VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Aaryan Prakash (1BM23CS006)

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
Sep-2024 to Jan-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 **Aaryan Prakash (1BM23CS006),** 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.

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

Index

Github Link:
https://github.com/TheAaryanPrakash/AI-Lab/tree/main

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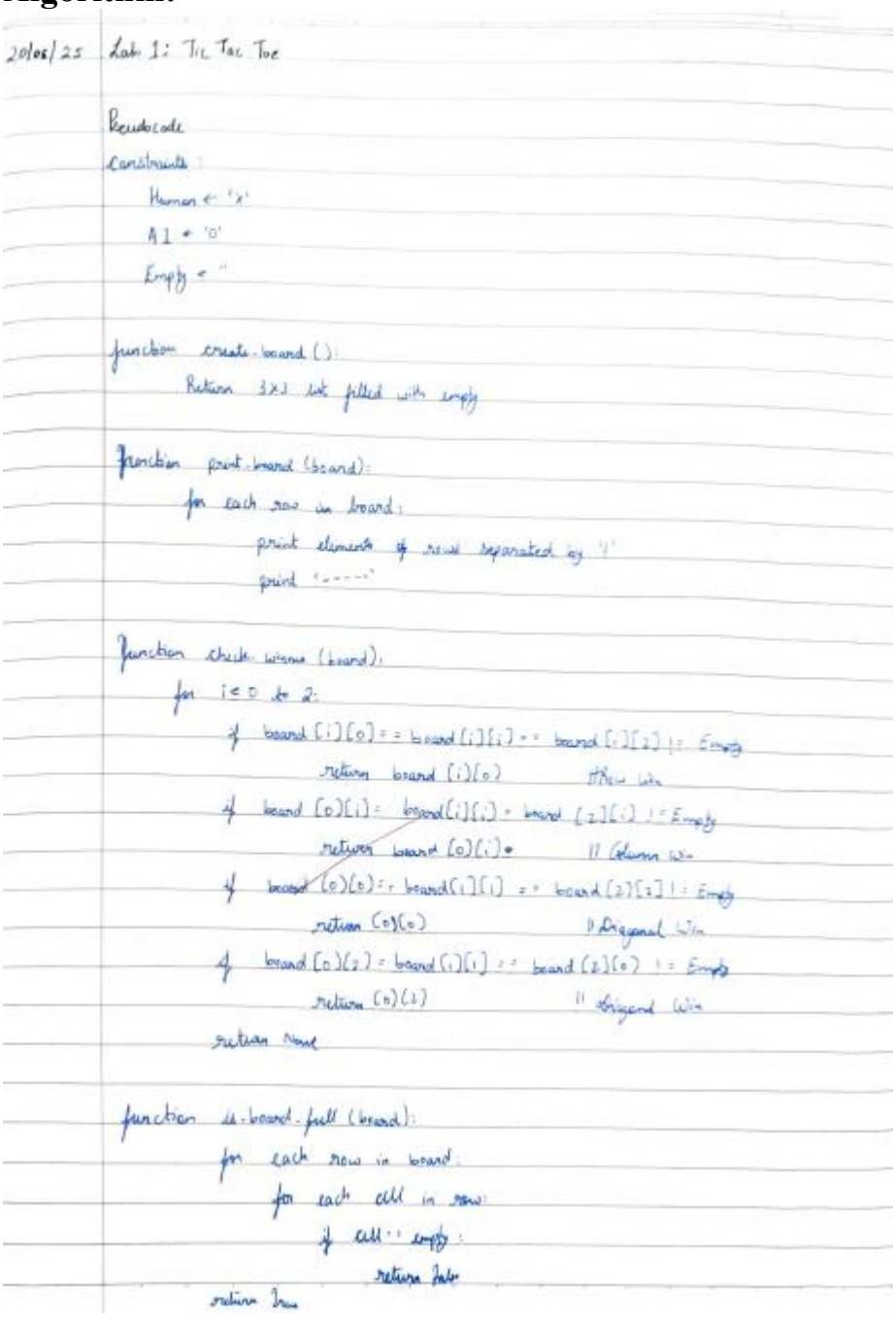
Program 1

Implement Tic –Tac –Toe Game
Implement vacuum cleaner agent

Algorithm:



20/08/25 Lab 1: Tic Tac Toe

Pseudocode

Constraints:

Human ← 'X'

AI = 'O'

Empty = ''

function create_board():

Return 3x3 list filled with empty

function print_board(board):

for each row in board:

print elements of row separated by '|'

print '-----'

function check_winner(board):

for i = 0 to 2:

if board[i][0] == board[i][1] == board[i][2] != Empty

return board[i][0] # Row win

if board[0][i] = board[1][i] = board[2][i] != Empty

return board[0][i] # Column win

if board[0][0] = board[1][1] = board[2][2] != Empty

return board[0][0] # Diagonal Win

if board[0][2] = board[1][1] = board[2][0] != Empty

return board[0][2] # Diagonal Win

return None

function is_board_full(board):

for each row in board:

for each cell in row:

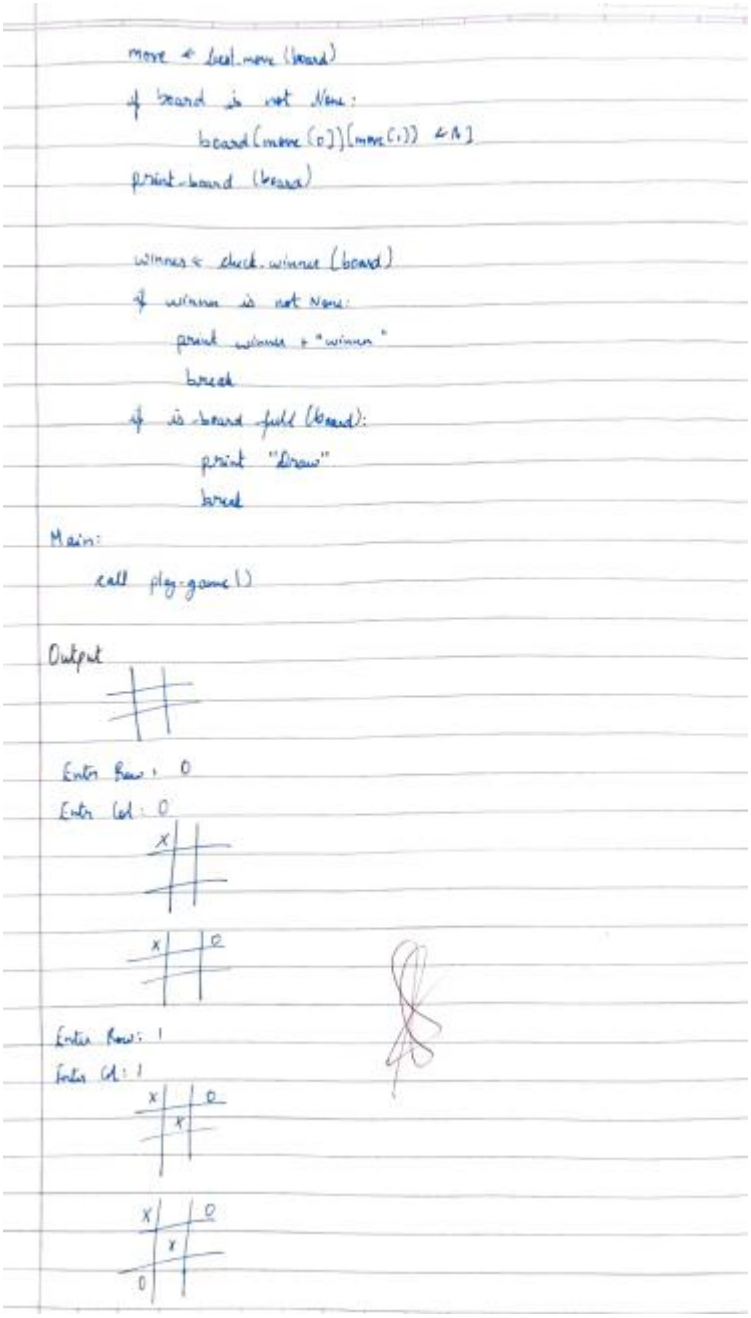
if cell == empty:

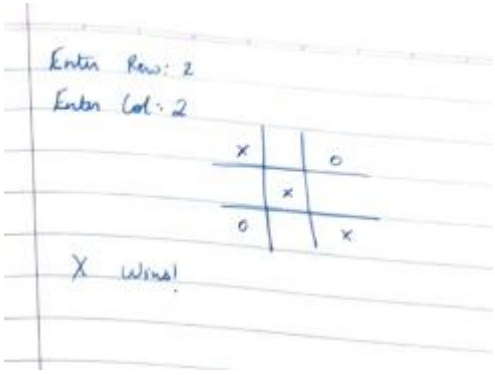
return false

return true

```
function get_available_moves(board):
    moves ← empty list
    for i from 0 to 2:
        for j from 0 to 2:
            if board[i][j] == Empty:
                append (i,j) to moves
    return moves

function minimax(board, depth, is_maximizing):
    winner ← check_board(board)
    if winner == AI
        return 1
    if winner == Human
        return -1
    else if is_board_full(board):
        return 0

    if is_maximizing:
        best_score ← -inf
        for each (i,j) in get_available_moves(board):
            board[i][j] ← AI
            score ← minimax(board, depth+1, false)
            board[i][j] = Empty
            best_score = max(score, best_score)
        return best_score
    else:
        best_score ← inf
        for each (i,j) in get_available_moves(board):
            board[i][j] = Human
            score ← minimax(board, depth+1, false)
            board[i][j] ← Empty
            best_score = min(score, best_score)
        return best_score
```

```
function best_move(board):
    best_score = -inf
    move = None
    for each (i,j) in get_available_moves(board):
        board[i][j] = AI
        score = minimax(board, 0, False)
        board[i][j] = Empty
        if score > best_score
            best_score = score
            move = (i,j)
    return move

function play_game():
    board = create_board()
    print_board(board)

    while True:
        while True:
            print "Enter Row" -> row
            print "Enter Column" -> column
            if board[row][column] == empty:
                board[row][column] = Human
                break; Else
            else "Cell is occupied"
    print_board(board)

    winner = check_winner(board)
    if winner is not None:
        print winner + "Wins"
        break
    if is_board_full(board):
        print "Draw"
        break
```

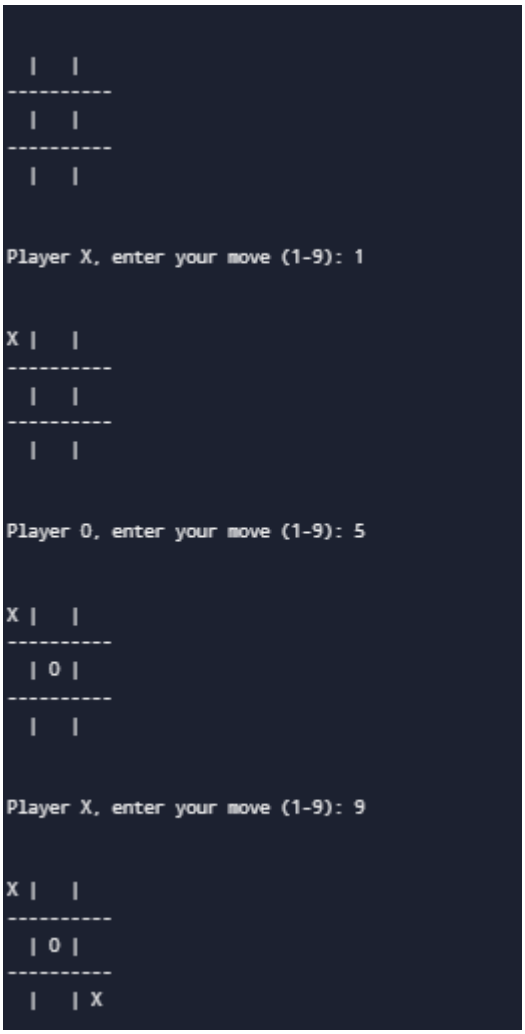




Code:

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

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

```
        [0, 3, 6], [1, 4, 7], [2, 5, 8],
        [0, 4, 8], [2, 4, 6]
    ]
    for combo in win_conditions:
        count=0
        for pos in combo:
            if board[pos]==player:
                count+=1
        if count==3:
            return True
    return False

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

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

    print_board(board)

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

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


| |

| |

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

| |

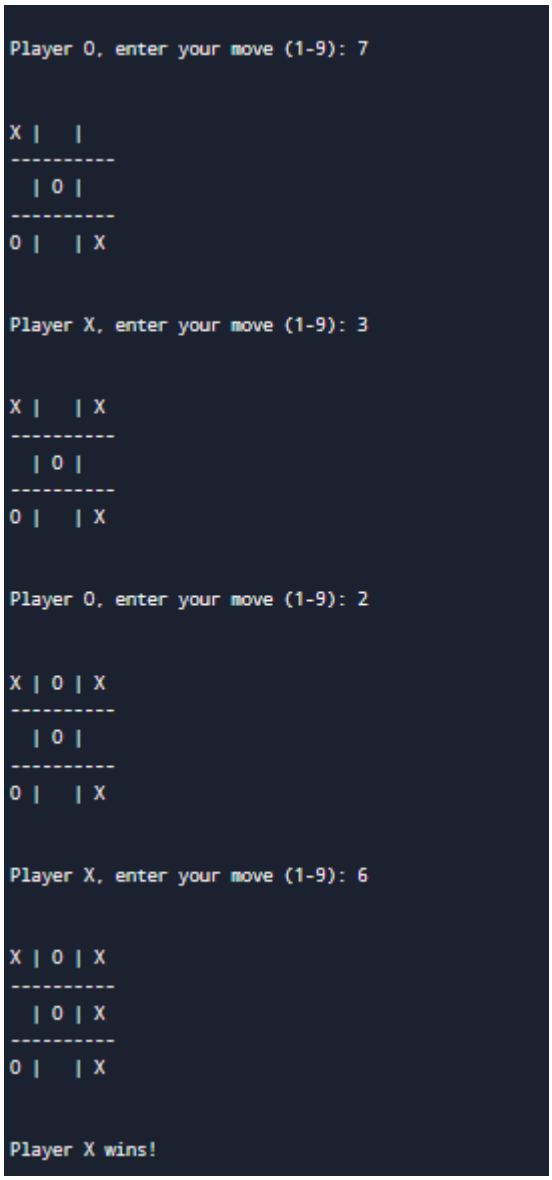
| |
Player O, enter your move (1-9): 5
X | |

| O |

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

| O |

| | X


Player O, enter your move (1-9): 7
X | |

| O |

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

| O |

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

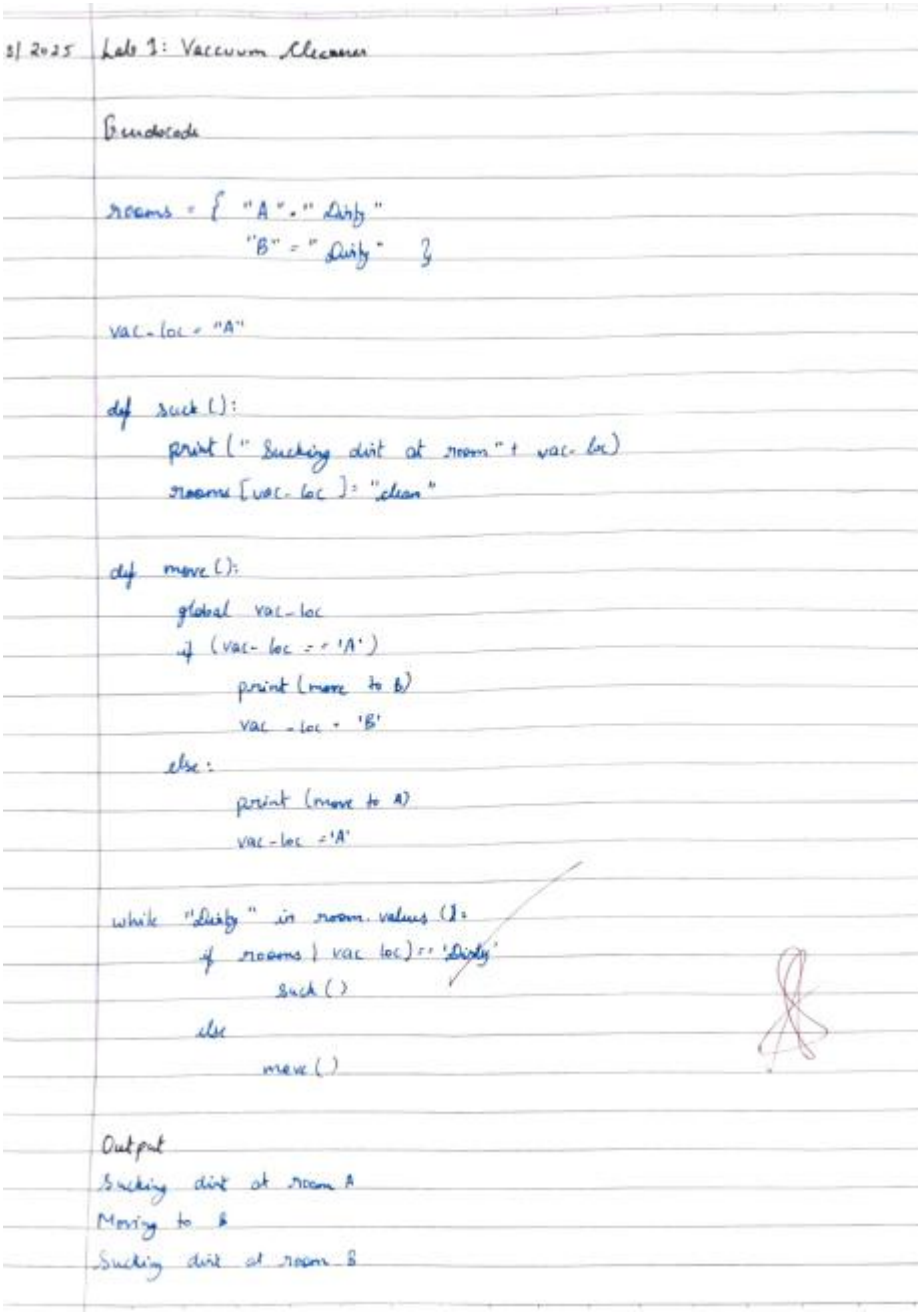
| O |

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

| O | X

O | | X
Player X wins!

Vacuum Cleaner



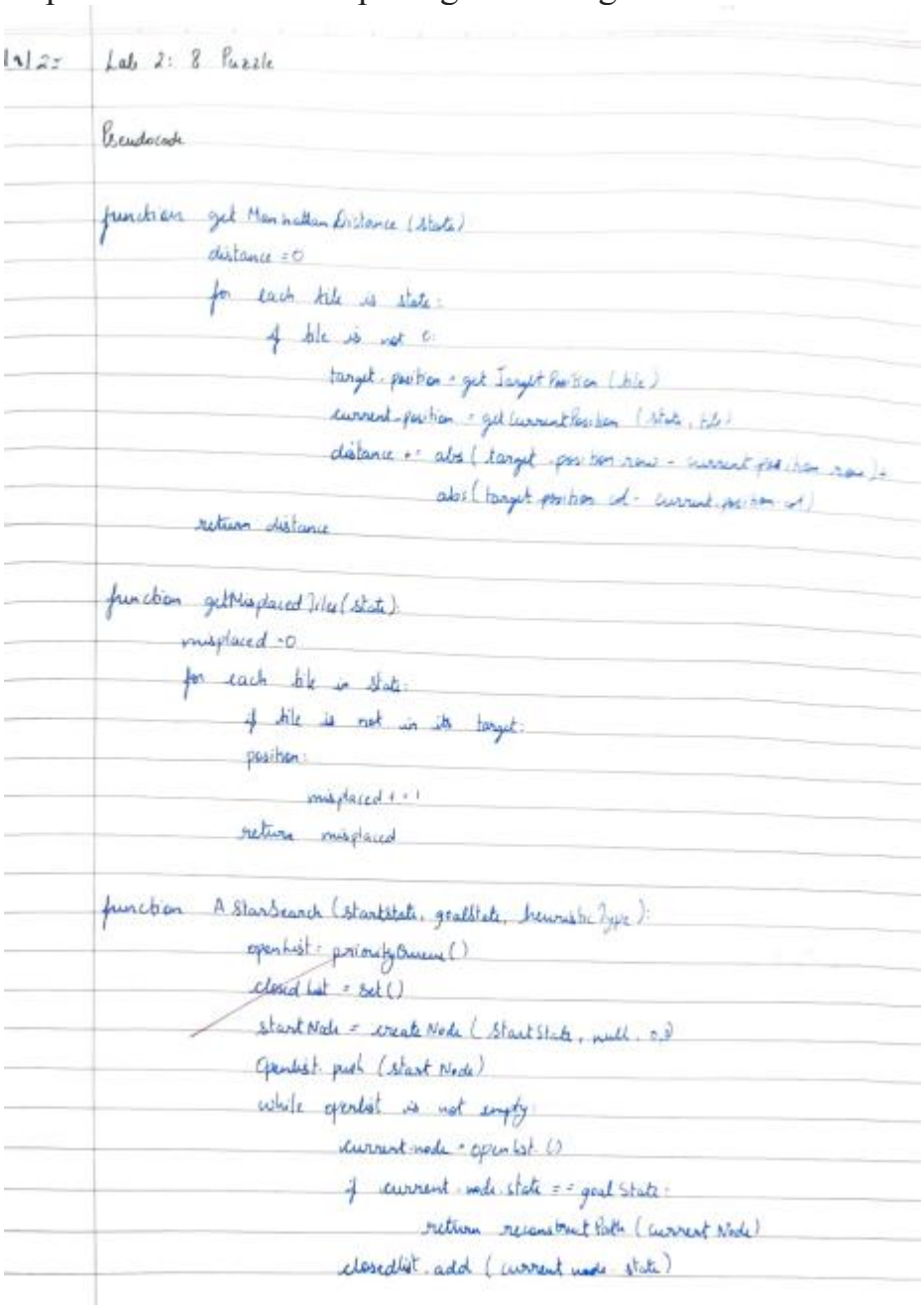

```
import random
rooms=[1,1,1,1]
botpos =(int(input("Enter Initial Position"))-1)
cleanedpos=[]
cost=0

def movebot(pos):

    while True:
```

```
        n= random.randint(0,3)
        if n != pos and n not in cleanedpos:
            pos = n
            break
    return pos

while True:
    print(str(rooms))
    print(botpos+1)

    if rooms[botpos]==1:

        rooms[botpos]=0
        cleanedpos.append(botpos)
        cost+=1
        if len(cleanedpos) == 4:
            break
        botpos=movebot(botpos)

    elif rooms[botpos]==0:
        cleanedpos.append(botpos)
        if len(cleanedpos) == 4:
            break
        botpos = movebot(botpos)

