VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Abhinav C (1BM23CS008)

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 **Abhinav C (1BM23CS008),** 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

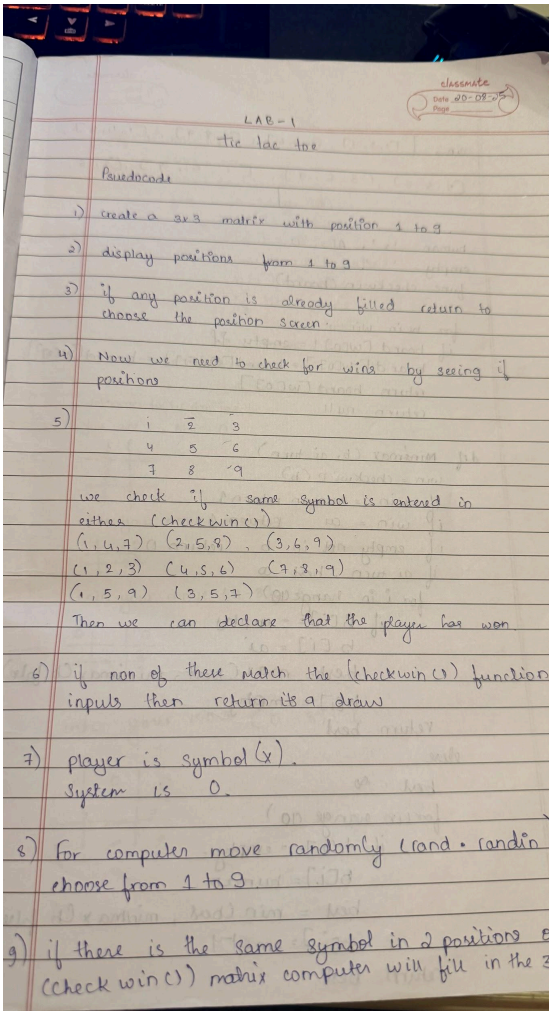
Sl. No.	Date	Experiment Title	Page No.
1	20-8-2025	Implement Tic –Tac –Toe Game Implement vacuum cleaner agent	5-12
2	28-8-2025	Implement 8 puzzle problems using Depth First Search (DFS) Implement Iterative deepening search algorithm	12-20
3	3-9-2025	Implement A* search algorithm	21-27
4	10-9-2025	Implement Hill Climbing search algorithm to solve N-Queens problem	28-29
5	17-9-2025	Simulated Annealing to Solve 8-Queens problem	30-23
6	24-9-2025	Create a knowledge base using propositional logic and show that the given query entails the knowledge base or not.	34-38
7	8-10-2025	Implement unification in first order logic	39-40
8	15-10-2025	Create a knowledge base consisting of first order logic statements and prove the given query using forward reasoning.	40-42
9	29-10-2025	Create a knowledge base consisting of first order logic statements and prove the given query using Resolution	42-45
10	12-11-2025	Implement Alpha-Beta Pruning. Covert given FOL to CNF	45-54

Github Link:
https://github.com/Abhinav-2013/ai-lab/tree/main

Program 1

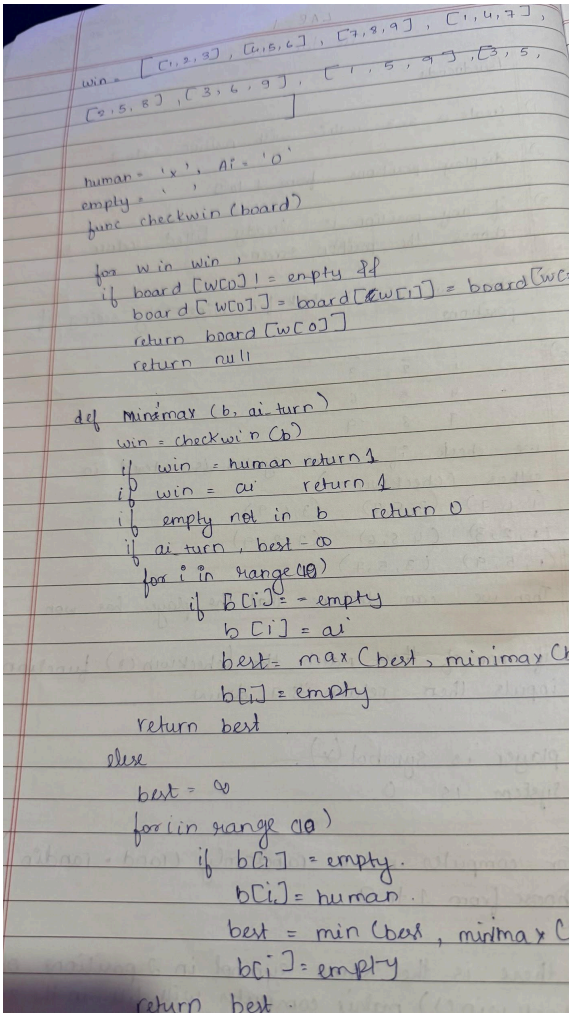
Implement Tic –Tac –Toe Game
Implement vacuum cleaner agent

Algorithm:


LAB-1
tic tac toe

Pseudocode

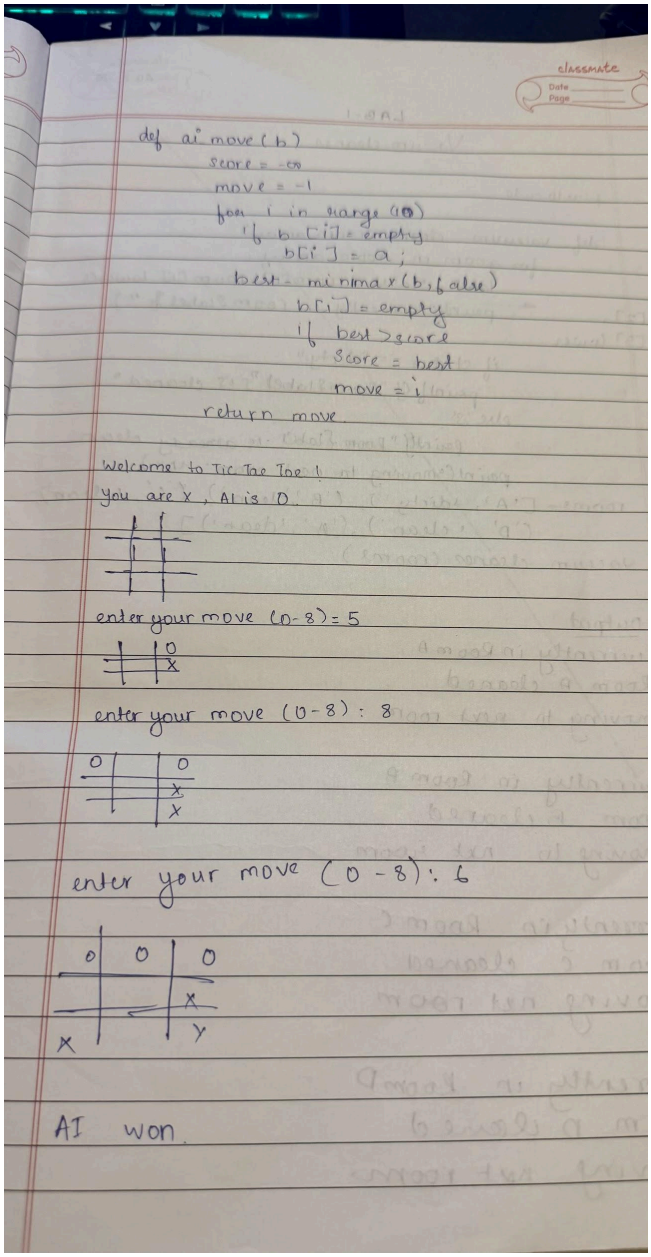
1) create a 3x3 matrix with position 1 to 9
2) display positions from 1 to 9
3) if any position is already filled return to choose the position screen
4) Now we need to check for wins by seeing if positions
5) 1 2 3
4 5 6
7 8 9
we check if same symbol is entered in either (checkwin())
(1,4,7) (2,5,8) (3,6,9)
(1,2,3) (4,5,6) (7,8,9)
(1,5,9) (3,5,7)
Then we can declare that the player has won
6) if non of these match the (checkwin()) function inputs then return its a draw
7) player is symbol (x).
System is 0.
8) For computer move randomly (rand.randin choose from 1 to 9.
9) if there is the same symbol in 2 positions (checkwin()) matrix computer will fill in the


win = [(1,2,3), (4,5,6), (7,8,9), (1,4,7), (2,5,8), (3,6,9), (1,5,9), (3,5,7)]

human = 'x', ai = 'o'
empty = ' '
func checkwin(board)

for w in win:
if board[w[0]] = empty
board[w[0]] = board[w[1]] = board[w
return board[w[0]]
return null

def Minimax(b, ai_turn)
win = checkwin(b)
if win = human return 1
if win = ai return 1
if empty not in b return 0
if ai_turn, best = ∞
for i in range(9)
if b[i] = empty
b[i] = ai
best = max(best, minimax(
b[i] = empty
return best
else
best = ∞
for i in range(9)
if b[i] = empty.
b[i] = human.
best = min(best, minimax(
b[i] = empty
return best



```
def ai move(b)
    score = -∞
    move = -1
    for i in range(9)
        if b[i] = empty
            b[i] = a;
    best = minimax(b, false)
            b[i] = empty
            if best > score
                score = best
                move = i
    return move
```

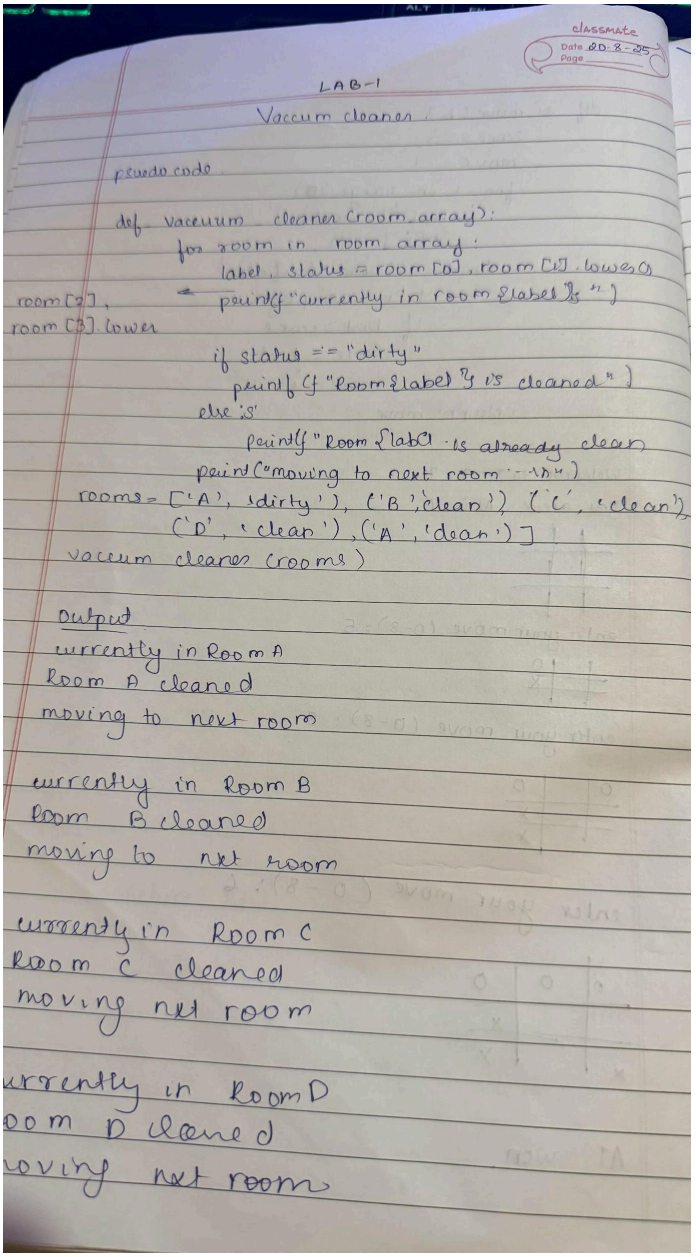
Welcome to Tic Tac Toe !
You are X, AI is O.

enter your move (0-8) = 5

enter your move (0-8) : 8

enter your move (0-8) : 6

AI won.



