables)$

$\forall y \forall z \; \neg eats(y, z) \vee killed(y) \vee food(z)$

$eats(Anil, Peanuts) \wedge alive(Anil)$

$\forall w \; \neg eats(Anil, w) \vee eats(Harry, w)$

$\forall g \; killed(g) \vee alive(g)$

Code:

```
import copy
import itertools

# ------------------------------
# Unification
# ------------------------------
def is_variable(x):
    return isinstance(x, str) and x[0].islower()

def unify(x, y, subs=None):
    if subs is None:
        subs = {}
    if x == y:
        return subs
    elif is_variable(x):
        return unify_var(x, y, subs)
    elif is_variable(y):
        return unify_var(y, x, subs)
    elif isinstance(x, list) and isinstance(y, list) and len(x) == len(y):
```

```
        for xi, yi in zip(x, y):
            subs = unify(xi, yi, subs)
            if subs is None:
                return None
        return subs
    else:
        return None

def unify_var(var, x, subs):
    if var in subs:
        return unify(subs[var], x, subs)
    elif x in subs:
        return unify(var, subs[x], subs)
    elif occurs_check(var, x, subs):
        return None
    else:
        subs_copy = subs.copy()
        subs_copy[var] = x
        return subs_copy

def occurs_check(var, x, subs):
    if var == x:
        return True
    elif isinstance(x, list):
        return any(occurs_check(var, xi, subs) for xi in x)
    elif x in subs:
        return occurs_check(var, subs[x], subs)
    return False


# ------------------------------
# Resolution
# ------------------------------
def negate(literal):
    if literal.startswith('~'):
        return literal[1:]
    else:
        return '~' + literal

def substitute(clause, subs):
    new_clause = []
    for literal in clause:
        pred, args = parse_predicate(literal)
        new_args = []
        for a in args:
            if a in subs:
```

```
                new_args.append(subs[a])
            else:
                new_args.append(a)
        new_clause.append(f"{'~' if literal.startswith('~') else ''}{pred}({','.join(new_args)})")
    return new_clause

def parse_predicate(literal):
    neg = literal.startswith('~')
    if neg:
        literal = literal[1:]
    name, args = literal.split('(')
    args = args[:-1].split(',')  # remove ')'
    return name, args

def resolve(ci, cj):
    for di in ci:
        for dj in cj:
            if di.startswith('~') != dj.startswith('~'):  # opposite polarity
                pred_i, args_i = parse_predicate(di)
                pred_j, args_j = parse_predicate(dj)
                if pred_i == pred_j:
                    subs = unify(args_i, args_j)
                    if subs is not None:
                        new_ci = substitute(ci, subs)
                        new_cj = substitute(cj, subs)
                        new_clause = list(set([x for x in new_ci + new_cj if x != di and x != dj]))
                        return new_clause
    return None

def resolution(kb, query):
    clauses = copy.deepcopy(kb)
    clauses.append([negate(query)])  # negate query for proof by contradiction
    new = set()

    print("\n--- Resolution Steps ---")
    while True:
        pairs = [(clauses[i], clauses[j]) for i in range(len(clauses)) for j in range(i+1, len(clauses))]
        for (ci, cj) in pairs:
            resolvent = resolve(ci, cj)
            if resolvent == []:
                print("Derived empty clause ⇒ Query proven
                return True
            if resolvent is not None:
                new.add(tuple(sorted(resolvent)))

        new_clauses = [list(x) for x in new if list(x) not in clauses]
```

```
        if not new_clauses:
            print("No new clauses ⇒ Query cannot be proven +")
            return False
        for c in new_clauses:
            clauses.append(c)


# -----------------------------
# Example Knowledge Base
# -----------------------------
# KB:
# 1. John likes all kinds of food.
# 2. Apple and vegetable are food.
# 3. Anything anyone eats and not killed is food.
# 4. Anil eats peanuts and still alive.
# 5. Harry eats everything Anil eats.
# 6. Anyone who is alive is not killed.
# 7. Anyone who is not killed is alive.
# Query: John likes peanuts.

kb = [
    ['~Food(x)', 'Likes(John,x)'],             # John likes all food
    ['Food(Apple)'],                            # Apple is food
    ['Food(Vegetable)'],                        # Vegetable is food
    ['~Eats(x,y)', '~Alive(x)', 'Food(y)'],     # Anything eaten by alive person is food
    ['Eats(Anil,Peanuts)'],                     # Anil eats peanuts
    ['Alive(Anil)'],                            # Anil is alive
    ['~Eats(Harry,y)', 'Eats(Anil,y)'],         # Harry eats everything Anil eats
    ['~Alive(x)', '~Killed(x)'],                # Alive(x) -> not Killed(x)
    ['~Killed(x)', 'Alive(x)']                  # not Killed(x) -> Alive(x)
]

query = 'Likes(John,Peanuts)'

print("Converting to CNF and proving using resolution...")
resolution(kb, query)
```

Output:

```
Converting to CNF and proving using resolution...

--- Resolution Steps ---
Derived empty clause ⇒ Query proven ✅
```