print("cost="+str(cost))
```

```
Enter Initial Position2
[1, 1, 1, 1]
2
[1, 0, 1, 1]
3
[1, 0, 0, 1]
1
[0, 0, 0, 1]
4
cost=4
```

Program 2

Implement 8 puzzle problems using Depth First Search (DFS)
Implement Iterative deepening search algorithm



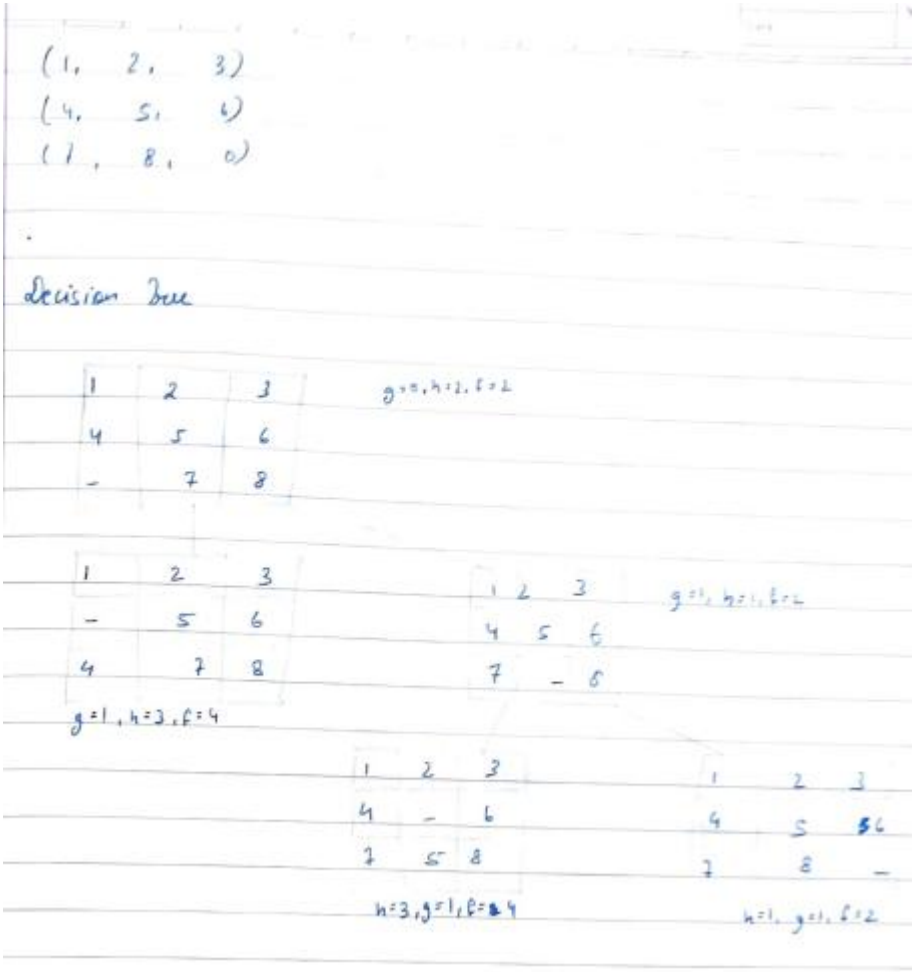
```
Lab 2: 8 Puzzle

Pseudocode

function getManhattanDistance(state)
    distance = 0
    for each tile in state:
        if tile is not 0:
            target_position = getTargetPosition(tile)
            current_position = getCurrentPosition(state, tile)
            distance += abs(target_position.row - current_position.row) +
                        abs(target_position.col - current_position.col)
    return distance

function getMisplacedTiles(state):
    misplaced = 0
    for each tile in state:
        if tile is not in its target
        position:
            misplaced += 1
    return misplaced

function AStarSearch(startState, goalState, heuristicType):
    openList = priorityQueue()
    closedList = set()
    startNode = createNode(startState, null, 0)
    openList.push(startNode)
    while openList is not empty
        currentNode = openList()
        if currentNode.state == goalState:
            return reconstructPath(currentNode)
        closedList.add(currentNode.state)
```

```
for each move in validMoves(currentNode.state):
    childState = applyMove(currentNode.state, move)
    childState = applyMove(currentNode.state, move)
    if childState in closedList:
        continue

    g = currentNode.g + 1
    if heuristicType == "misplacedTiles":
        h = getMisplacedTiles(childState)
    else if heuristicType == "manhattan"
        h = getManhattanDistance(childState)
    f = g + h
    childNode = createNode(childState, currentNode, g, f)
    openList.push(childNode)
return Null

function reconstructPath(node):
    path = []
    while node is not null:
        path.append(node.state)
        node = node.parent
    return reverse(path)
```

Output

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

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




```
import time

def find_possible_moves(state):
    index = state.index('_')
    moves = {
        0: [1, 3],
        1: [0, 2, 4],
        2: [1, 5],
        3: [0, 4, 6],
        4: [1, 3, 5, 7],
        5: [2, 4, 8],
        6: [3, 7],
        7: [6, 8, 4],
        8: [5, 7],
    }
    return moves.get(index, [])

def dfs(initial_state, goal_state, max_depth=50):
    stack = [(initial_state, [], 0)]
    visited = {tuple(initial_state)}
    states_explored = 0
```

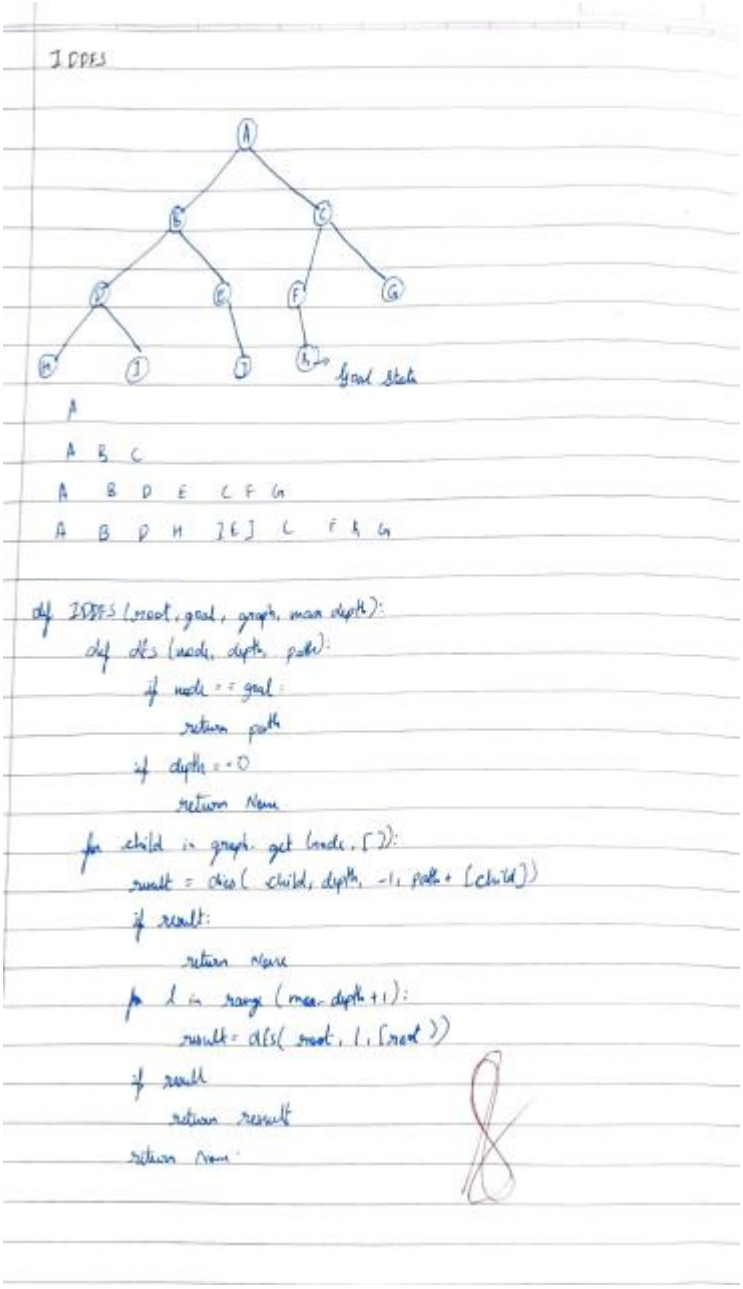
```
    printed_depths = set()

    while stack:
        current_state, path, depth = stack.pop()

        if depth > max_depth:
            continue

        if depth not in printed_depths:
            print(f"\n--- Depth {depth} ---")
            printed_depths.add(depth)

        states_explored += 1
        print(f"State #{states_explored}: {current_state}")

        if current_state == goal_state:
            print(f"\n Goal reached at depth {depth} after exploring {states_explored} states.\n")
            return path, states_explored

        possible_moves_indices = find_possible_moves(current_state)

        for move_index in reversed(possible_moves_indices):  # Reverse for DFS order
            next_state = list(current_state)
            blank_index = next_state.index('_')
            next_state[blank_index], next_state[move_index] = next_state[move_index],
next_state[blank_index]

            if tuple(next_state) not in visited:
                visited.add(tuple(next_state))
                stack.append((next_state, path + [next_state], depth + 1))

    print(f"\n Goal state not reachable within depth {max_depth}. Explored {states_explored}
states.\n")
    return None, states_explored


# ----------------- TEST -----------------
initial_state = [1, 2, 3,
                 4, 8, '_',
                 7, 6, 5]

goal_state    = [1, 2, 3,
                 4, 5, 6,
                 7, 8, '_']

# Measure execution time
start_time = time.time()
```

```
solution_path, explored = dfs(initial_state, goal_state, max_depth=50)
end_time = time.time()

if solution_path is None:
    print("No solution found.")
else:
    print("Solution path:")
    for step, state in enumerate(solution_path, start=1):
        print(f"Step {step}: {state}")

print("\nExecution time: {:.6f} seconds".format(end_time - start_time))
print("Total states explored:", explored)
```

```
--- Depth 0 ---
State #1: [1, 2, 3, 4, 8, '_', 7, 6, 5]

--- Depth 1 ---
State #2: [1, 2, '_', 4, 8, 3, 7, 6, 5]

--- Depth 2 ---
State #3: [1, '_', 2, 4, 8, 3, 7, 6, 5]

--- Depth 3 ---
State #4: ['_', 1, 2, 4, 8, 3, 7, 6, 5]

--- Depth 4 ---
State #5: [4, 1, 2, '_', 8, 3, 7, 6, 5]

--- Depth 5 ---
State #6: [4, 1, 2, 8, '_', 3, 7, 6, 5]

--- Depth 6 ---
State #7: [4, '_', 2, 8, 1, 3, 7, 6, 5]

--- Depth 7 ---
State #8: ['_', 4, 2, 8, 1, 3, 7, 6, 5]

--- Depth 8 ---
State #9: [8, 4, 2, '_', 1, 3, 7, 6, 5]
```

```
--- Depth 9 ---
State #10: [8, 4, 2, 1, '_', 3, 7, 6, 5]

--- Depth 10 ---
State #11: [8, '_', 2, 1, 4, 3, 7, 6, 5]

--- Depth 11 ---
State #12: ['_', 8, 2, 1, 4, 3, 7, 6, 5]

--- Depth 12 ---
State #13: [1, 8, 2, '_', 4, 3, 7, 6, 5]

--- Depth 13 ---
State #14: [1, 8, 2, 7, 4, 3, '_', 6, 5]

--- Depth 14 ---
State #15: [1, 8, 2, 7, 4, 3, 6, '_', 5]

--- Depth 15 ---
State #16: [1, 8, 2, 7, 4, 3, 6, 5, '_']