LAB-1

Vaccum cleaner

pseudo code

```
def vaccuum cleaner(room_array):
    for room in room_array:
        label, status = room[0], room[1].lower()
        print(f"currently in room {label}")
room[2],
room[3].lower
        if status == "dirty"
            print(f"Room {label} is cleaned")
        else:
            print("Room {label} is already clean
            print("moving to next room")
rooms = [('A', 'dirty'), ('B', 'clean'), ('C', 'clean'),
         ('D', 'clean'), ('A', 'clean')]
vaccum cleaner(rooms)
```

Output

```
currently in Room A
Room A cleaned
moving to next room

currently in Room B
Room B cleaned
moving to next room

currently in Room C
Room C cleaned
moving next room

urrently in RoomD
oom D cleaned
oving next room
```

Code:
Tic tac toa game:-

```
import math

def print_board(board):
    print("\n")
    for row in board:
```

```
            print(" | ".join(row))
            print("-" * 9)
        print("\n")


def check_winner(board, player):
    for row in board:
        if all(cell == player for cell in row):
            return True

    for col in range(3):
        if all(board[row][col] == player for row in range(3)):
            return True

    if all(board[i][i] == player for i in range(3)):
        return True
    if all(board[i][2 - i] == player for i in range(3)):
        return True

    return False


def is_full(board):
    return all(cell != ' ' for row in board for cell in row)


def get_human_move(board):
    while True:
        try:
            move = input("Enter your move (row and column: 1 1): ")
            row, col = map(int, move.split())
            row -= 1
            col -= 1

            if row not in range(3) or col not in range(3):
                print("Please enter values between 1 and 3.")
                continue

            if board[row][col] != ' ':
                print("That cell is already taken. Try again.")
                continue

            return row, col
        except ValueError:
            print("Invalid input. Enter row and column numbers separated by a space.")
```

```
def minimax(board, depth, is_maximizing, human, computer):
    if check_winner(board, computer):
        return 1
    elif check_winner(board, human):
        return -1
    elif is_full(board):
        return 0

    if is_maximizing:
        best_score = -math.inf
        for i in range(3):
            for j in range(3):
                if board[i][j] == ' ':
                    board[i][j] = computer
                    score = minimax(board, depth + 1, False, human, computer)
                    board[i][j] = ' '
                    best_score = max(score, best_score)
        return best_score
    else:
        best_score = math.inf
        for i in range(3):
            for j in range(3):
                if board[i][j] == ' ':
                    board[i][j] = human
                    score = minimax(board, depth + 1, True, human, computer)
                    board[i][j] = ' '
                    best_score = min(score, best_score)
        return best_score


def get_best_move(board, human, computer):
    best_score = -math.inf
    move = None

    for  i  in  range(3):
        for j in range(3):
            if   board[i][j]   ==   '   ':
                board[i][j] = computer
                score = minimax(board, 0, False, human, computer)
                board[i][j] = ' '
                if score > best_score:
                    best_score = score
                    move = (i, j)
    return move


def play_game():
```

```
    board = [[' ' for _ in range(3)] for _ in range(3)]
    human = 'X'
    computer = 'O'
    current_player = human # Human starts first

    print("Welcome to Tic-Tac-Toe (You vs Unbeatable Computer)!")
    print_board(board)

    while True:
        if current_player == human:
            row, col = get_human_move(board)
        else:
            print("Computer is making a smart move...")
            row, col = get_best_move(board, human, computer)

        board[row][col] = current_player
        print_board(board)

        if check_winner(board, current_player):
            if current_player == human:
                print("🎉 You win!")
            else:
                print("☎ Computer wins!")
            break

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

        # Switch turns
        current_player = computer if current_player == human else human


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

Vacuum cleaner agent:-

```
def display_state(vacuum_location, rooms):
    print("\nCurrent State:")
    print(f"Vacuum is in Room {vacuum_location}")
    print(f"Room states: Left = {rooms['R']} | Right = {rooms['L']}")


def vacuum_simulation():
    # Initial setup
```

```
    rooms = {
        'L': input("Is Left room dirty or clean? (Dirty/Clean): ").strip().capitalize(),
        'R': input("Is Right room dirty or clean? (Dirty/Clean): ").strip().capitalize()
    }

    vacuum_location = input("Where should the vacuum start? (L/R): ").strip().upper()
    if vacuum_location not in ['R', 'L']:
        print("Invalid input. Defaulting to 'L'")
        vacuum_location = 'L'
    print("\n--- Vacuum Cleaner Simulation Started ---")


    while True:

        display_state(vacuum_location, rooms)

        # Check if both rooms are clean
        if rooms['L'] == 'Clean' and rooms['R'] == 'Clean':
            print("✅ All rooms are clean! Job done.")
            break
        action = input("Enter action (left / right / pick / exit): ").strip().lower()
        if action == 'exit':
            print("Simulation ended by user.")
            break

        if action == 'pick':
            if rooms[vacuum_location] == 'Dirty':
                print(f"□ Picking dust in Room {vacuum_location}")
                rooms[vacuum_location] = 'Clean'
            else:
                print(f"Room {vacuum_location} is already clean.")
        elif action == 'left':
            vacuum_location = 'L' # Moving to right if user says left
            print("Vacuum moves to Room R (user chose 'left')")
        elif action == 'right':
            vacuum_location = 'R' # Moving to left if user says right
            print("Vacuum moves to Room L (user chose 'right')")
        else:
            print("❌ Invalid action. Try again.")

    print("Simulation complete.")


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

Output:-

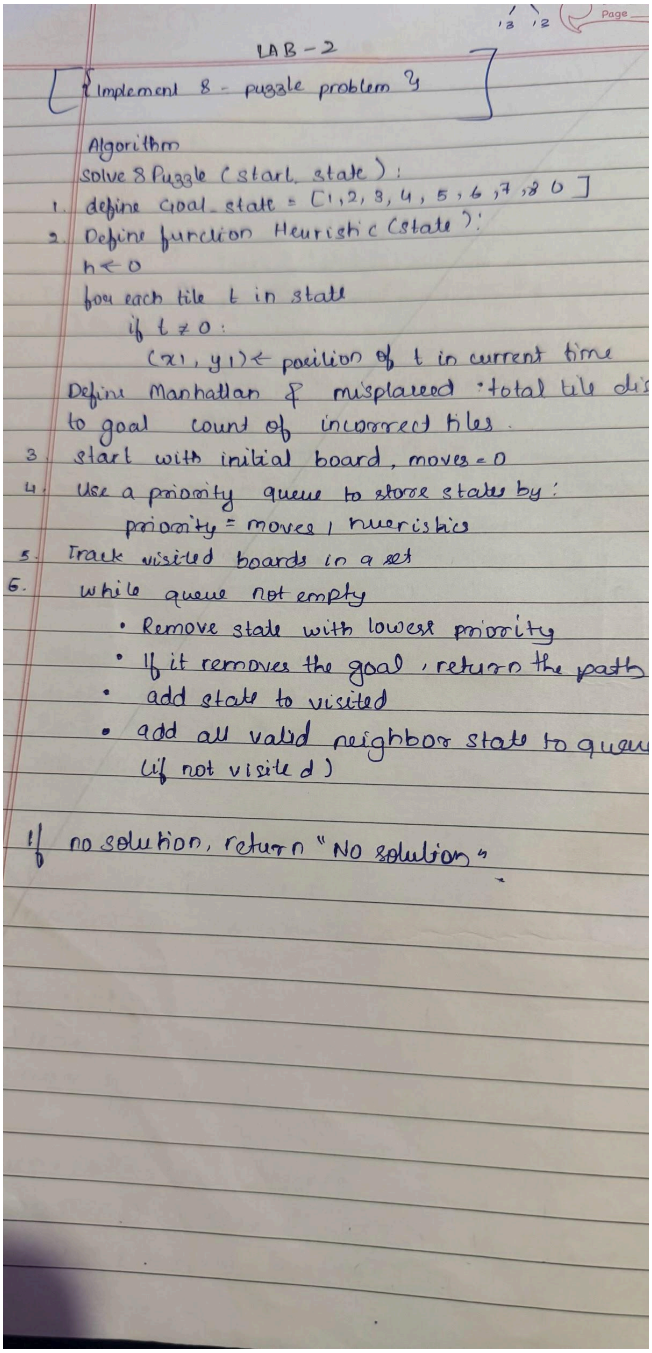

```
Is Left room dirty or clean? (Dirty/Clean): dirty
Is Right room dirty or clean? (Dirty/Clean): dirty
Where should the vacuum start? (L/R): L

--- Vacuum Cleaner Simulation Started ---

Current State:
Vacuum is in Room L
Room states: Left = Dirty | Right = Dirty
Enter action (left / right / pick / exit): right
Vacuum moves to Room L (user chose 'right')

Current State:
Vacuum is in Room R
Room states: Left = Dirty | Right = Dirty
Enter action (left / right / pick / exit):
❌ Invalid action. Try again.

Current State:
Vacuum is in Room R
Room states: Left = Dirty | Right = Dirty
Enter action (left / right / pick / exit): pick
🧹 Picking dust in Room R

Current State:
Vacuum is in Room R
Room states: Left = Clean | Right = Dirty
Enter action (left / right / pick / exit):
```

Program 2

Solve 8 puzzle problems

Implement Iterative deepening search algorithm
Implement Depth first search algorithm

Algorithm:



LAB - 2

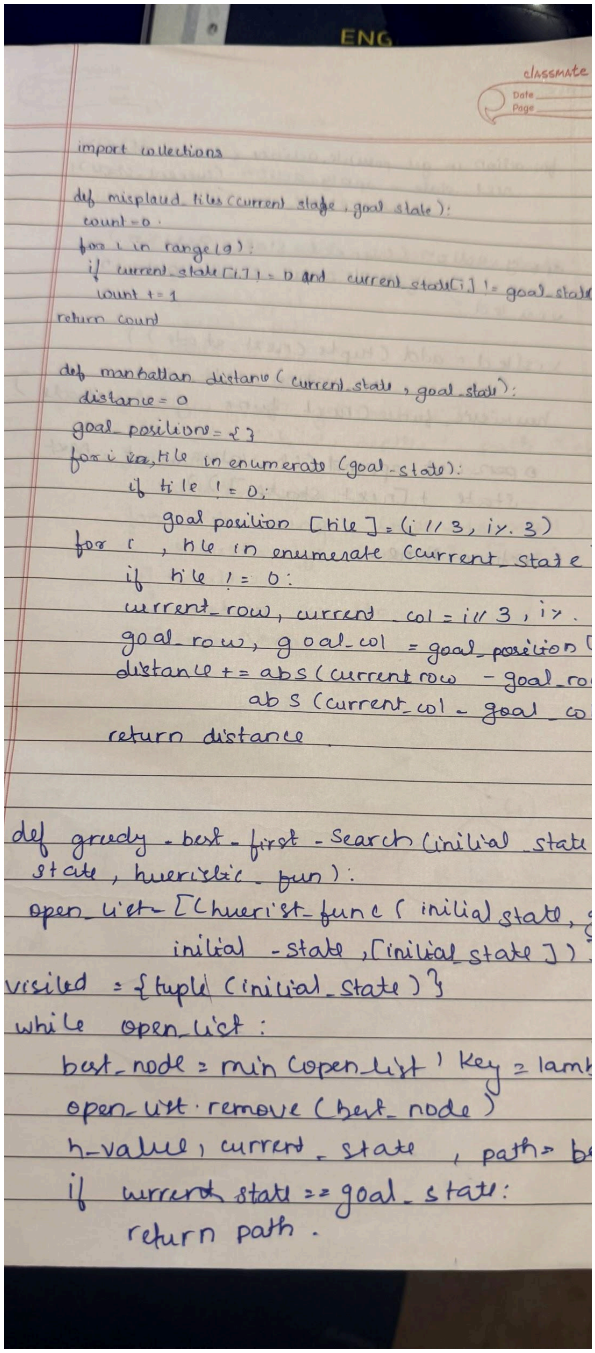
[Implement 8 - puzzle problem]

Algorithm

Solve 8 Puzzle (start_state):