--- Depth 16 ---
State #17: [1, 8, 2, 7, 4, '_', 6, 5, 3]
```

IDDFS



import time

# ---------- MOVE GENERATOR ----------
def find_possible_moves(state):
    index = state.index('_')

    if index == 0:
        return [1, 3]
    elif index == 1:
        return [0, 2, 4]
    elif index == 2:

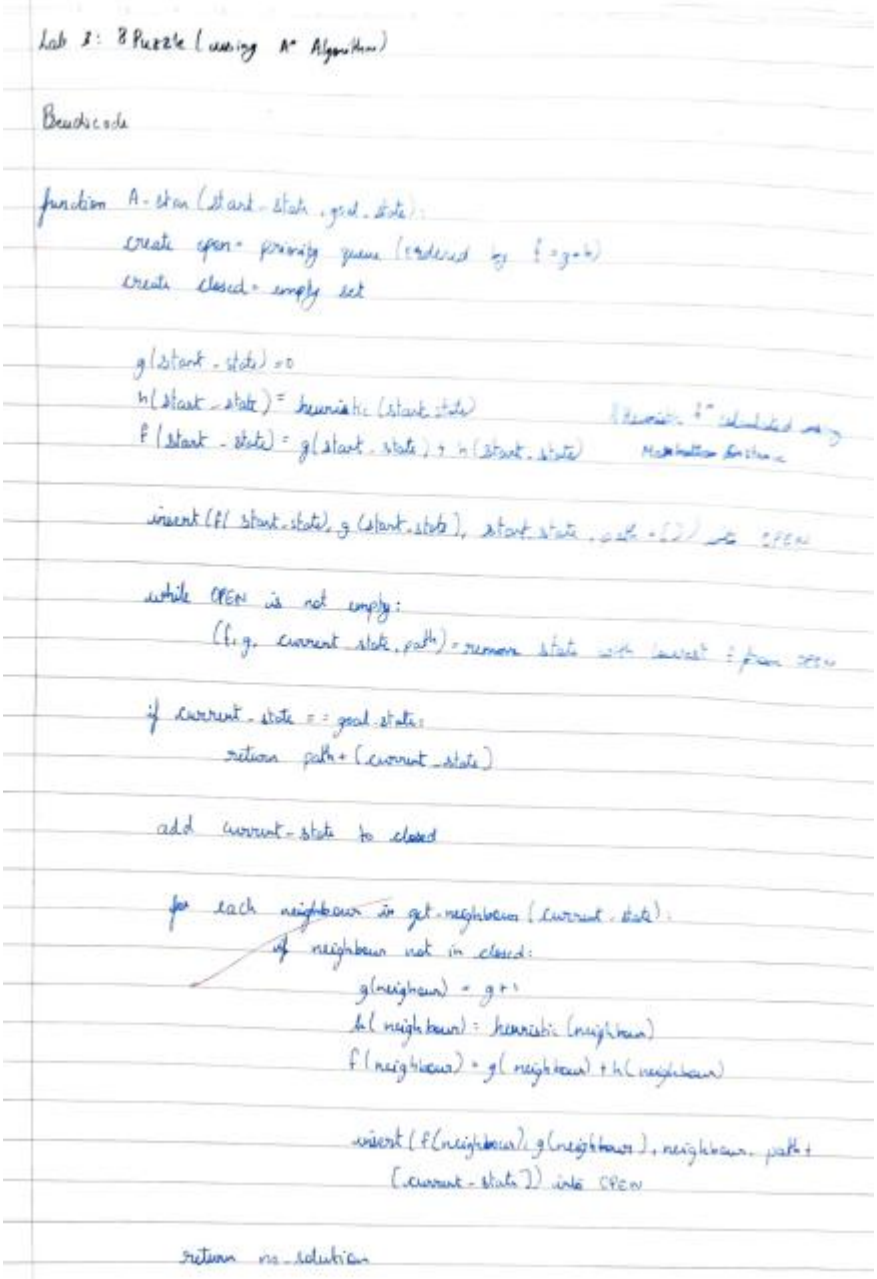
```
        return [1, 5]
    elif index == 3:
        return [0, 4, 6]
    elif index == 4:
        return [1, 3, 5, 7]
    elif index == 5:
        return [2, 4, 8]
    elif index == 6:
        return [3, 7]
    elif index == 7:
        return [4, 6, 8]
    elif index == 8:
        return [5, 7]
    return []

# ----------------- DEPTH LIMITED SEARCH -----------------
def depth_limited_dfs(state, goal_state, limit, path, visited):
    if state == goal_state:
        return path

    if limit <= 0:
        return None

    visited.add(tuple(state))

    for move_index in find_possible_moves(state):
        next_state = list(state)
        blank_index = next_state.index('_')
        next_state[blank_index], next_state[move_index] = next_state[move_index],
next_state[blank_index]

        if tuple(next_state) not in visited:
            result = depth_limited_dfs(next_state, goal_state, limit - 1, path + [next_state], visited)
            if result is not None:
                return result
    return None

# ----------------- ITERATIVE DEEPENING DFS -----------------
def iddfs(initial_state, goal_state, max_depth=30):
    for depth in range(max_depth):
        print(f"Searching at depth limit = {depth}")
        visited = set()
        result = depth_limited_dfs(initial_state, goal_state, depth, [initial_state], visited)
        if result is not None:
            return result, depth
    return None, max_depth
```

```
# ----------------- TEST -----------------
initial_state = [1, 2, 3,
                 4, 8, '_',
                 7, 6, 5]

goal_state    = [1, 2, 3,
                 4, 5, 6,
                 7, 8, '_']

# Measure execution time
start_time = time.time()
solution_path, depth_reached = iddfs(initial_state, goal_state, max_depth=30)
end_time = time.time()

if solution_path is None:
    print("Goal state is not reachable within given depth limit.")
else:
    print("\n\nSolution path found:")
    for step, state in enumerate(solution_path, start=0):
        print(f"Step {step}: {state}")

print("\nExecution time: {:.6f} seconds".format(end_time - start_time))
print("Depth reached:", depth_reached)
```

```
Searching at depth limit = 0
Searching at depth limit = 1
Searching at depth limit = 2
Searching at depth limit = 3
Searching at depth limit = 4
Searching at depth limit = 5


Solution path found:
Step 0: [1, 2, 3, 4, 8, '_', 7, 6, 5]
Step 1: [1, 2, 3, 4, 8, 5, 7, 6, '_']
Step 2: [1, 2, 3, 4, 8, 5, 7, '_', 6]
Step 3: [1, 2, 3, 4, '_', 5, 7, 8, 6]
Step 4: [1, 2, 3, 4, 5, '_', 7, 8, 6]
Step 5: [1, 2, 3, 4, 5, 6, 7, 8, '_']

Execution time: 0.000194 seconds
Depth reached: 5

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

Program 3

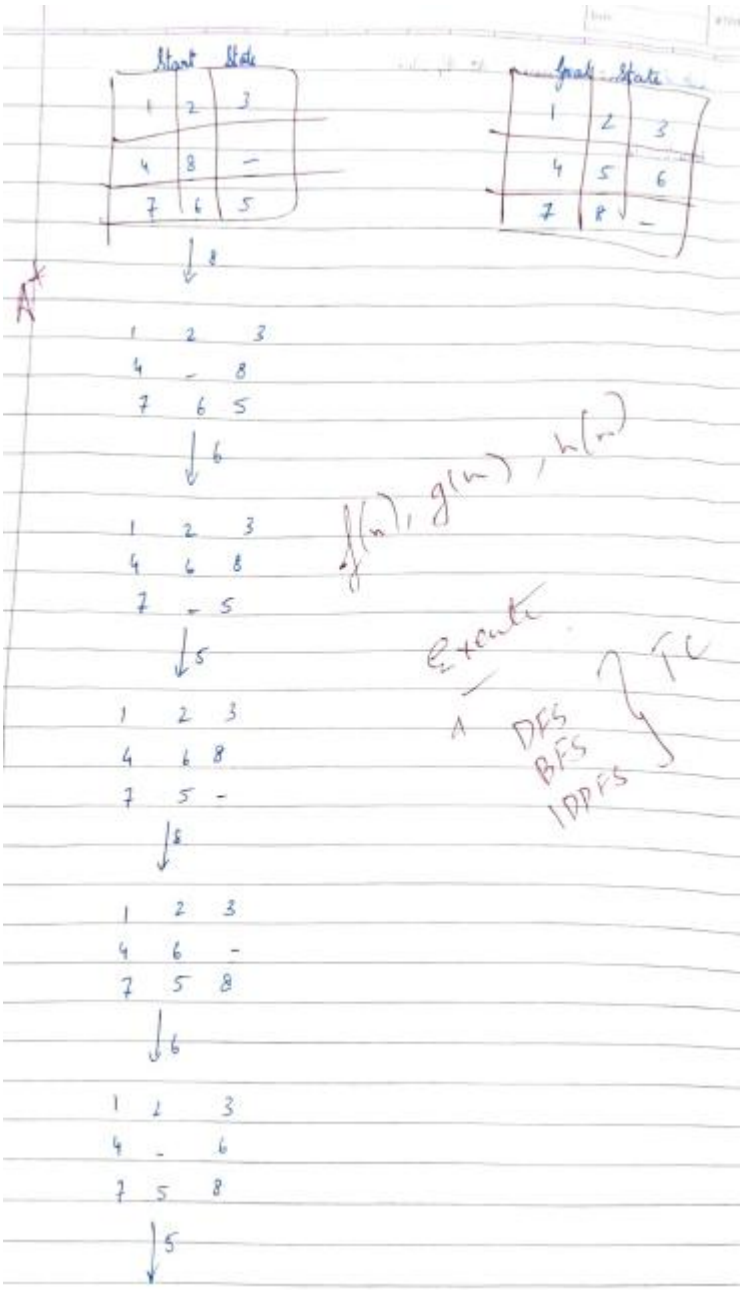
Implement A* search algorithm

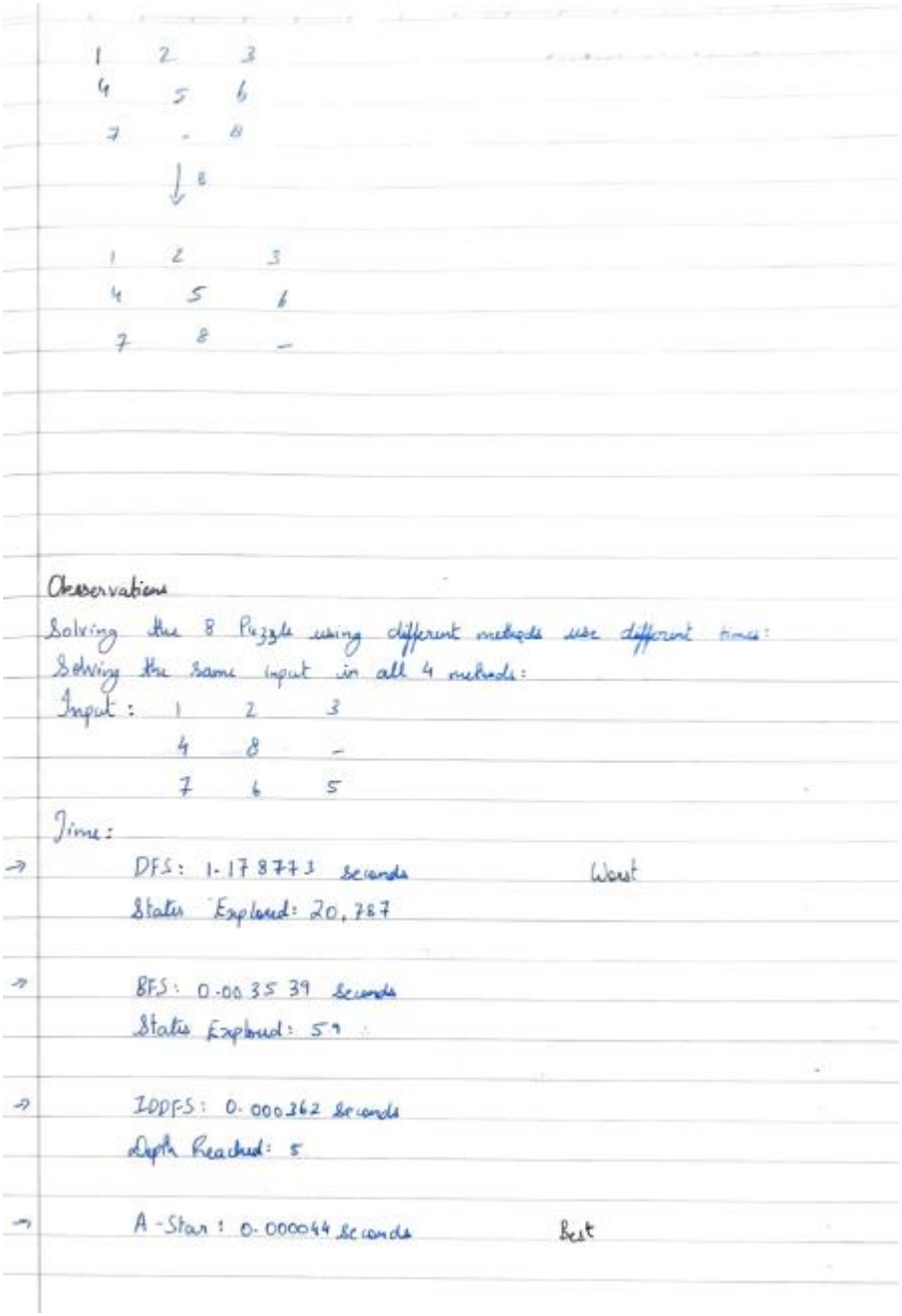


Lab 3: 8 Puzzle (using A* Algorithm)

Pseudocode

```
function A-star (start_state, goal_state):
    create open = priority queue (ordered by f = g+h)
    create closed = empty set

    g(start_state) = 0
    h(start_state) = heuristic (start_state)
    f(start_state) = g(start_state) + h(start_state)

    insert (f(start_state), g(start_state), start_state, path = [])

    while OPEN is not empty:
        (f, g, current_state, path) = remove state with lowest f from OPEN

    if current_state == goal_state:
        return path + (current_state)

    add current_state to closed

    for each neighbour in get_neighbours (current_state):
        if neighbour not in closed:
            g(neighbour) = g+1
            h(neighbour) = heuristic (neighbour)
            f(neighbour) = g(neighbour) + h(neighbour)

            insert (f(neighbour), g(neighbour), neighbour, path +
                [current_state]) into OPEN

    return no_solution
```


Start State
1 2 3
4 8 -
7 6 5
Goal State
1 2 3
4 5 6
7 8 -
A*
1 2 3
4 - 8
7 6 5
1 2 3
4 6 8
7 - 5
1 2 3
4 6 8
7 5 -
1 2 3
4 6 -
7 5 8
1 2 3
4 - 6
7 5 8
f(n), g(n), h(n)
Execute
A
DFS
BFS
IDDFS




```
import heapq
import time

# Heuristic: Manhattan Distance
def heuristic(state, goal):
    distance = 0
    for i in range(1, 9):  # tile numbers 1 to 8
        x1, y1 = divmod(state.index(i), 3)
        x2, y2 = divmod(goal.index(i), 3)
        distance += abs(x1 - x2) + abs(y1 - y2)
    return distance
```

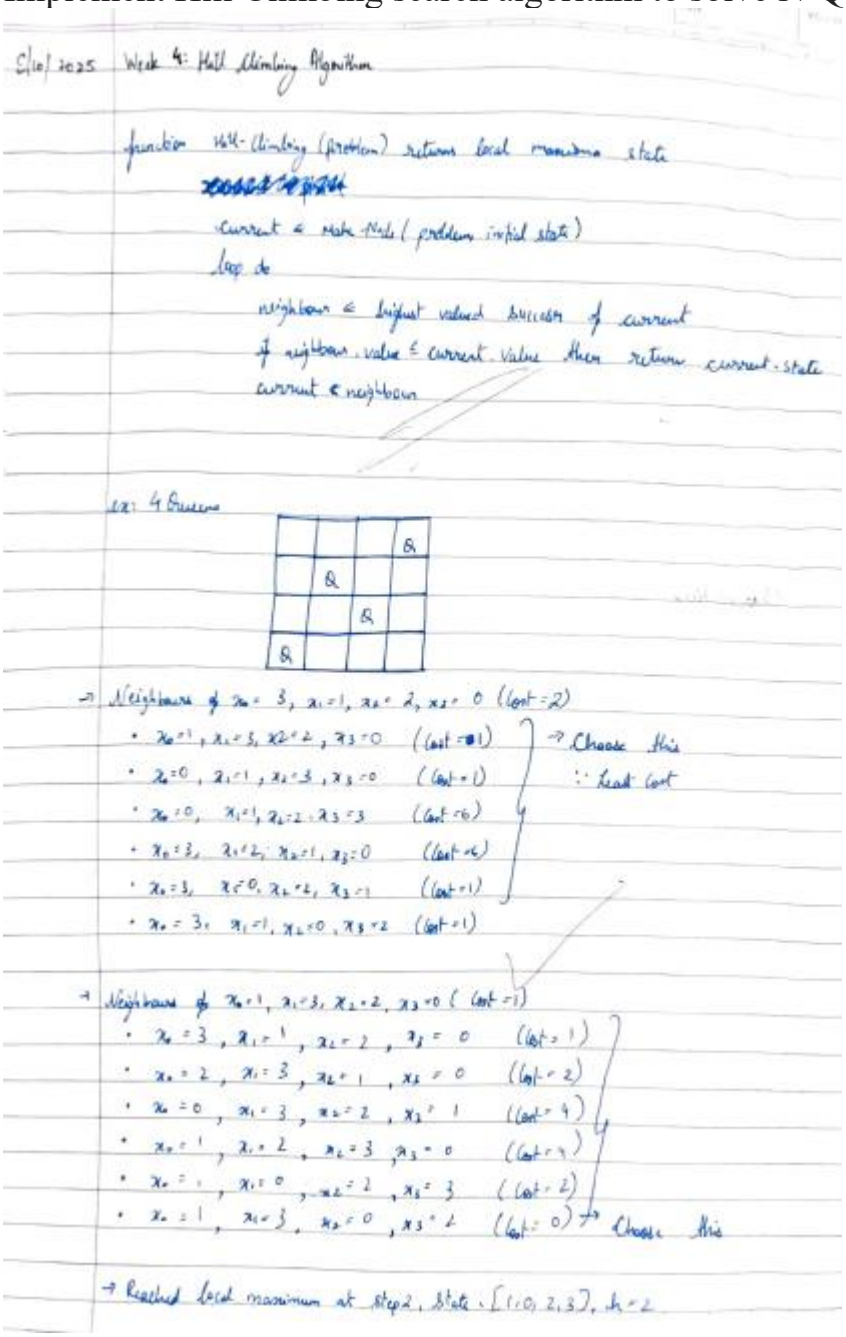
```
# Get neighbors by sliding blank (0) up/down/left/right
def get_neighbors(state):
    neighbors = []
    i = state.index(0)  # position of blank
    x, y = divmod(i, 3)
    moves = [(-1,0), (1,0), (0,-1), (0,1)]

    for dx, dy in moves:
        new_x, new_y = x + dx, y + dy
        if 0 <= new_x < 3 and 0 <= new_y < 3:
            j = new_x * 3 + new_y
            new_state = list(state)
            new_state[i], new_state[j] = new_state[j], new_state[i]
            neighbors.append(tuple(new_state))
    return neighbors

# A* Search for 8-puzzle
def astar(start, goal):
    open_set = []
    heapq.heappush(open_set, (heuristic(start, goal), 0, start))

    came_from = {}
    g_score = {start: 0}

    while open_set:
        _, cost, current = heapq.heappop(open_set)

        if current == goal:
            # Reconstruct path
            path = []
            while current in came_from:
                path.append(current)
                current = came_from[current]
            path.append(start)
            return path[::-1]

        for neighbor in get_neighbors(current):
            tentative_g = g_score[current] + 1
            if neighbor not in g_score or tentative_g < g_score[neighbor]:
                came_from[neighbor] = current
                g_score[neighbor] = tentative_g
                f_score = tentative_g + heuristic(neighbor, goal)
                heapq.heappush(open_set, (f_score, tentative_g, neighbor))

    return None  # no solution

# ----------------- TEST -----------------
```

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

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

# Measure execution time
start_time = time.time()
path = astar(start, goal)
end_time = time.time()

if path:
    print("Steps to solve ({} moves):".format(len(path)-1))
    for state in path:
        for i in range(0, 9, 3):
            print(state[i:i+3])
        print()
else:
    print("No solution found")

print("Execution time: {:.6f} seconds".format(end_time - start_time))
```

```
Steps to solve (5 moves):
(1, 2, 3)
(4, 8, 0)
(7, 6, 5)

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

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

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

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

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

Execution time: 0.000111 seconds
```

Program 4

Implement Hill Climbing search algorithm to solve N-Queens problem




```
import random
import math

def compute_cost(state):
    """Count diagonal conflicts for a permutation-state (one queen per row & column)."""
    conflicts = 0
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
```

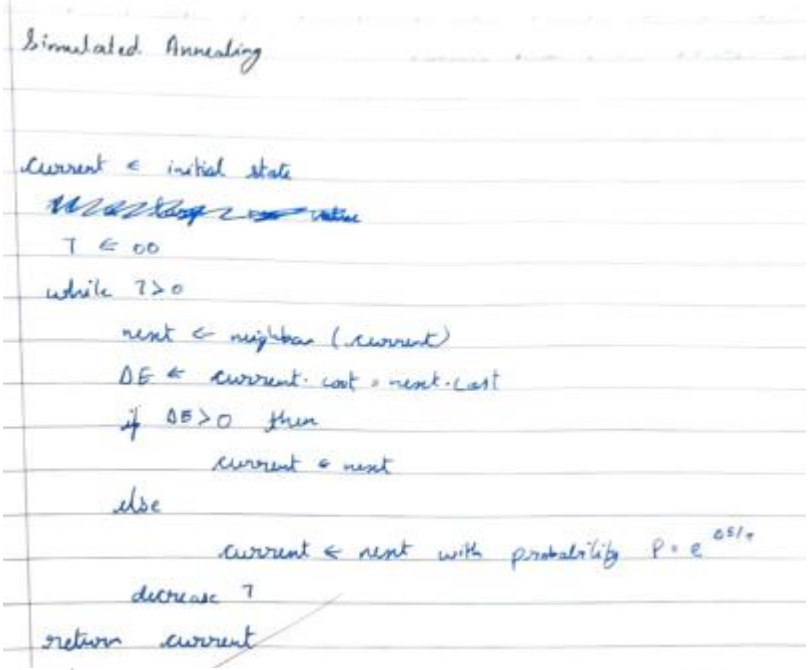
```
            if abs(state[i] - state[j]) == abs(i - j):
                conflicts += 1
    return conflicts

def random_permutation(n):
    arr = list(range(n))
    random.shuffle(arr)
    return arr

def neighbors_by_swaps(state):
    """All neighbors obtained by swapping two columns (keeps permutation property)."""
    n = len(state)
    for i in range(n - 1):
        for j in range(i + 1, n):
            nb = state.copy()
            nb[i], nb[j] = nb[j], nb[i]
            yield nb

def hill_climb_with_restarts(n, max_restarts=None):
    """Hill climbing on permutations with random restart on plateau (no revisits)."""
    visited = set()
    total_states = math.factorial(n)
    restarts = 0

    while True:
        # pick a random unvisited start permutation
        if len(visited) >= total_states:
            raise RuntimeError("All states visited — giving up (no solution found).")

        state = random_permutation(n)
        while tuple(state) in visited:
            state = random_permutation(n)
        visited.add(tuple(state))

        # climb from this start
        while True:
            cost = compute_cost(state)
            if cost == 0:
                return state, restarts

            # find best neighbor (swap-based neighbors)
            best_neighbor = None
            best_cost = float("inf")
            for nb in neighbors_by_swaps(state):
                c = compute_cost(nb)
                if c < best_cost:
                    best_cost = c
```

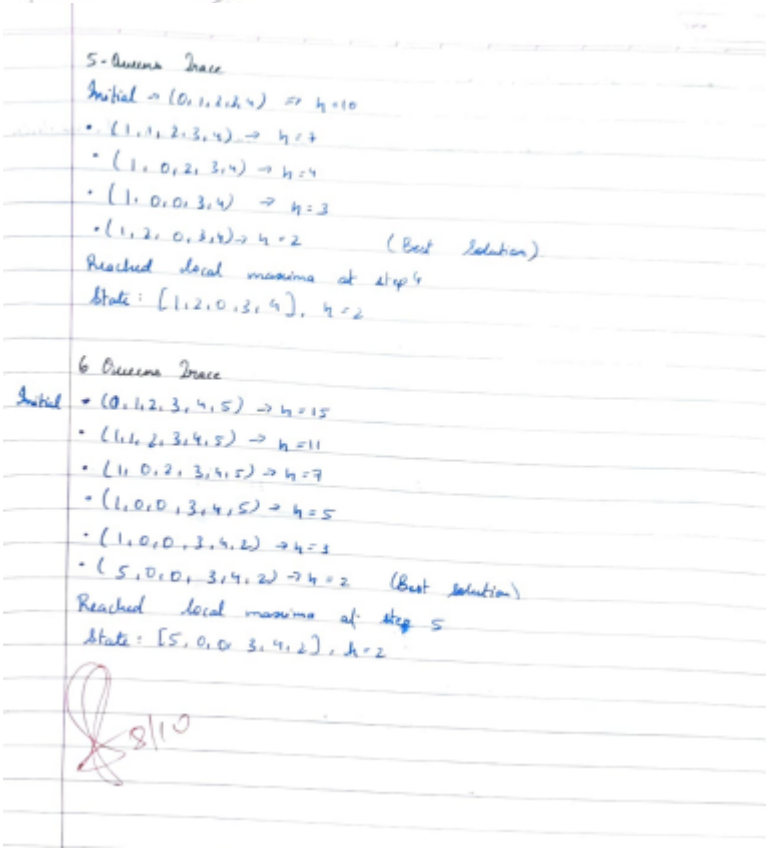
```
                best_neighbor = nb