1. define Goal_state = [1,2,3,4,5,6,7,8,0]
2. Define function Heuristic (state):
   h ← 0
   for each tile t in state
   if t ≠ 0:
   (x1, y1) ← position of t in current time
   Define Manhattan & misplaced :total tile di
   to goal count of incorrect tiles.
3. start with initial board, moves = 0
4. Use a priority queue to store states by:
   priority = moves + heuristics
5. Track visited boards in a set
6. while queue not empty
   - Remove state with lowest priority
   - If it removes the goal, return the path
   - add state to visited
   - add all valid neighbor state to queu
     (if not visited)

If no solution, return "No solution"



ENG

classmate

```
import collections

def misplaced_tiles(current_state, goal_state):
    count = 0
    for i in range(9):
        if current_state[i] != 0 and current_state[i] != goal_state
            count += 1
    return count

def manhattan_distance(current_state, goal_state):
    distance = 0
    goal_positions = {}
    for i, tile in enumerate(goal_state):
        if tile != 0:
            goal_position[tile] = (i // 3, i % 3)
    for i, tile in enumerate(current_state
        if tile != 0:
            current_row, current_col = i // 3, i %
            goal_row, goal_col = goal_position[
            distance += abs(current_row - goal_ro
                        abs(current_col - goal_co
    return distance

def greedy_best_first_search(initial_state
    state, heuristic_fun):
    open_list = [(heuristic_fun(initial_state),
                  initial_state, [initial_state])]
    visited = {tuple(initial_state)}
    while open_list:
        best_node = min(open_list, key = lamb
        open_list.remove(best_node)
        h_value, current_state, path = be
        if current_state == goal_state:
            return path
```

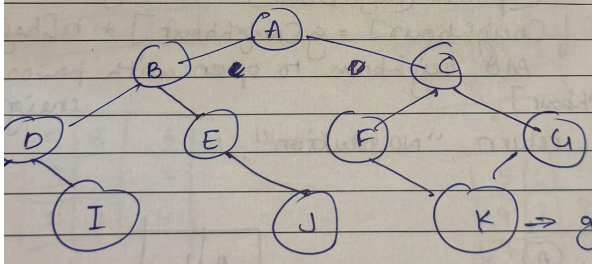
```
for action in get_possible_actions(current_state):
    next_state = apply_action(current_state, state):
        next_state

apply_action(current_state, action)
        if tuple(next_state not in:
visited:

visited.add(tuple(next_state))
        h_value next =
heuristic_func(next_func, goal_stat

open_list.append((h_value next, next
state + [next_state]))

return None.
```

LAB-2

IDDFS

pseudocode

```
def IDDFS (root, goal, graph, max_depth):
    def dfs (node, depth, path):
        if node == goal:
            return path
        if depth == 0
            return None
    for child in graph.get(node, []):
        result = dfs (child, depth-1, path +
        if result:
            return None
        for l in range (max-depth +
            result = dfs (root, l, root
        if result =
            return result=
        return None
```



A

C → F → K

Code:

IDS:-

```
GOAL_STATE = (1, 2, 3, 4, 5, 6, 7, 8, 0)
MOVES = {
    'UP': -3,
    'DOWN': 3,
    'LEFT': -1,
    'RIGHT': 1
}

def is_valid_move(pos, move):
    if move == 'UP' and pos < 3:
        return False
    if move == 'DOWN' and pos > 5:
        return False
    if move == 'LEFT' and pos % 3 == 0:
        return False
    if move == 'RIGHT' and (pos + 1) % 3 == 0:
        return False
    return True

def move_tile(state, move):
    new_state = list(state)
    idx = new_state.index(0)
    if not is_valid_move(idx, move):
        return None
    swap_idx = idx + MOVES[move]
    new_state[idx], new_state[swap_idx] = new_state[swap_idx], new_state[idx]
    return tuple(new_state)

def get_successors(state):
    successors = []
    for move in MOVES:
        new_state = move_tile(state, move)
        if new_state:
            successors.append(new_state)
    return successors

def dls(state, depth):
    stack = [(state, [])]
    visited = set()

    while stack:
        curr_state, path = stack.pop()
```

```
        if curr_state in visited:
            continue
        visited.add(curr_state)

        if curr_state == GOAL_STATE:
            return path + [curr_state]

        if len(path) >= depth:
            continue

        for succ in get_successors(curr_state):
            stack.append((succ, path + [curr_state]))

    return None

def ids(start_state, max_depth=50):
    for depth in range(max_depth + 1):
        result = dls(start_state, depth)
        if result:
            return result
    return None

def print_path(path):
    print("Number of steps:", len(path) - 1)
    for state in path:
        for i in range(0, 9, 3):
            print(state[i:i+3])
        print()

def get_user_input():
    print("Enter the initial 8-puzzle state row by row.")
    print("Use digits 0-8 exactly once (0 is the blank). Example input for one row: 1 2 3")
    user_values = []

    while len(user_values) < 9:
        try:
            row_input = input(f"Row {len(user_values)//3 + 1}: ").strip()
            row = list(map(int, row_input.split()))
            if len(row) != 3:
                print("Please enter exactly 3 numbers.")
                continue
            user_values.extend(row)
        except ValueError:
            print("Invalid input. Please enter numbers only.")

    if sorted(user_values) != list(range(9)):
        print("The puzzle must contain all digits from 0 to 8 exactly once.\nLet's try again.")
```

```
        return get_user_input()

    print("\n✅ Puzzle input accepted!\n")
    return tuple(user_values)

if __name__ == "__main__":
    start_state = get_user_input()
    print("=== Solving 8-puzzle with IDS ===")
    solution = ids(start_state)
    if solution:
        print_path(solution)
    else:
        print("No solution found within depth limit.")
```

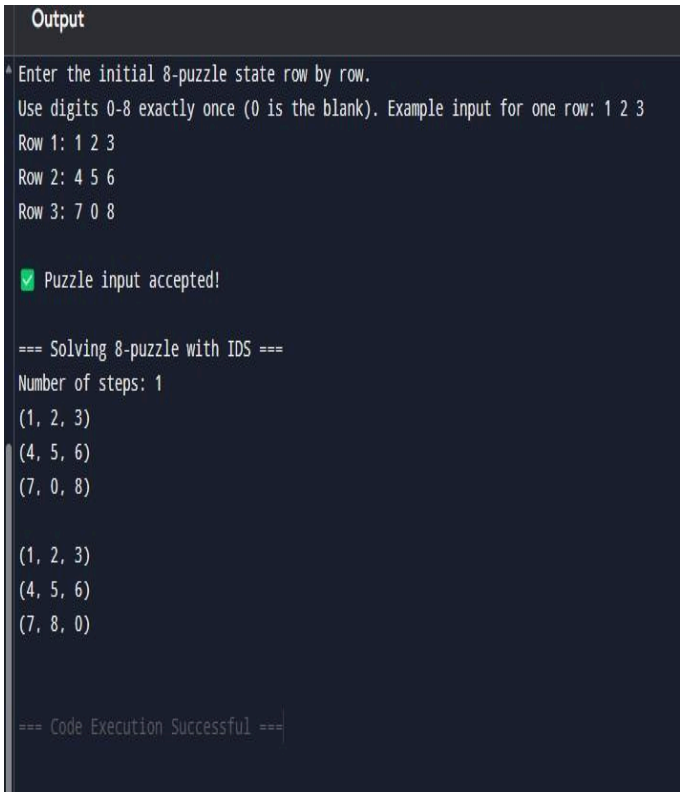
DFS:-

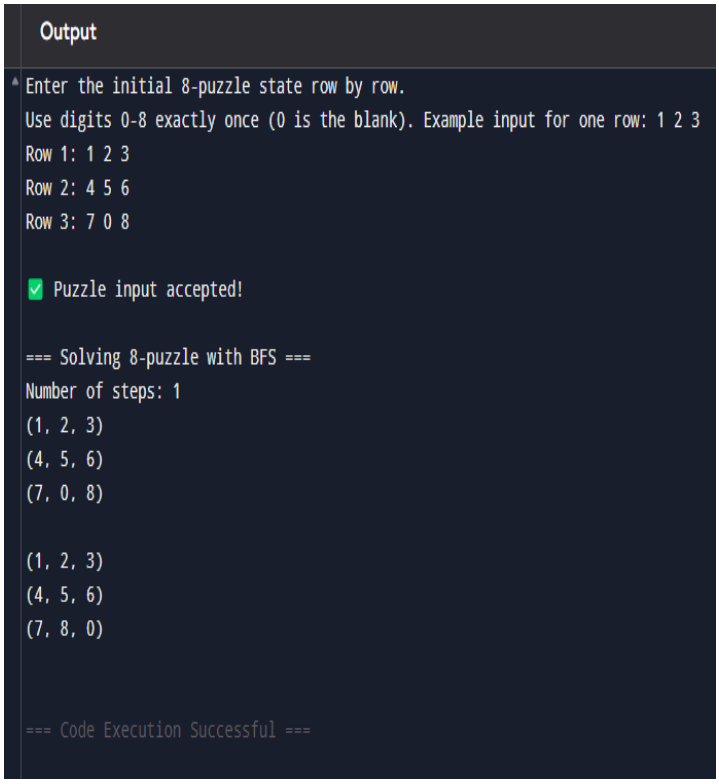
```
from collections import deque

GOAL_STATE = (1, 2, 3, 4, 5, 6, 7, 8, 0)

MOVES = {
    'UP': -3,
    'DOWN': 3,
    'LEFT': -1,
    'RIGHT': 1
}

def is_valid_move(pos, move):
    if move == 'UP' and pos < 3:
        return False
    if move == 'DOWN' and pos > 5:
        return False
    if move == 'LEFT' and pos % 3 == 0:
        return False
    if move == 'RIGHT' and (pos + 1) % 3 == 0:
        return False
    return True

def move_tile(state, move):
    new_state = list(state)
    idx = new_state.index(0)
    if not is_valid_move(idx, move):
        return None
    swap_idx = idx + MOVES[move]
    new_state[idx], new_state[swap_idx] = new_state[swap_idx], new_state[idx]
    return tuple(new_state)
```

```
def get_successors(state):
    successors = []
    for move in MOVES:
        new_state = move_tile(state, move)
        if new_state:
            successors.append(new_state)
    return successors

def bfs(start_state):
    queue = deque([(start_state, [])])
    visited = set()

    while queue:
        state, path = queue.popleft()
        if state in visited:
            continue
        visited.add(state)

        if state == GOAL_STATE:
            return path + [state]

        for succ in get_successors(state):
            queue.append((succ, path + [state]))

    return None

def print_path(path):
    print("Number of steps:", len(path) - 1)
    for state in path:
        for i in range(0, 9, 3):
            print(state[i:i+3])
        print()

def get_user_input():
    print("Enter the initial 8-puzzle state row by row.")
    print("Use digits 0-8 exactly once (0 is the blank). Example input for one row: 1 2 3")
    user_values = []

    while len(user_values) < 9:
        try:
            row_input = input(f"Row {len(user_values)//3 + 1}: ").strip()
            row = list(map(int, row_input.split()))
            if len(row) != 3:
                print(" Please enter exactly 3 numbers.")
                continue
            user_values.extend(row)
        except ValueError:
```

```
            print(" Invalid input. Please enter numbers only.")

    if sorted(user_values) != list(range(9)):
        print("The puzzle must contain all digits from 0 to 8 exactly once.")
        return get_user_input()

    print("\n Puzzle input accepted!\n")
    return tuple(user_values)


if __name__ == "__main__":
    start_state = get_user_input()
    print("=== Solving 8-puzzle with BFS ===")
    result = bfs(start_state)
    if result:
        print_path(result)
    else:
        print("No solution found.")
```

Output:-



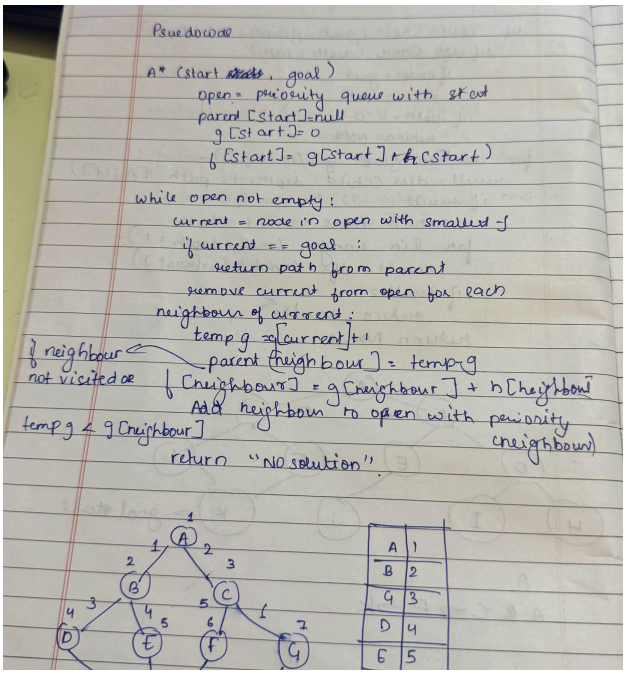


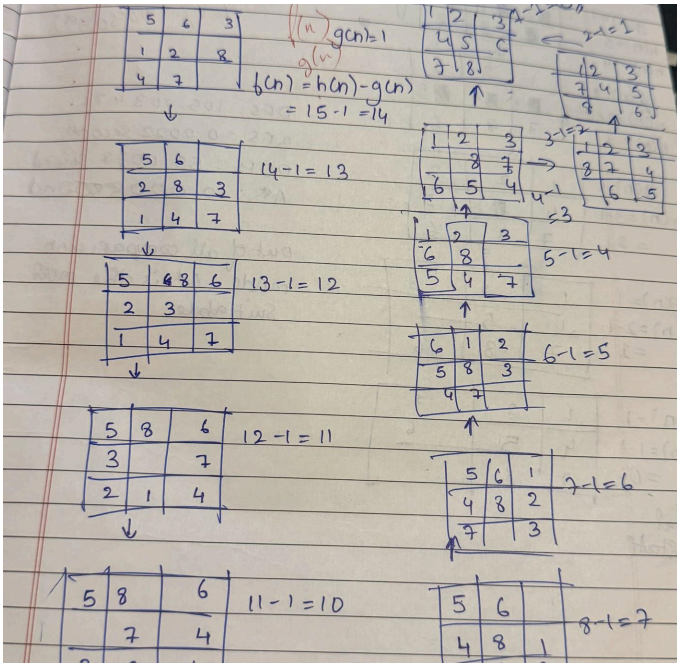
Program 3

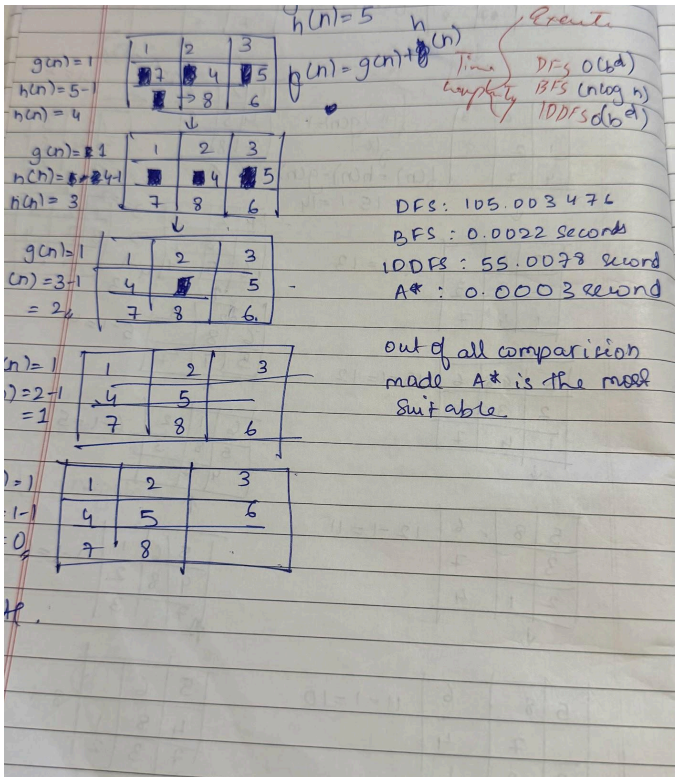
Solve 8 puzzle problems

Implement A* search algorithm

Algorithm:





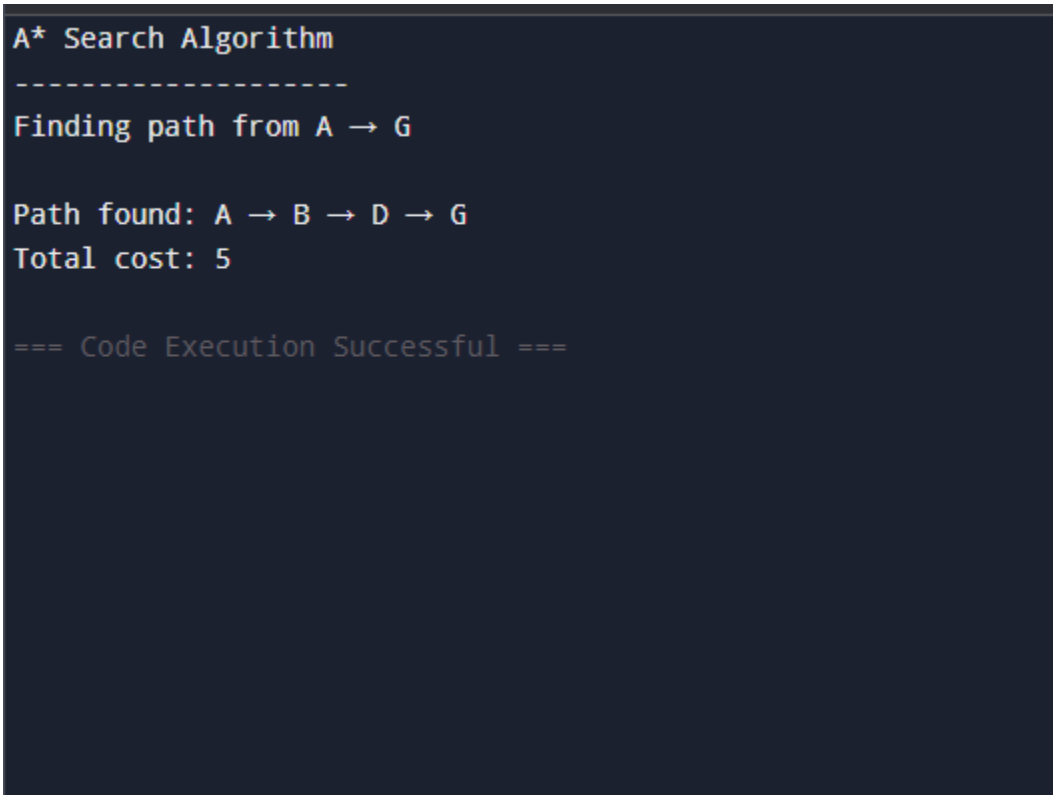


Code:-

```
# A* Search Algorithm Implementation in Python

from queue import PriorityQueue

def a_star_search(graph, heuristic, start, goal):
    # Priority queue to store (f_score, node,
    path) pq = PriorityQueue()
    pq.put((0, start, [start]))

    # Dictionary to store g_scores (cost from start)
    g_score = {node: float('inf') for node in graph}
    g_score[start] = 0

    while not pq.empty():
        f, current, path = pq.get()

        # Goal check
        if current == goal:
            print("Path found:", ' → '.join(path))
            print("Total cost:", g_score[goal])
            return

        # Explore neighbors
        for neighbor, cost in graph[current]:
            tentative_g = g_score[current] + cost

            if tentative_g < g_score[neighbor]:
                g_score[neighbor] = tentative_g
                f_score = tentative_g + heuristic[neighbor]
                pq.put((f_score, neighbor, path + [neighbor]))
    print("No path found!")
# Example usage
if _name___== "_main_":
    # Define the graph as adjacency list
    # Each node: [(neighbor, cost), ...]
    graph = {
        'A': [('B', 1), ('C', 3)],
        'B': [('D', 1), ('E', 5)],
        'C': [('F', 2)],
        'D': [('G', 3)],
        'E': [('G', 1)],
        'F': [('G', 5)],
        'G': []
```

```
}

# Define heuristic values (estimated cost to reach goal)
heuristic = {
    'A': 7,
    'B': 6,
    'C': 5,
    'D': 4,
    'E': 2,
    'F': 1,
    'G': 0
}

start_node = 'A'
goal_node = 'G'

print("A* Search Algorithm")
print("--------------")
print(f"Finding path from {start_node} → {goal_node}\n")

a_star_search(graph, heuristic, start_node, goal_node)
```