            # if strictly better, move; otherwise it's a plateau/local optimum -> restart
            if best_cost < cost:
                state = best_neighbor
                visited.add(tuple(state))
            else:
                # plateau or local optimum -> restart
                restarts += 1
                if max_restarts is not None and restarts >= max_restarts:
                    raise RuntimeError(f"Stopped after {restarts} restarts (no solution found).")
                break  # go pick a new unvisited start

def format_board(state):
    n = len(state)
    lines = []
    for r in range(n):
        lines.append(" ".join("Q" if state[c] == r else "-" for c in range(n)))
    return "\n".join(lines)

if __name__ == "__main__":
    n = 4
    solution, restarts = hill_climb_with_restarts(n)
    print("Found solution:", solution)
    print(format_board(solution))
```

```
Found solution: [2, 0, 3, 1]
- Q - -
- - - Q
Q - - -
- - Q -
```

Program 5

Simulated Annealing to Solve 8-Queens problem






```
import random
import math

def cost(state):
```

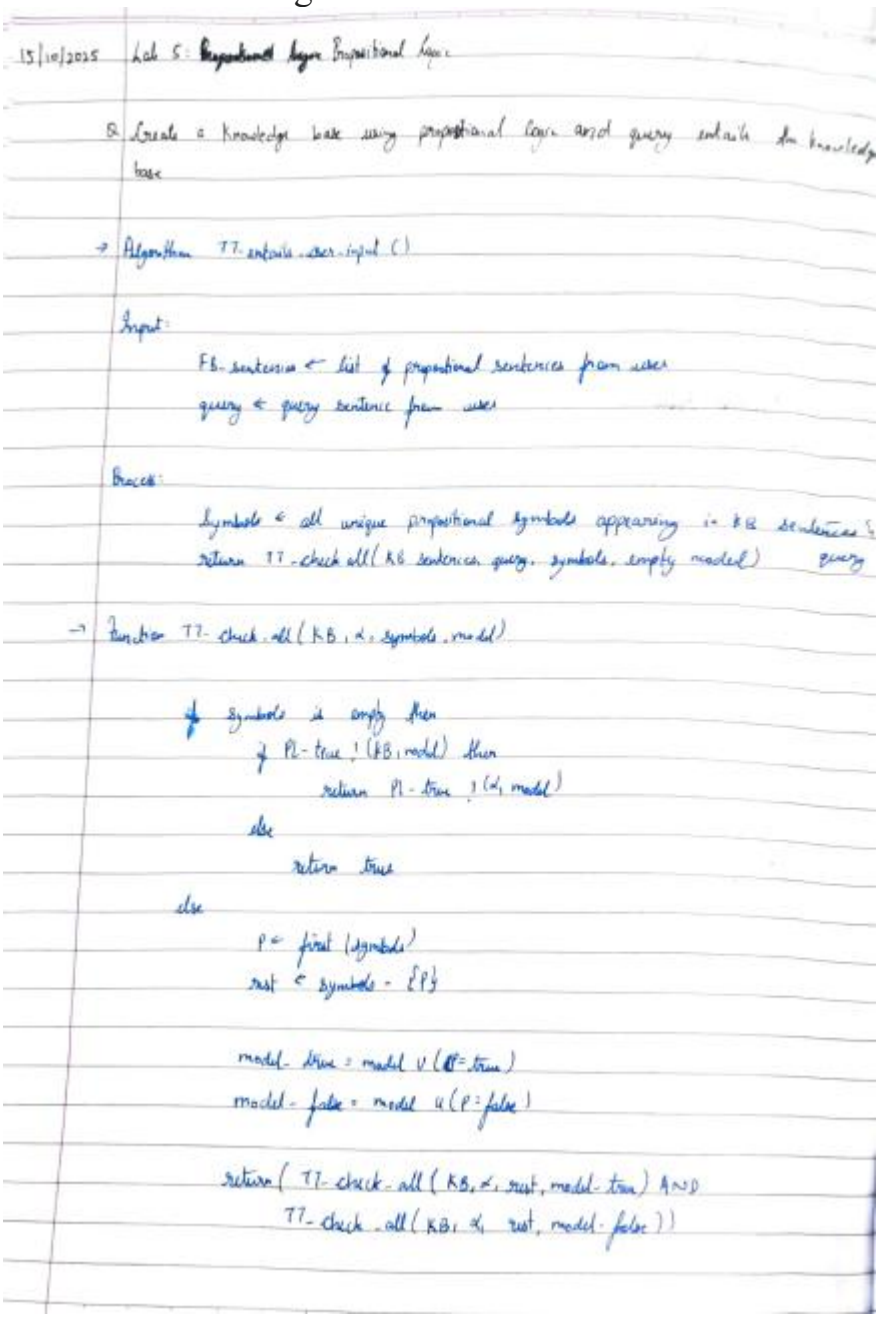
```
    attacks = 0
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                attacks += 1
    return attacks

def get_neighbor(state):

    neighbor = state[:]
    i, j = random.sample(range(len(state)), 2)
    neighbor[i], neighbor[j] = neighbor[j], neighbor[i]
    return neighbor

def simulated_annealing(n=8, max_iter=10000, temp=100.0, cooling=0.95):

    current = list(range(n))
    random.shuffle(current)
    current_cost = cost(current)

    temperature = temp
    cooling_rate = cooling

    best = current[:]
    best_cost = current_cost

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

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

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

        temperature *= cooling_rate

    return best, best_cost

def print_board(state):
```

```
    n = len(state)
    for row in range(n):
        line = " ".join("Q" if state[col] == row else "." for col in range(n))
        print(line)
    print()


n = 8
solution, cost_val = simulated_annealing(n, max_iter=20000)
print("Best position found:", solution)
print(f"Number of non-attacking pairs: {n*(n-1)//2 - cost_val}")
print("\nBoard:")
print_board(solution)
```

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

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


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

Program 6

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



15/10/2025 Lab 5: Propositional logic

8. Create a knowledge base using propositional logic and query entails the knowledge base

→ Algorithm TT_entails_user_input ()

Input:

KB_sentences ← list of propositional sentences from user
query ← query sentence from user

Process:

symbols ← all unique propositional symbols appearing in KB sentences & query
return TT_check_all(KB sentences, query, symbols, empty model)

→ function TT_check_all(KB, α, symbols, model)

if symbols is empty then
  if PL_true?(KB, model) then
    return PL_true?(α, model)
  else
    return true
else
  P ← first(symbols)
  rest ← symbols - {P}

  model_true = model ∪ (P=true)
  model_false = model ∪ (P=false)

  return (TT_check_all(KB, α, rest, model_true) AND
    TT_check_all(KB, α, rest, model_false))

→ function PL-true? (sentence, set, model)

for each sentence S in sentence-set do

if S evaluate to false under model

return false

return true

8. Consider a knowledge base KB that contains the following propositional logic sentences

$Q \rightarrow P$

$P \rightarrow \neg Q$

$Q \vee R$

i Construct a truth table that shows the truth value of each sentence in KB and indicate the models in which the KB is true.

P	Q	R	$Q \rightarrow P$	$P \rightarrow \neg Q$	$Q \vee R$	KB true
T	T	T	T	F	T	F
T	T	F	T	F	T	F
T	F	T	T	T	T	T
T	F	F	T	T	F	F
F	T	T	F	T	T	F
F	T	F	F	T	T	F
F	F	T	T	T	T	T
F	F	F	T	T	F	F

ii Does KB entail R

In all models where KB is true, R = T

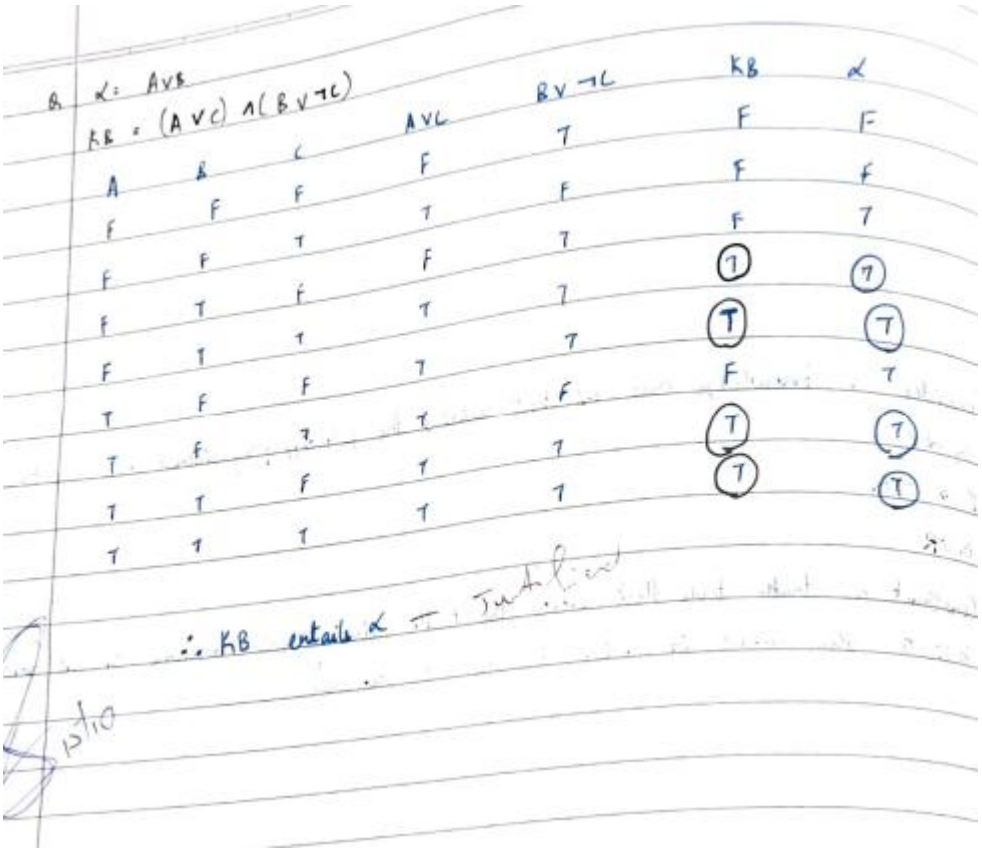
∴ KB entails R

iii Does KB entail $R \rightarrow P$

P or R	$R \rightarrow P$	
TFT	F	Both false ⇒ KB does not entail $R \rightarrow P$
FFT	F	

iii Does KB entail $Q \rightarrow R$

P or R	$Q \rightarrow R$	
TFT	T	Always true ⇒ KB entails $Q \rightarrow R$
FFT	T	



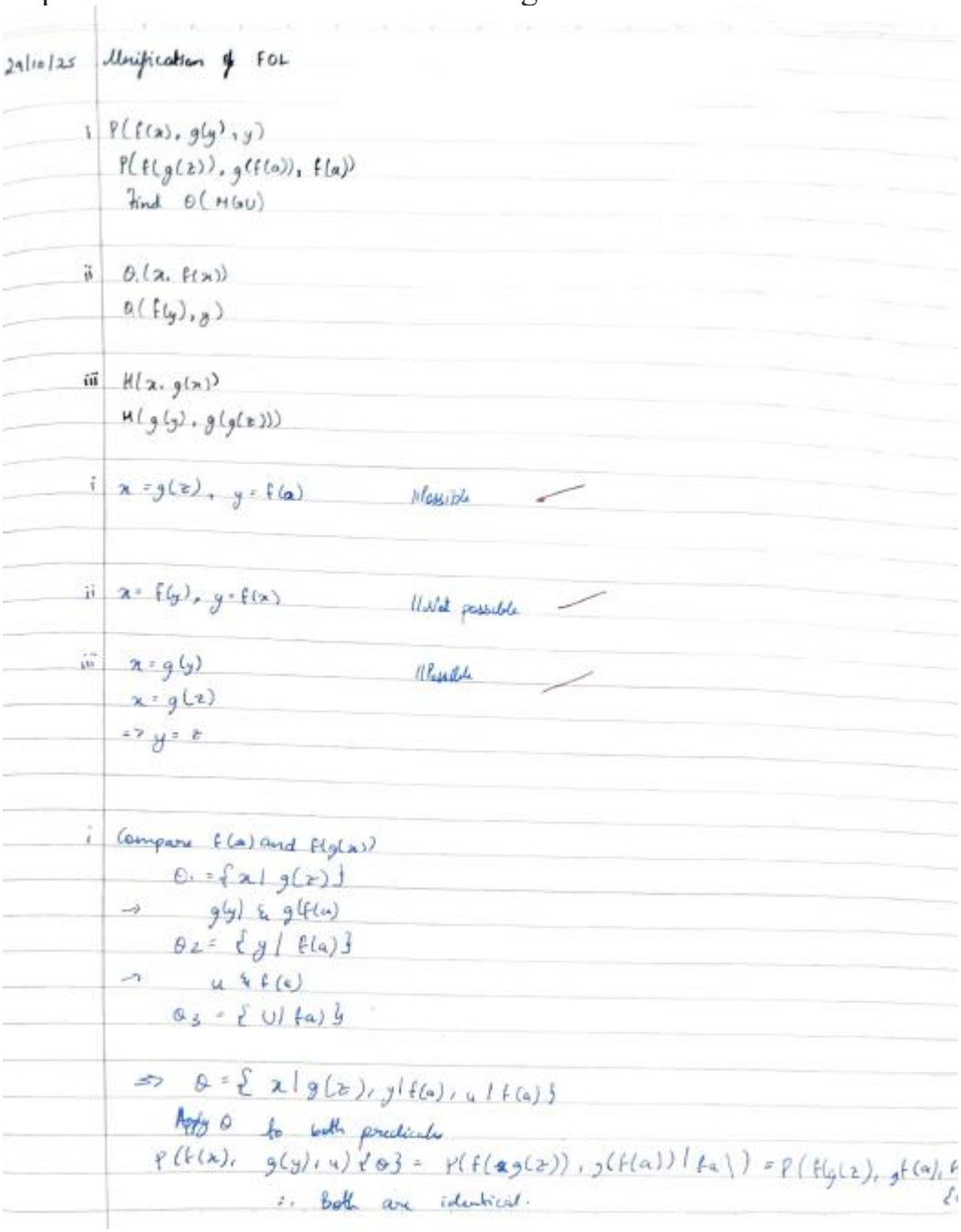