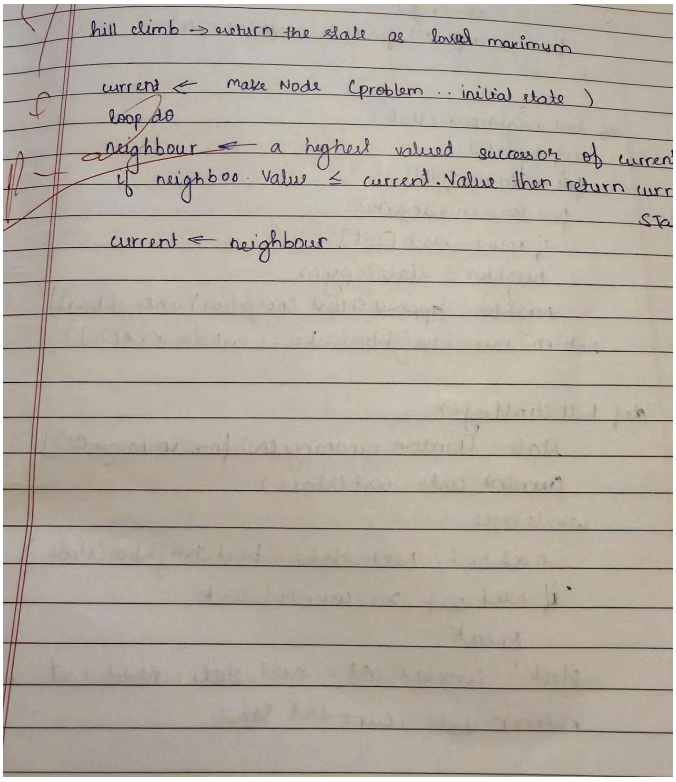
Output:-

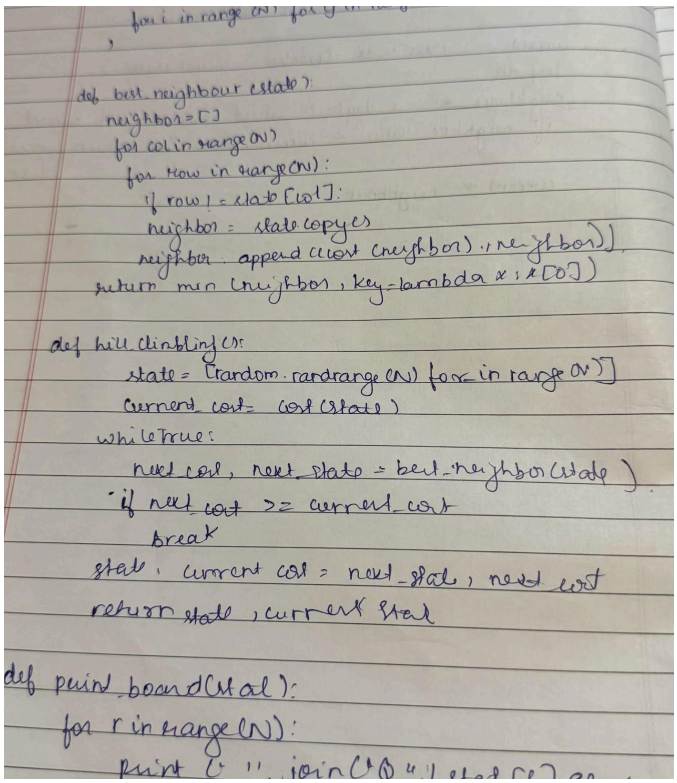


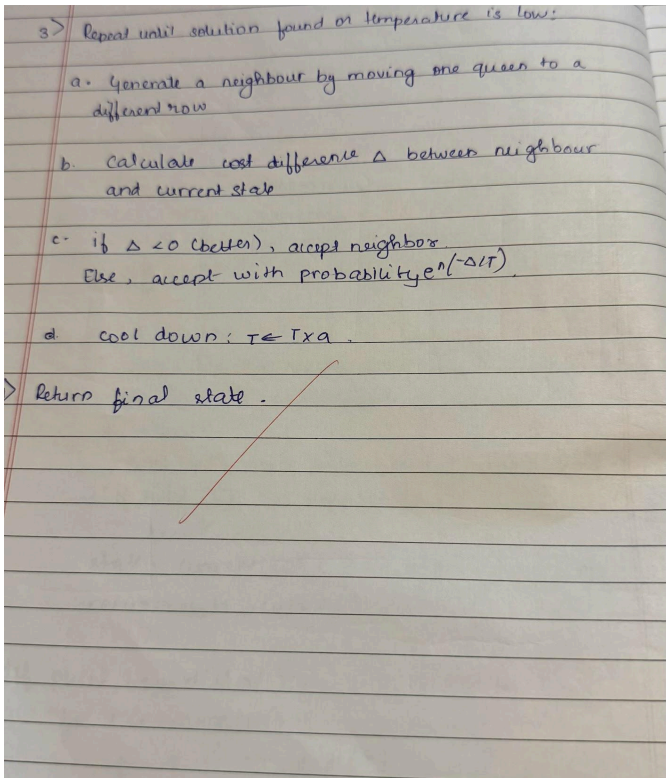
Program 4

Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm:-







Code:-

```
import random

def generate_board(N):
    """Generate a random board: board[i] = row of queen in column i"""
    return [random.randint(0, N-1) for _ in range(N)]

def compute_heuristic(board):
    """Compute number of pairs of queens attacking each other"""
    h = 0
    N = len(board)
    for i in range(N):
        for j in range(i+1, N):
            if board[i] == board[j]:            # same row
                h += 1
            elif abs(board[i] - board[j]) == j - i: # same diagonal
                h += 1
    return h

def get_neighbors(board):
    """Generate all neighbors by moving one queen in its column"""
    neighbors = []
    N = len(board)
    for col in range(N):
        for row in
        range(N):
            if board[col] != row:
                new_board = list(board)
                new_board[col] = row
                neighbors.append(new_board)
    return neighbors

def hill_climbing(N, max_restarts=100):
    for restart in range(max_restarts):
        board = generate_board(N)
        steps = 0
        while True:
            h = compute_heuristic(board)
            if h == 0:
                print(f"Solution found in {steps} steps after {restart} restarts!")
```

return board

```
            neighbors = get_neighbors(board)
            h_values = [compute_heuristic(nb) for nb in neighbors]
            min_h = min(h_values)
            if min_h >= h: # no improvement
                break       # local maxima, do random restart
            # move to the neighbor with minimum heuristic
            board = neighbors[h_values.index(min_h)]
            steps += 1
    print("No solution found")
    return None

# Example usage
N = 8
solution = hill_climbing(N)
if solution:
    print("Board (column: row):",
```

solution) Output:-

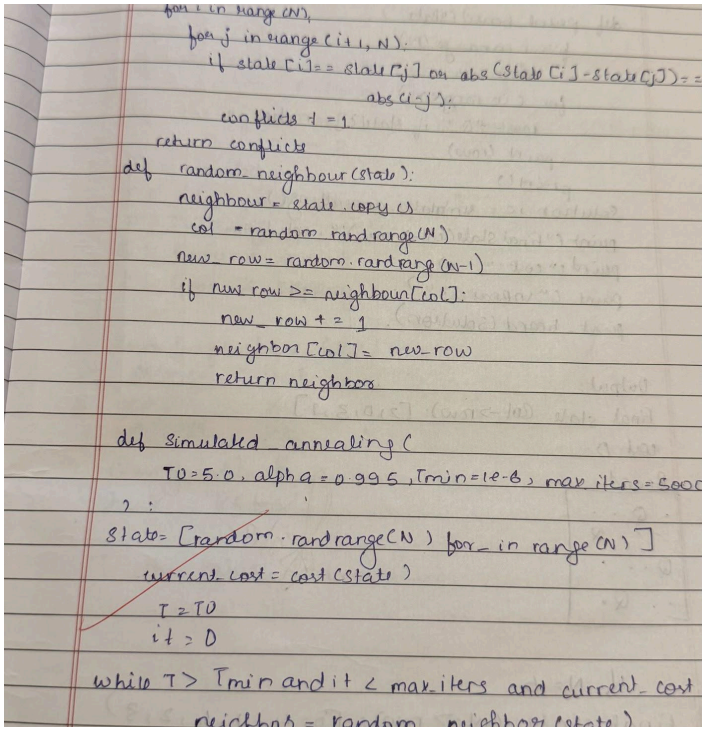
```
Solution found in 3 steps after 10 restarts!
Board (column: row): [3, 7, 0, 4, 6, 1, 5, 2]

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

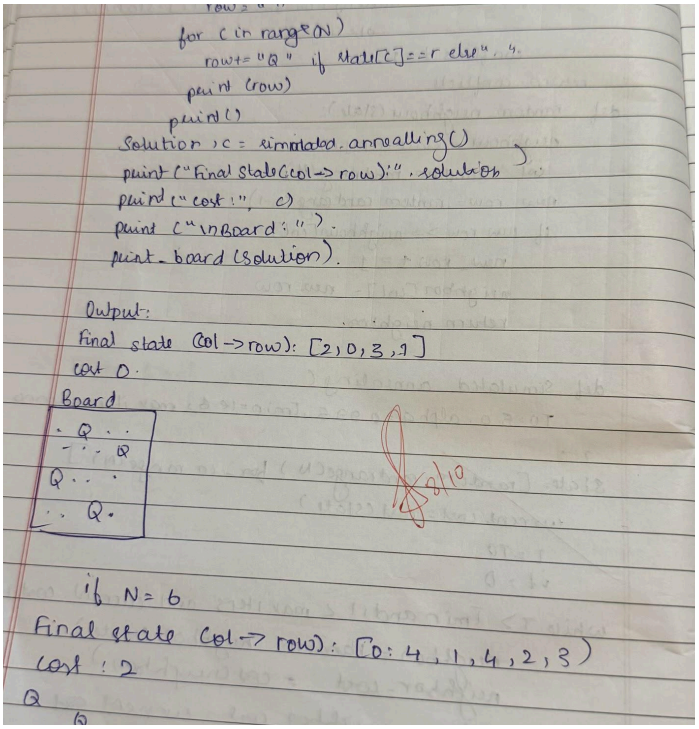
Program 5

Simulated Annealing

To Solve 8-Queens problem

Algorithm:-





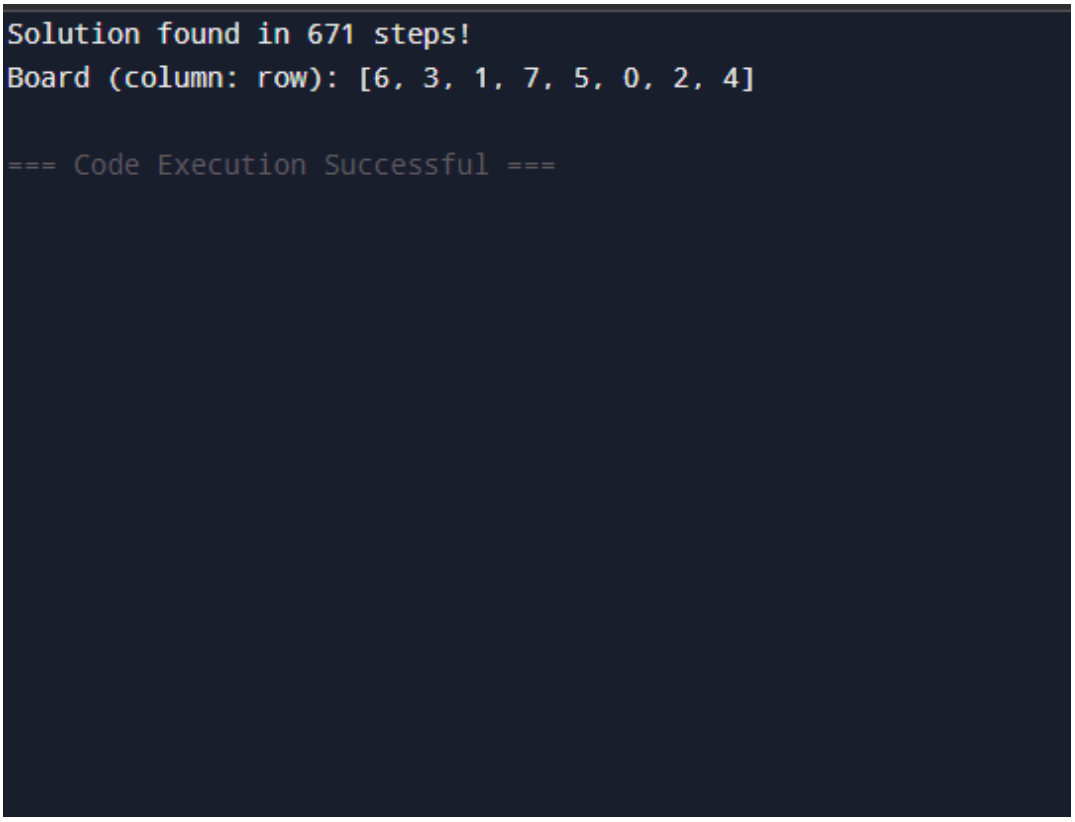
Code:-

```
import random
import math

def generate_board(N):
    """Generate a random board: board[i] = row of queen in column i"""
    return [random.randint(0, N-1) for _ in range(N)]

def compute_heuristic(board):
    """Compute number of pairs of queens attacking each other"""
    h = 0
    N = len(board)
    for i in range(N):
```

```
        for j in range(i+1, N):
            if board[i] == board[j]:              # same row
                h += 1
            elif abs(board[i] - board[j]) == j - i: # same diagonal
                h += 1
    return h

def get_random_neighbor(board):
    """Generate a neighbor by moving one queen in its column to a random row"""
    N = len(board)
    col = random.randint(0, N-1)
    row = random.randint(0, N-1)
    while board[col] == row:
        row = random.randint(0, N-1)
    new_board = list(board)
    new_board[col] = row
    return new_board

def simulated_annealing(N, max_steps=100000, initial_temp=1000, cooling_rate=0.99):
    board = generate_board(N)
    current_h = compute_heuristic(board)
    T = initial_temp

    for step in range(max_steps):
        if current_h == 0:
            print(f"Solution found in {step} steps!")
            return board
        neighbor = get_random_neighbor(board)
        neighbor_h = compute_heuristic(neighbor)
        delta_h = neighbor_h - current_h

        if delta_h < 0:
            # Better neighbor, move to it
            board = neighbor
            current_h = neighbor_h
        else:
            # Worse neighbor, move with probability e^(-ΔH/T)
            probability = math.exp(-delta_h / T)
            if random.random() < probability:
                board = neighbor
                current_h = neighbor_h
```