```
import itertools
def evaluate_formula(formula, truth_assignment):
    eval_formula = formula
    for symbol, value in truth_assignment.items():
        eval_formula = eval_formula.replace(symbol, str(value))
    return eval(eval_formula)

def generate_truth_table(variables):
    return list(itertools.product([False, True], repeat=len(variables)))

def is_entailed(KB_formula, alpha_formula, variables):
    truth_combinations = generate_truth_table(variables)
    print(f"{' '.join(variables)} | KB Result | Alpha Result")
    print("-" * (len(variables) * 2 + 15))
    for combination in truth_combinations:
        truth_assignment = dict(zip(variables, combination))
        KB_value = evaluate_formula(KB_formula, truth_assignment)
        alpha_value = evaluate_formula(alpha_formula, truth_assignment)
        result_str = " ".join(["T" if value else "F" for value in combination])
        print(f"{result_str} | {'T' if KB_value else 'F'}         | {'T' if alpha_value else 'F'}")
        if KB_value and not alpha_value:
            return False
    return True
```

```
KB = "(A or C) and (B or not C)"
alpha = "A or B"
variables = ['A', 'B', 'C']

if is_entailed(KB, alpha, variables):
    print("\nThe knowledge base entails alpha.")
else:
    print("\nThe knowledge base does not entail alpha.")
```

```
A B C | KB Result | Alpha Result
---------------------
F F F | F         | F
F F T | F         | F
F T F | F         | T
F T T | T         | T
T F F | T         | T
T F T | F         | T
T T F | T         | T
T T T | T         | T

The knowledge base entails alpha.
```

Program 7

Implement unification in first order logic



29/10/25 Unification of FOL

i. $P(f(x), g(y), y)$
$P(f(g(z)), g(f(a)), f(a))$
Find θ (MGU)

ii. $\theta_1(x, f(x))$
$\theta(f(y), g)$

iii. $H(x, g(x))$
$H(g(y), g(g(z)))$

i. $x = g(z)$, $y = f(a)$ — Possible ✓

ii. $x = f(y)$, $y = f(x)$ — Not possible ✓

iii. $x = g(y)$ — Possible ✓
$x = g(z)$
$\Rightarrow y = z$

i. Compare $f(a)$ and $f(g(x))$
$\theta_1 = \{x / g(z)\}$
$\rightarrow$ $g(y)$ & $g(f(u))$
$\theta_2 = \{y / f(a)\}$
$\rightarrow$ u & $f(a)$
$\theta_3 = \{u / f(a)\}$

$\Rightarrow \theta = \{x / g(z), y / f(a), u / f(a)\}$
Apply θ to both predicate
$P(f(x), g(y), u)\{\theta\} = P(f(g(z)), g(f(a)), f(a)) = P(f(g(z)), g(f(a)), f$
$\therefore$ Both are identical.

2 Comparing x and f(y)

x = f(y)

f(x) & y

f(x) = y

Now, x: f(f(y)) = y

↳ cyclic, not primitive

3 Comparing x & g(y)

x = g(y)

Comparing g(x) and g(g(z))

x = g(y)

g(x) = g(g(y))

g(g(y)) & g(g(z))

can be unified

when y = z

x = g(y)

y = z

x = g(z)

y = z

Thus, MGU is

θ = {x/g(z), y/z}

Substitute

H(x, g(x)) {x/g(z), y/z} = H(g(z), g(g(z)))

H(g(y), g(g(z)), y) {z/y} = H(g(z), g(g(z)))

Thus, successful unification.

Recursive

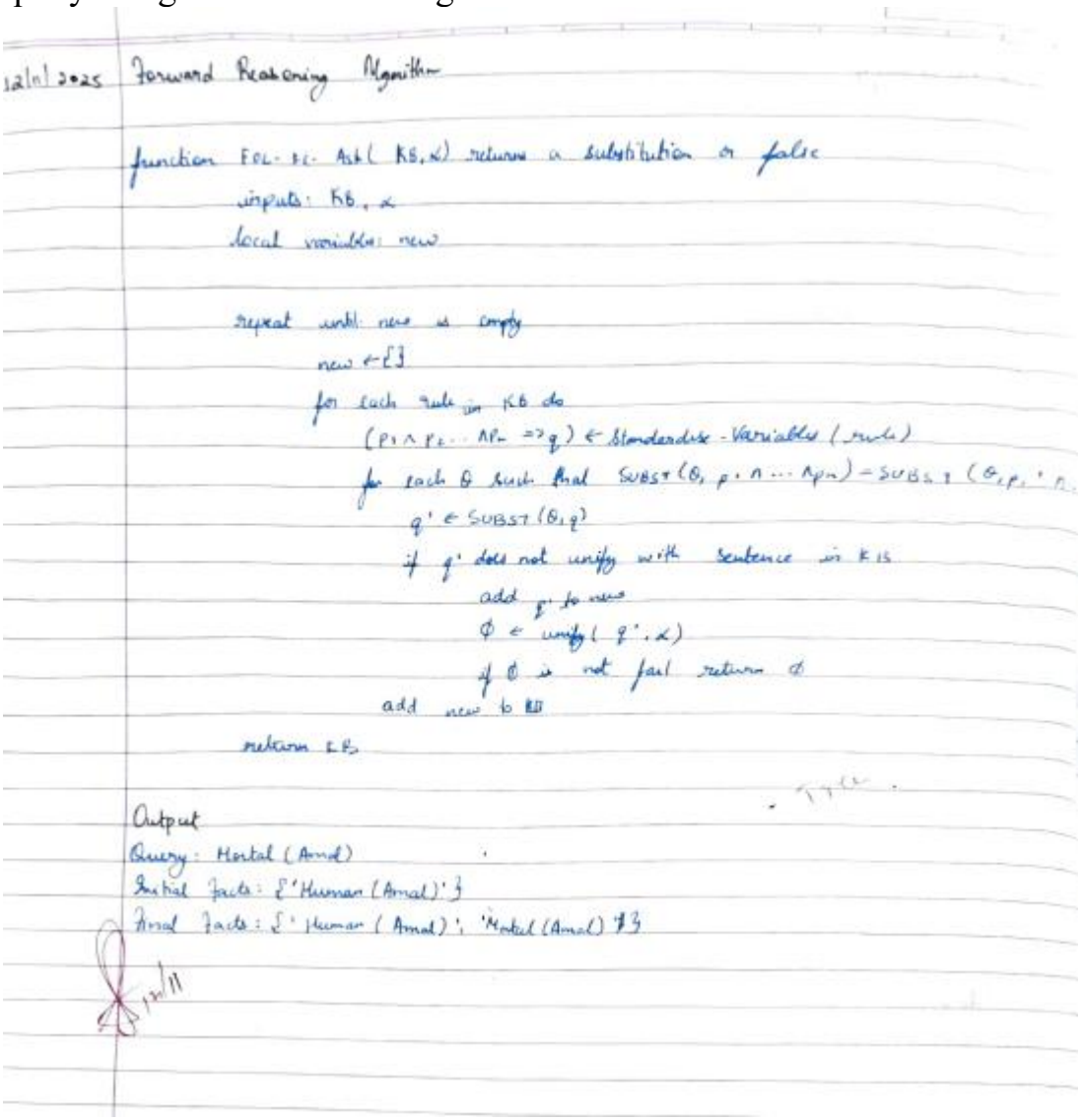
Min Max

AB prune

Tic Tac Toe

Program 8

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




```
import re

def match_pattern(pattern, fact):
    """
    Checks if a fact matches a rule pattern using regex-style variable substitution.
    Variables are lowercase words like p, q, x, r etc.
    Returns a dict of substitutions or None if not matched.
    """
    # Extract predicate name and arguments
    pattern_pred, pattern_args = re.match(r'(\w+)
', pattern).groups()
    fact_pred, fact_args = re.match(r'(\w+)
', fact).groups()
```

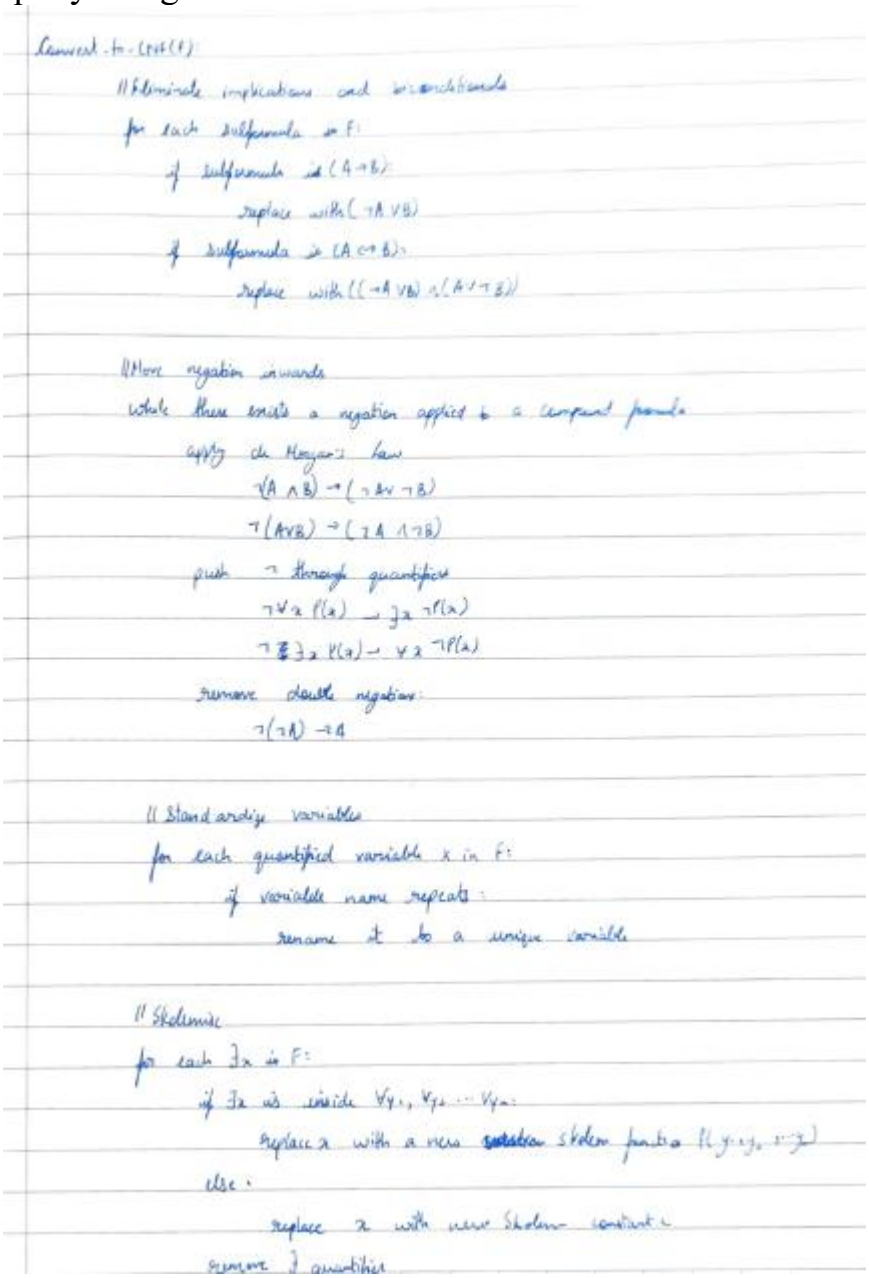
```
    if pattern_pred != fact_pred:
        return None  # predicate mismatch