```
        # Cool down the temperature
        T *= cooling_rate

    print("No solution found")
    return None

# Example usage
N = 8
solution = simulated_annealing(N)
if solution:
    print("Board (column: row):", solution)
```

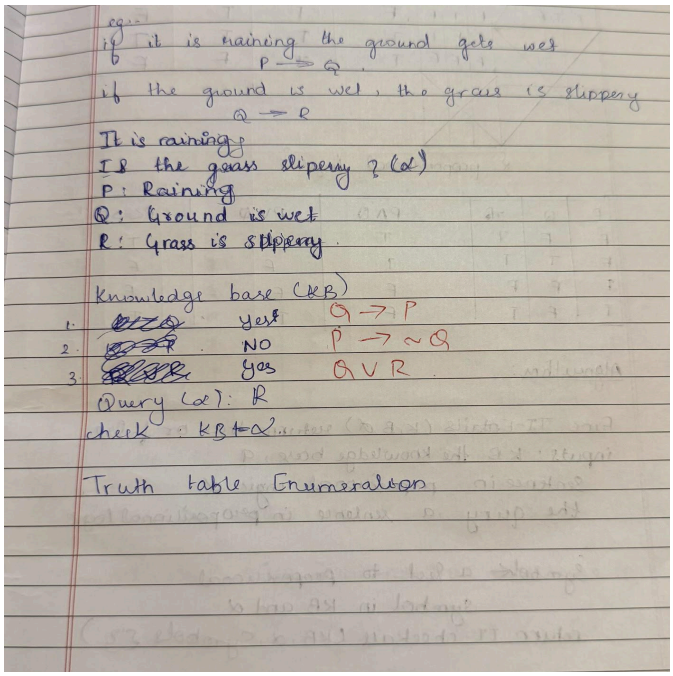
Output:-

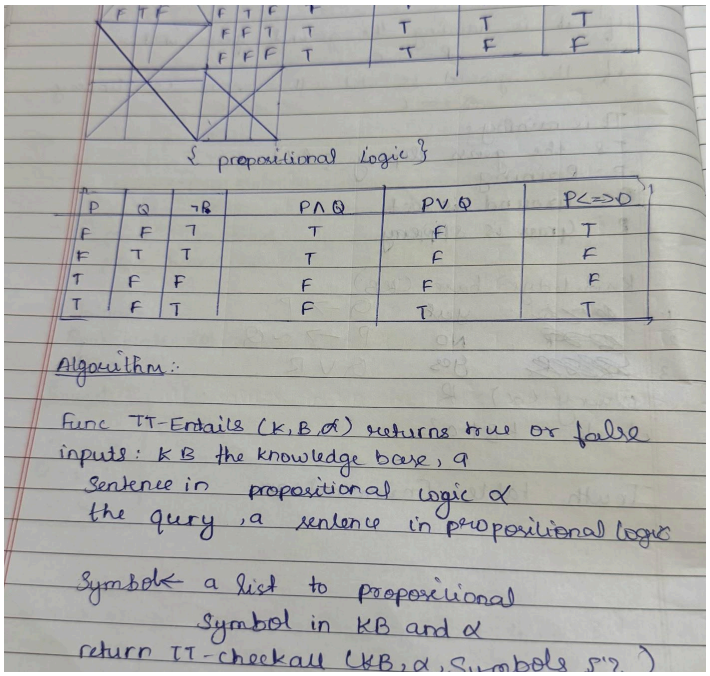


Program 6

Propositional Logic

Algorithm:-



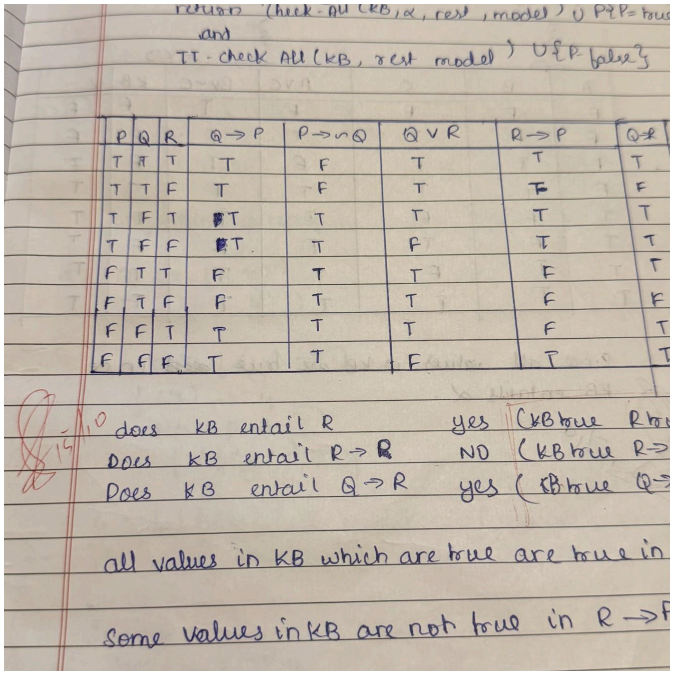


Code:-

```
from itertools import product

# Define the propositional variables
variables = ['P', 'Q', 'R']

# Define all possible truth assignments
assignments = list(product([True, False], repeat=len(variables)))

# Function to evaluate the KB sentences
def evaluate_KB(P, Q, R):
```

```
    s1 = (not Q) or P       # Q -> P
    s2 = (not P) or (not Q) # P -> ¬Q
    s3 = Q or R             # Q ∨ R
    KB_true = s1 and s2 and s3
    return KB_true, s1, s2, s3

# Function to evaluate a statement
def evaluate_statement(statement, P, Q, R):
    # statement is a lambda function
    return statement(P, Q, R)

# Statements to check entailment
statements = {
    "R": lambda P,Q,R: R,
    "R -> P": lambda P,Q,R: (not R) or P,
    "Q -> R": lambda P,Q,R: (not Q) or R
}

# Loop through all assignments
print(f"{'P':^5}{'Q':^5}{'R':^5}{'KB':^5}{'R':^5}{'R->P':^7}{'Q->R':^7}")
for values in assignments:
    P, Q, R = values
    KB_true, s1, s2, s3 = evaluate_KB(P, Q, R)
    R_val = evaluate_statement(statements["R"], P, Q, R)
    RtoP_val = evaluate_statement(statements["R -> P"], P, Q, R)
    QtoR_val = evaluate_statement(statements["Q -> R"], P, Q, R)
    print(f"{P!s:^5}{Q!s:^5}{R!s:^5}{KB_true!s:^5}{R_val!s:^5}{RtoP_val!s:^7}{QtoR_val!s:^7}"

) # Check entailment


def check_entailment(statement_func):
    for values in assignments:
        P,Q,R = values
        KB_true, _, _, _ = evaluate_KB(P,Q,R)
        if KB_true and not statement_func(P,Q,R):
            return False
    return True

print("\nEntailment results:")
for name, func in statements.items():
```

```
print(f"KB entails {name}? {check_entailment(func)}")
```

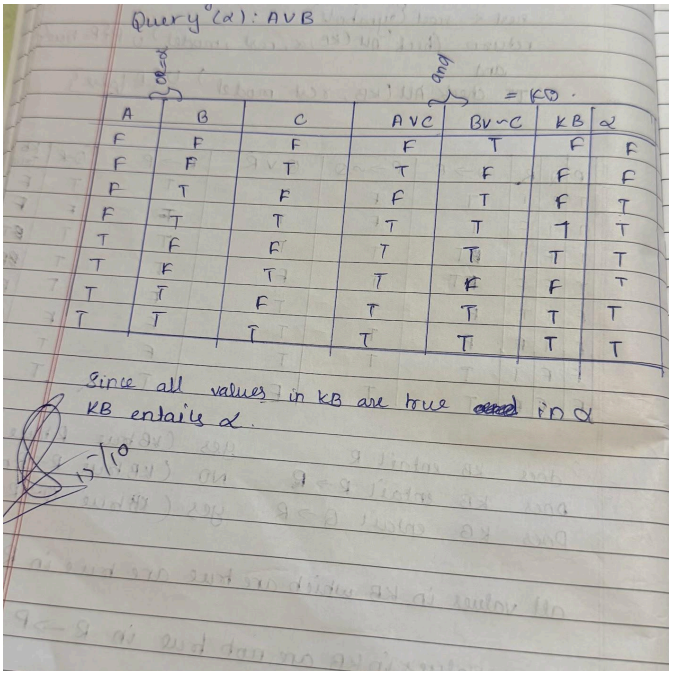


P	Q	R	Q→P	P→¬Q	Q∨R	R→P	Q→
T	T	T	T	F	T	T	T
T	T	F	T	F	T	T	F
T	F	T	T	T	T	T	T
T	F	F	T	T	F	T	T
F	T	T	F	T	T	F	T
F	T	F	F	T	T	F	F
F	F	T	T	T	T	F	T
F	F	F	T	T	F	T	T

does KB entail R — yes (KB true R
Does KB entail R→R — NO (KB true R→
Does KB entail Q→R — yes (KB true Q→

all values in KB which are true are true in

Some values in KB are not true in R→



Query (α): A∨B

A	B	C	A∨C	B∨¬C	KB	α
F	F	F	F	T	F	F
F	F	T	T	F	F	F
F	T	F	F	T	F	T
F	T	T	T	T	T	T
T	F	F	T	T	T	T
T	F	T	T	F	F	T
T	T	F	T	T	T	T
T	T	T	T	T	T	T

Since all values in KB are true in α
KB entails α.

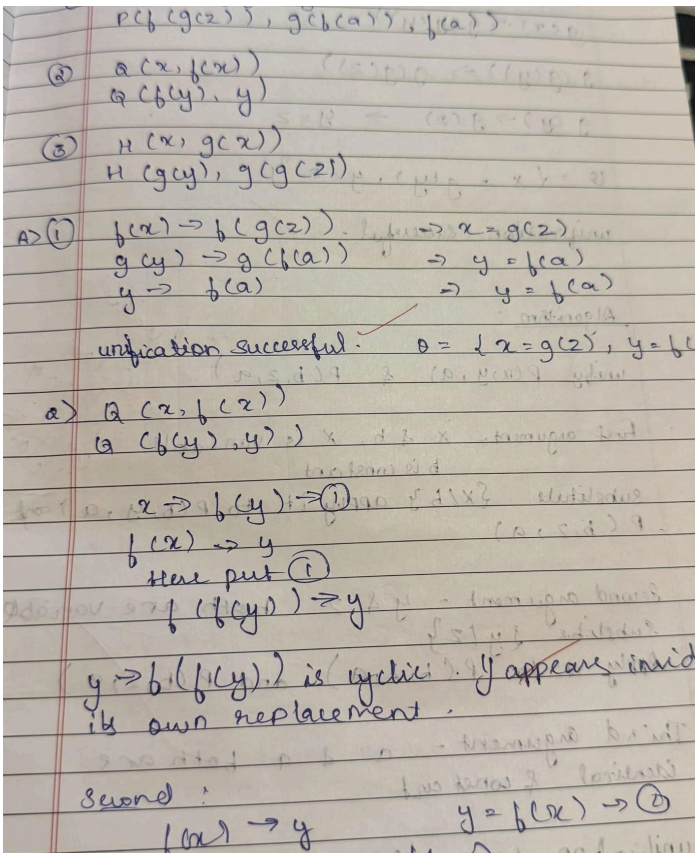
Output:-

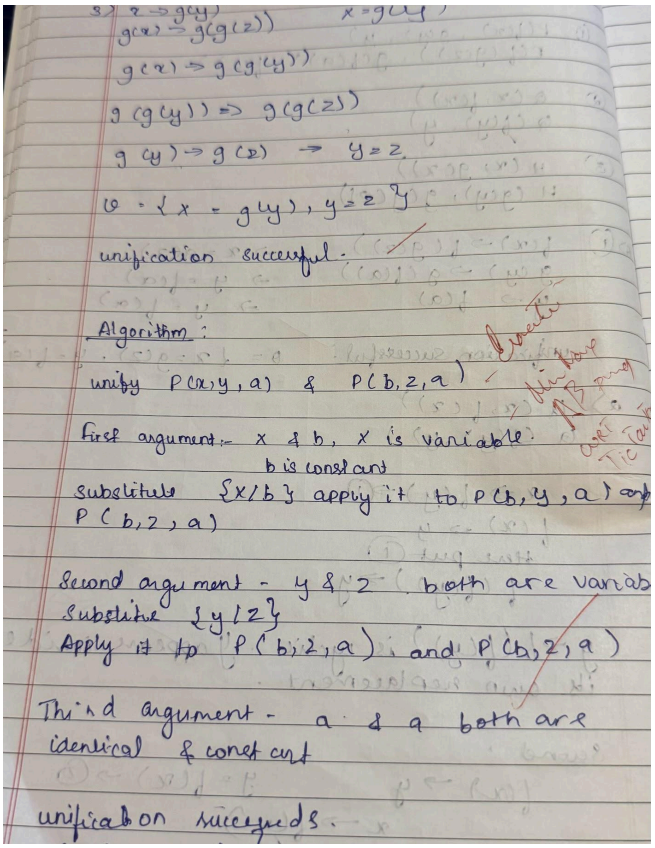
```
  P     Q     R    KB     R    R->P    Q->R
True  True  True  FalseTrue   True    True
True  True  FalseFalseFalse  True    False
True  FalseTrue  True  True   True    True
True  FalseFalseFalseFalse  True    True
FalseTrue  True  FalseTrue   False   True
FalseTrue  FalseFalseFalse  True    False
FalseFalseTrue  True  True   False   True
FalseFalseFalseFalseFalse  True    True

Entailment results:
KB entails R? True
KB entails R -> P? False
KB entails Q -> R? True

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

Program 7

Implement unification in first order logic

Algorithm:-





Code:-

```
# ---------------------
# Unification Algorithm in First-Order Logic
# ---------------------

class Term:
    def _init_(self, name, args=None):
        self.name = name
        self.args = args or []
```

```
def is_variable(self):
```

```
        return self.args == [] and self.name[0].isupper()

    def is_constant(self):
        return self.args == [] and self.name[0].islower()

    def __repr__(self): if
        not self.args:
            return self.name
        else:
            return f"{self.name}({', '.join(map(str, self.args))})"


# Occurs check: prevents infinite recursion like X = f(X)
def occurs_check(var, term, subs):
    if var == term:
        return True
    elif term.is_variable() and term.name in subs:
        return occurs_check(var, subs[term.name], subs)
    elif term.args:
        return any(occurs_check(var, t, subs) for t in term.args)
    return False


# Apply substitution to a term
def apply(subs, term):
    if term.is_variable() and term.name in subs:
        return apply(subs, subs[term.name])
    elif term.args:
        return Term(term.name, [apply(subs, t) for t in term.args])
    else:
        return term


# Unification function
def unify(x, y, subs=None):
    if subs is None:
        subs = {}

    x = apply(subs, x)
    y = apply(subs, y)
```

```
    if x == y:
        return subs
    elif x.is_variable():
        if occurs_check(x, y, subs):
            return None
        subs[x.name] = y
        return subs
    elif y.is_variable():
        if occurs_check(y, x, subs):
            return None
        subs[y.name] = x
        return subs
    elif x.name == y.name and len(x.args) == len(y.args):
        for a, b in zip(x.args, y.args):
            subs = unify(a, b, subs)
            if subs is None:
                return None
        return subs
    else:
        return None

# -------- Example Test Cases --------
if __name__ == "__main__":
    tests = [
        ("Unify X with a", Term("X"), Term("a")),
        ("Unify f(X,b) with f(a,Y)", Term("f", [Term("X"), Term("b")]), Term("f", [Term("a"),
Term("Y")])),
        ("Unify f(X) with X (occurs check fail)", Term("f", [Term("X")]), Term("X")),
        ("Unify g(X,h(Y)) with g(h(Z),h(a))", Term("g", [Term("X"), Term("h", [Term("Y")])]),
Term("g", [Term("h", [Term("Z")]), Term("h", [Term("a")])])),
        ("Unify p(X,X) with p(a,b) (should fail)", Term("p", [Term("X"), Term("X")]), Term("p",
[Term("a"), Term("b")])),
    ]

    for desc, t1, t2 in tests:
        print("Test:", desc)
        result = unify(t1, t2)
        if result is None:
            print(" ❌ Unification failed")
```

```
    else:
        print(" ✅ Substitution:")
        for k, v in result.items():
            print(f"     {k} -> {v}")
    print()
```

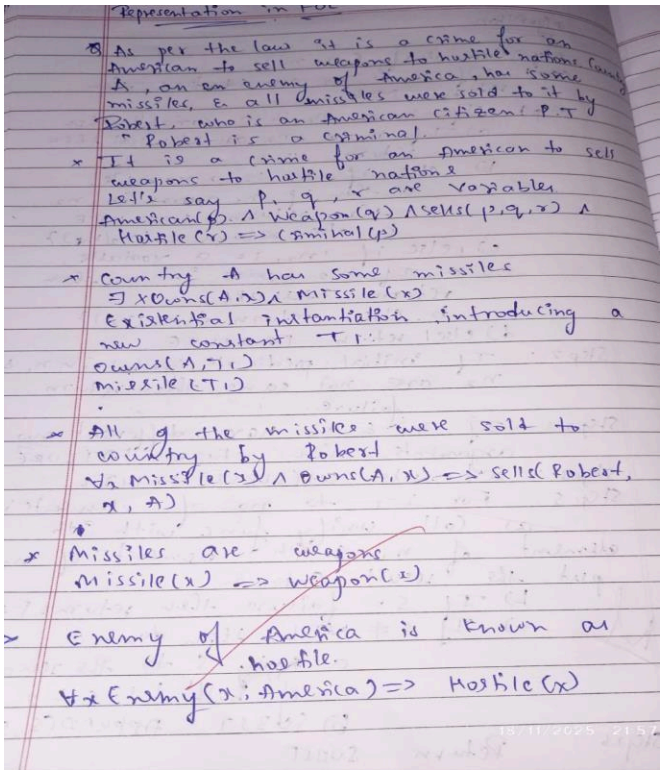
Output:-

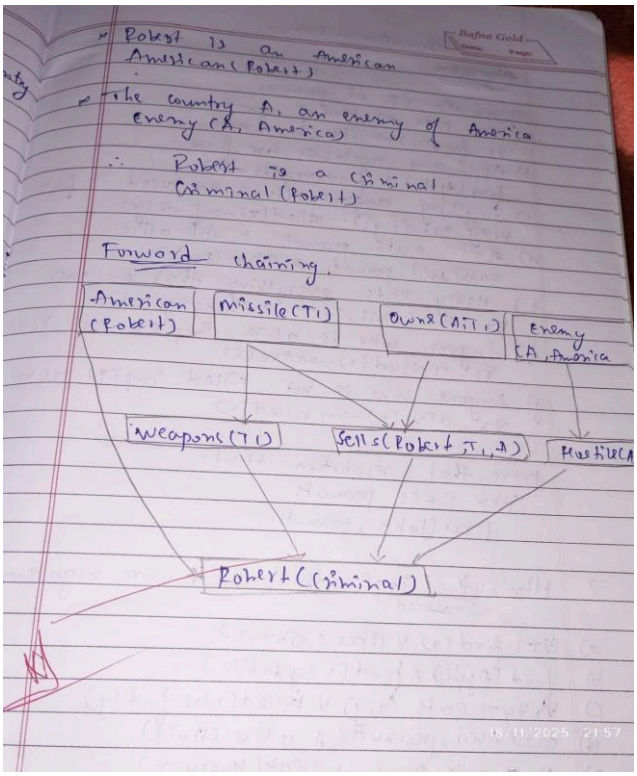
```
Test: Unify X with a
  ✅ Substitution:
     X -> a

Test: Unify f(X,b) with f(a,Y)
  ✅ Substitution:
     X -> a
     Y -> b

Test: Unify f(X) with X (occurs check fail)
  ✅ Substitution:
     X -> f(X)

Test: Unify g(X,h(Y)) with g(h(Z),h(a))
  ✅ Substitution:
     X -> h(Z)
     Y -> a

Test: Unify p(X,X) with p(a,b) (should fail)
  ❌ Unification failed


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

Program 8

Forward Reasoning Algorithm

Algorithm:-





Code:-

```
# Facts as tuples (Predicate, Arguments)
facts = [
    ('American', 'Robert'),
    ('Enemy', 'CountryA', 'America'),
    ('Sells', 'Robert', 'Missile1', 'CountryA'),
    ('Sells', 'Robert', 'Missile2', 'CountryA')
]

# Rule: American sells weapons to hostile nation -> Criminal
def infer_criminal(facts):
    new_facts = []
    for fact in facts:
        if fact[0] == 'American':
            person = fact[1]
            for sell in facts:
                if sell[0] == 'Sells' and sell[1] == person:
                    weapon, country = sell[2], sell[3]
```

```
                for enemy in facts:
                    if enemy[0] == 'Enemy' and enemy[1] == country and enemy[2] == 'America':
                        criminal_fact = ('Criminal', person)
                        if criminal_fact not in facts and criminal_fact not in new_facts:
                            new_facts.append(criminal_fact)
    return new_facts

# Forward chaining
while True:
    new_facts = infer_criminal(facts)
    if not new_facts:
        break
    facts.extend(new_facts)

# Result
for f in facts:
    print(f)
```

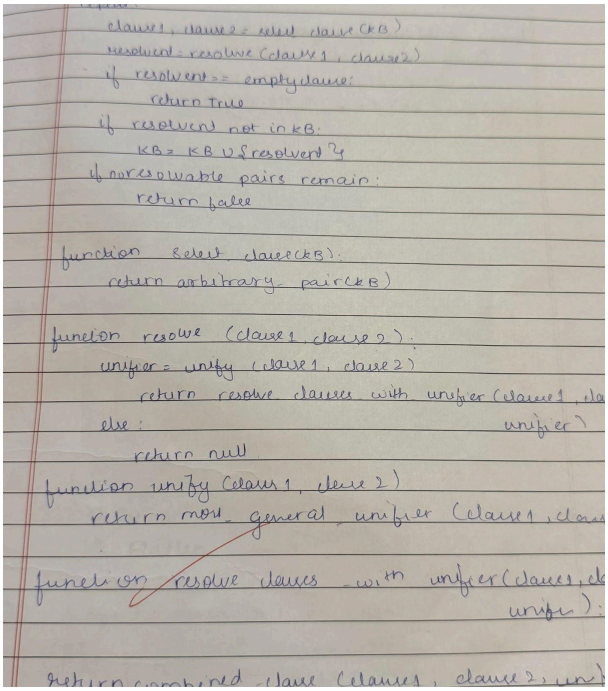
Output:-

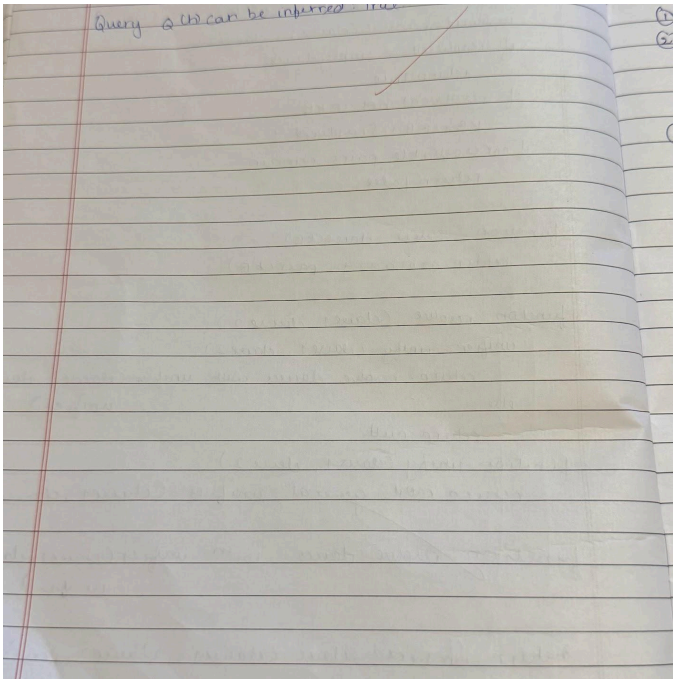
```
('American', 'Robert')
('Enemy', 'CountryA', 'America')
('Sells', 'Robert', 'Missile1', 'CountryA')
('Sells', 'Robert', 'Missile2', 'CountryA')
('Criminal', 'Robert')

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

Program 9

Resolution in FOL

Algorithm:-





Code:-

```
def resolve(ci, cj):


    Try resolving two clauses.

    Returns a list of possible resolvents.

     resolvents = []

 for literal in ci:

        # complement literal

        comp = "-" + literal if literal[0] != "-" else literal[1:]

 if comp in cj:
```

```
            # resolvent = (ci U cj) − {literal, comp}
            new_clause = (ci - {literal}) | (cj - {comp})
            resolvents.append(new_clause)

    return resolvents



def resolution(clauses):
    Main resolution algorithm.
    clauses: list of sets, e.g. [{"A","B"}, {"-A"}]
    new = set()

    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:
            resolvents = resolve(ci, cj)
            for r in resolvents:
                print(f"Resolving {ci} and {cj}  →  {r}")

                if len(r) == 0:   # Empty clause found
                    print("\n❌ Empty clause produced: CONTRADICTION")
```

```
                return True

            new.add(frozenset(r))

    # Stop if no new clauses
    if new.issubset(set(map(frozenset, clauses))):
        print("\nNo new clauses. Cannot derive contradiction.")
        return False

    # Add new clauses
    for c in new:
        if set(c) not in clauses:
            clauses.append(set(c))
```

Input :

```
clauses = [
    {"A", "B"},     # A ∨ B
    {"-A"},         # ¬A
    {"-B"}          # ¬B
]

resolution(clauses)
```

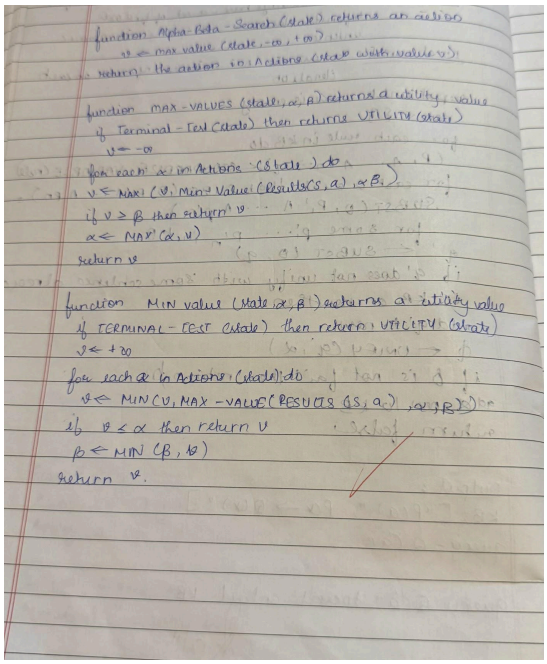
Output:-

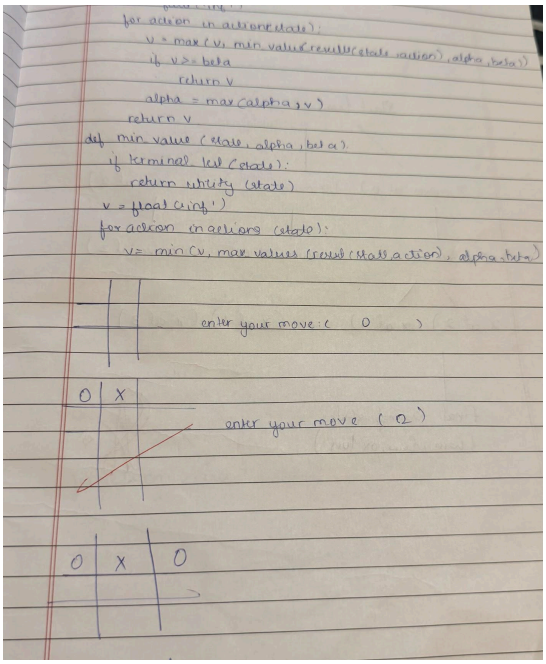
```
Resolving {'B', 'A'} and {'-A'}  →  {'B'}
Resolving {'B', 'A'} and {'-B'}  →  {'A'}
Resolving {'B', 'A'} and {'-A'}  →  {'B'}
Resolving {'B', 'A'} and {'-B'}  →  {'A'}
Resolving {'-A'} and {'A'}  →  set()

❌ Empty clause produced: CONTRADICTION
```

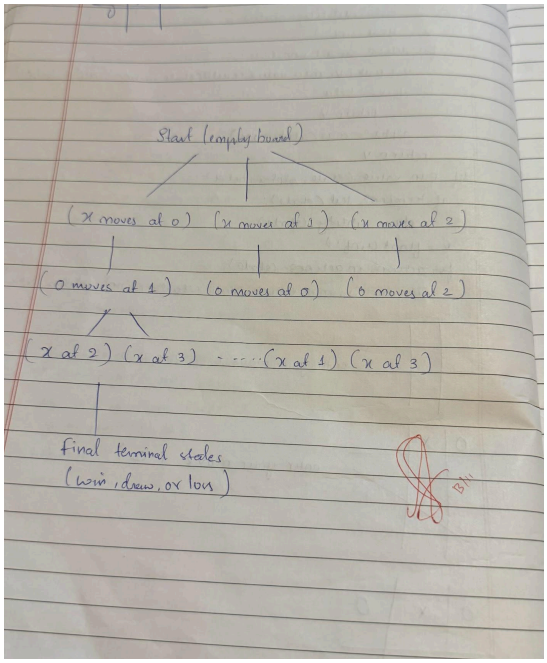
Program 10

Alpha beta pruning

Algorithm:-







Code:-

```
# Alpha-Beta Pruning in Python for tic tac toe

    import math
    import random

    # -------- TIC TAC TOE CLASS --------
    class TicTacToe:
        def __init__(self):
            self.board = [" "] * 9

        def print_board(self):
            b = self.board
            print("\n")
            print(f" {b[0]} | {b[1]} | {b[2]} ")
            print("---+---+---")
            print(f" {b[3]} | {b[4]} | {b[5]} ")
            print("---+---+---")
            print(f" {b[6]} | {b[7]} | {b[8]} ")
            print("\n")

        def available_moves(self):
            return [i for i, v in enumerate(self.board) if v == " "]

        def make_move(self, move, player):
            self.board[move] = player

        def undo_move(self, move):
            self.board[move] = " "

        def winner(self):
            winning_patterns = [
                [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
        ]
        for a,b,c in winning_patterns:
            if self.board[a] == self.board[b] == self.board[c] != " ":
                return self.board[a]
        return None

    def is_full(self):
        return " " not in self.board

    def game_over(self):
        return self.winner() is not None or self.is_full()


# -------- ALPHA-BETA MINIMAX --------
def minimax(game, depth, alpha, beta, maximizing):
    winner = game.winner()

    if winner == "X": return 10 - depth
    if winner == "O": return depth - 10
    if game.is_full(): return 0

    if maximizing:
        max_eval = -math.inf
        for move in game.available_moves():
            game.make_move(move, "X")
            eval = minimax(game, depth + 1, alpha, beta, False)
            game.undo_move(move)
            max_eval = max(max_eval, eval)
            alpha = max(alpha, eval)
            if beta <= alpha: break
        return max_eval
    else:
        min_eval = math.inf
        for move in game.available_moves():
```

```
            game.make_move(move, "O")
            eval = minimax(game, depth + 1, alpha, beta, True)
            game.undo_move(move)
            min_eval = min(min_eval, eval)
            beta = min(beta, eval)
            if beta <= alpha: break
        return min_eval


def best_move(game, player):
    best_val = -math.inf if player == "X" else math.inf
    best_move = None

    for move in game.available_moves():
        game.make_move(move, player)
        move_val = minimax(game, 0, -math.inf, math.inf, player == "O")
        game.undo_move(move)

        if player == "X" and move_val > best_val:
            best_val = move_val
            best_move = move
        elif player == "O" and move_val < best_val:
            best_val = move_val
            best_move = move

    return best_move


# -------- COMPUTER VS COMPUTER --------
def computer_vs_computer():
    game = TicTacToe()
    player = "X"

    print("Computer vs Computer (Alpha-Beta Pruning)\n")
    game.print_board()
```

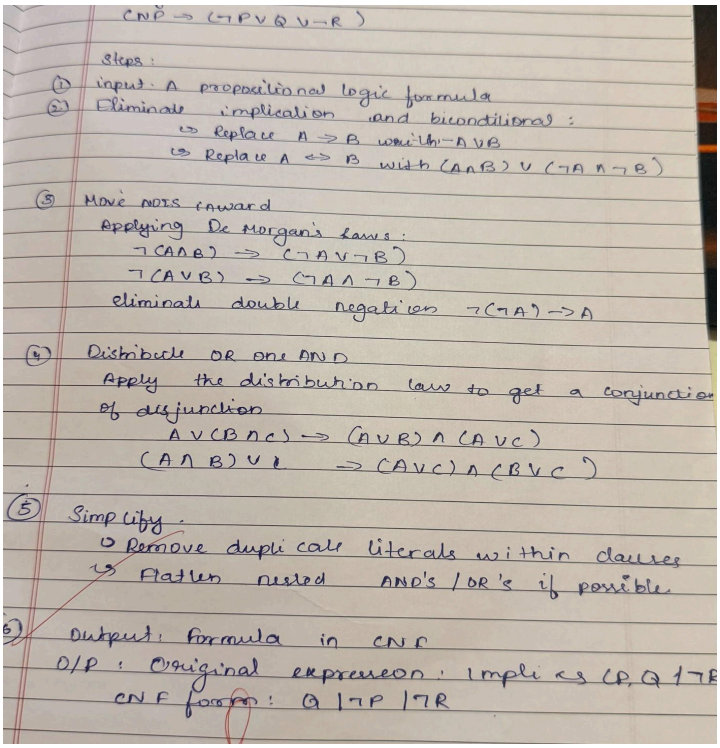
```
    while not game.game_over():
        move = best_move(game, player)
        game.make_move(move, player)
        print(f"Player {player} plays at {move}")
        game.print_board()

        player = "O" if player == "X" else "X"

    winner = game.winner()
    if winner:
        print(f"Winner: {winner}")
    else:
        print("It's a draw!")


# Run the match
computer_vs_computer()
```

Output:-

```
Player O plays at 7

 X | X | O
---+---+---
 O | O | X
---+---+---
 X | O |

Player X plays at 8

 X | X | O
---+---+---
 O | O | X
---+---+---
 X | O | X

It's a draw!
```

Program 10

Conversion of a given FOL to CNF



Code:-

```
import re


# ----- STEP 1: Remove Implications -----
def remove_implications(expr):
    expr = expr.replace("->", "=>")
    # A => B becomes ¬A ∨ B
    while "=>" in expr:
        expr = re.sub(r"(.*?)=>(.*)",
                      r"(~(\1)) | (\2)", expr)
    return expr


# ----- STEP 2: Move NOT inward -----
def move_not_inward(expr):
    # ~~A → A
    expr = expr.replace("~~", "")
```

```
    # DeMorgan: ~(A & B) → (~A | ~B)
    expr = expr.replace("~(", "~")
    expr = expr.replace("&", ") & (")
    expr = expr.replace("|", ") | (")
    return expr

# ----- STEP 3: Standardize variables -----
def standardize_variables(expr):
    # replace x, y, z with unique names
    counter = 0
    def repl(match):
        nonlocal counter
        counter += 1
        return "v" + str(counter)

    return re.sub(r"\b[a-z]\b", repl, expr)

# ----- STEP 4: Skolemization -----
def skolemize(expr):

    count = 1
    while "∃" in expr:
        expr = re.sub(r"∃[a-z]\s*", f"Sk{count} ", expr, count=1)
        count += 1
    return expr

# ----- STEP 5: Drop universal quantifiers -----
def drop_universal(expr):
    expr = expr.replace("∀", "")
    return expr

# ----- STEP 6: Distribute OR over AND -----
def distribute(expr):
```

```
    expr = expr.replace(" & ", ") & (")
    expr = expr.replace(" | ", ") | (")
    return "(" + expr + ")"

def fol_to_cnf(expr):
    print("\nOriginal:", expr)

    expr = remove_implications(expr)
    print("After removing implications:", expr)

    expr = move_not_inward(expr)
    print("After moving NOT inwards:", expr)

    expr = standardize_variables(expr)
    print("After standardizing variables:", expr)

    expr = skolemize(expr)
    print("After skolemization:", expr)

    expr = drop_universal(expr)
    print("After dropping universals:", expr)

    expr = distribute(expr)
    print("Final CNF:", expr)

    return expr
expr = "∀x ( P(x) -> ∃y Q(y,x) )"

fol_to_cnf(expr)
```

Output:

```
Original: ∀x ( P(x) -> ∃y Q(y,x) )
After removing implications: (~(∀x ( P(x) )) | ( ∃y Q(y,x) ))
After moving NOT inwards: (~∀x ( P(x) )) ) | ( ( ∃y Q(y,x) ))
After standardizing variables: (~∀v1 ( P(v2) )) ) | ( ( ∃v3 Q(v4,v5) ))
After skolemization: (~∀v1 ( P(v2) )) ) | ( ( Sk1 3 Q(v4,v5) ))
After dropping universals: (~v1 ( P(v2) )) ) | ( ( Sk1 3 Q(v4,v5) ))
Final CNF: ((~v1 ( P(v2) )) )) | (( ( Sk1 3 Q(v4,v5) )))
```