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

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

    subst = {}
    for p_arg, f_arg in zip(pattern_args, fact_args):
        if re.fullmatch(r'[a-z]\w*', p_arg):  # variable
            subst[p_arg] = f_arg
        elif p_arg != f_arg:  # constants mismatch
            return None
    return subst


def apply_substitution(expr, subst):
    """Replaces all variable names in expr using the given substitution dict."""
    for var, val in subst.items():
        expr = re.sub(rf'\b{var}\b', val, expr)
    return expr


# ---------- Knowledge Base ----------

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

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

goal = "Criminal(Robert)"

def forward_chain(rules, facts, goal):
    added = True
    while added:
```

```
        added = False
        for premises, conclusion in rules:

            possible_substs = []
            for p in premises:
                for f in facts:
                    subst = match_pattern(p, f)
                    if subst:
                        possible_substs.append(subst)
                        break
                else:

                    break
            else:

                combined = {}
                for s in possible_substs:
                    combined.update(s)

                new_fact = apply_substitution(conclusion, combined)

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


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

```
Inferred: Weapon(T1)
Inferred: Hostile(A)
Inferred: Sells(Robert, T1, A)
Inferred: Criminal(Robert)
Goal achieved: True
```

Program 9

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



Convert to CNF(F):

// Eliminate implications and biconditionals

for each subformula in F:

if subformula is (A → B):

replace with (¬A ∨ B)

if subformula is (A ↔ B):

replace with ((¬A ∨ B) ∧ (A ∨ ¬B))

// Move negation inwards

while there exists a negation applied to a compound formula:

apply de Morgan's law

¬(A ∧ B) → (¬A ∨ ¬B)

¬(A ∨ B) → (¬A ∧ ¬B)

push ¬ through quantifiers

¬∀x P(x) → ∃x ¬P(x)

¬∃x P(x) → ∀x ¬P(x)

remove double negation:

¬(¬A) → A

// Standardize variables

for each quantified variable x in F:

if variable name repeats:

rename it to a unique variable

// Skolemize

for each ∃x in F:

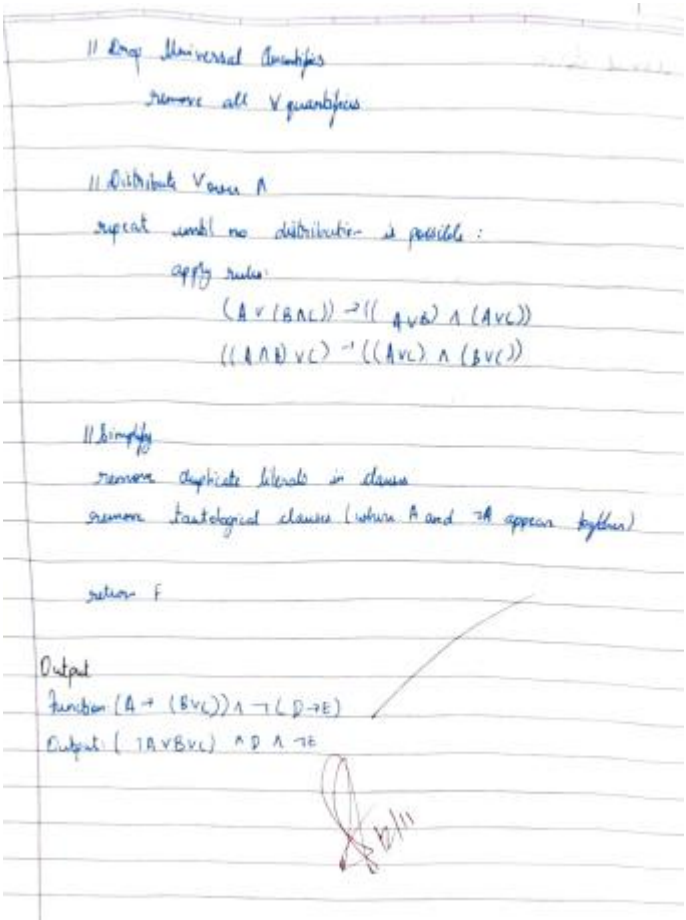
if ∃x is inside ∀y1, ∀y2 ... ∀yn:

replace x with a new skolem function f(y1, y2, ..., yn)

else:

replace x with new Skolem constant c

remove ∃ quantifier




```
from copy import deepcopy

def print_step(title, content):
    print(f"\n{'='*45}\n{title}\n{'='*45}")
    if isinstance(content, list):
        for i, c in enumerate(content, 1):
            print(f"{i}. {c}")
    else:
        print(content)

KB = [
    ["¬Food(x)", "Likes(John,x)"],
    ["Food(Apple)"],
    ["Food(Vegetable)"],
    ["¬Eats(x,y)", "Killed(x)", "Food(y)"],
    ["Eats(Anil,Peanuts)"],
    ["Alive(Anil)"],
    ["¬Alive(x)", "¬Killed(x)"],
    ["Killed(x)", "Alive(x)"]
]

QUERY = ["Likes(John,Peanuts)"]
```

```
def negate(literal):
    if literal.startswith("¬"):
        return literal[1:]
    return "¬" + literal

def substitute(clause, subs):
    new_clause = []
    for lit in clause:
        for var, val in subs.items():
            lit = lit.replace(var, val)
        new_clause.append(lit)
    return new_clause

def unify(lit1, lit2):
    """Small unifier for patterns like Food(x) and Food(Apple)."""
    if "(" not in lit1 or "(" not in lit2:
        return None
    pred1, args1 = lit1.split("(")
    pred2, args2 = lit2.split("(")
    args1 = args1[:-1].split(",")
    args2 = args2[:-1].split(",")
    if pred1 != pred2 or len(args1) != len(args2):
        return None
    subs = {}
    for a, b in zip(args1, args2):
        if a == b:
            continue
        if a.islower():
            subs[a] = b
        elif b.islower():
            subs[b] = a
        else:
            return None
    return subs

def resolve(ci, cj):
    """Return list of (resolvent, substitution, pair)."""
    resolvents = []
    for li in ci:
        for lj in cj:
            if li == negate(lj):
                new_clause = [x for x in ci if x != li] + [x for x in cj if x != lj]
                resolvents.append((list(set(new_clause)), {}, (li, lj)))
            else:
                # same predicate, opposite sign
                if li.startswith("¬") and not lj.startswith("¬") and li[1:].split("(")[0] == lj.split("(")[0]:
```

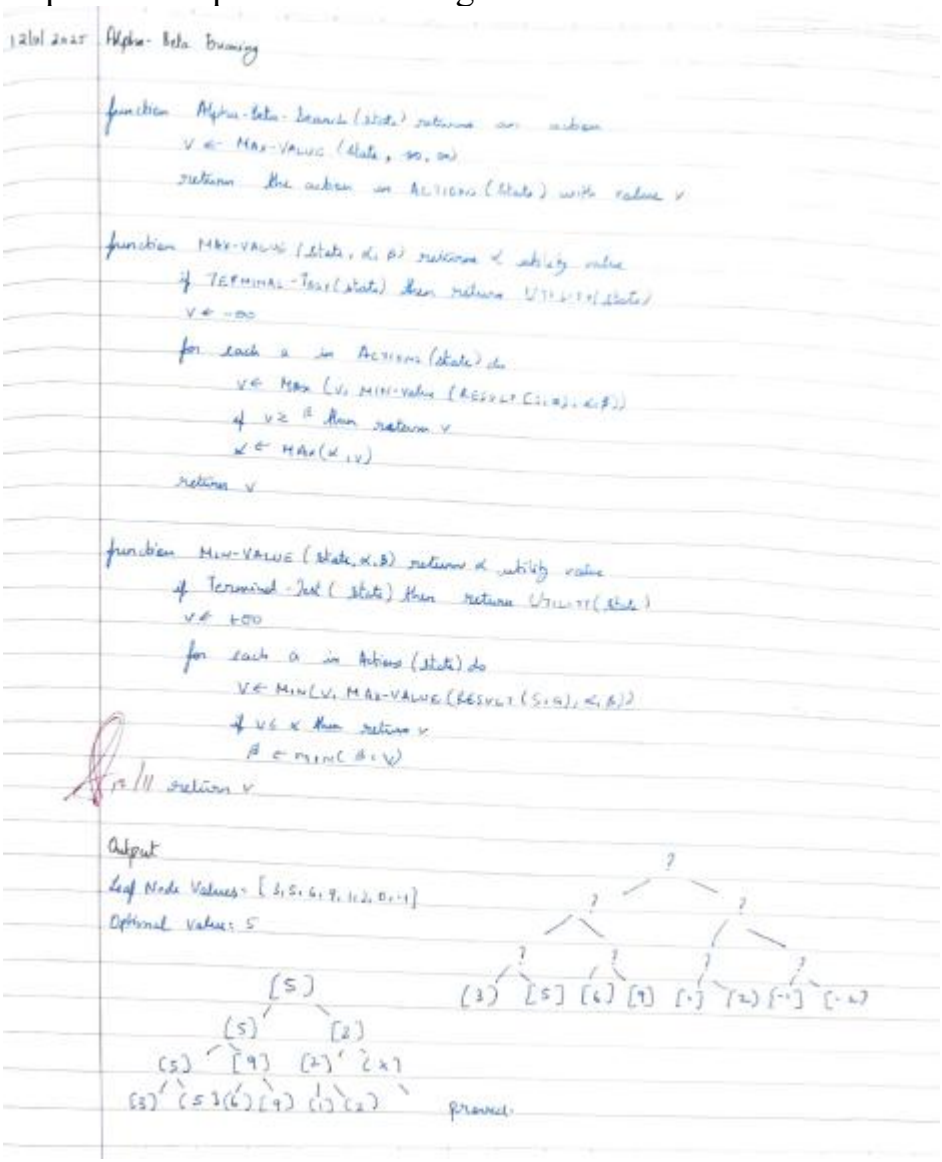
```
                subs = unify(li[1:], lj)
                if subs:
                    new_clause = substitute([x for x in ci if x != li] + [x for x in cj if x != lj], subs)
                    resolvents.append((list(set(new_clause)), subs, (li, lj)))
            elif lj.startswith("¬") and not li.startswith("¬") and lj[1:].split("(")[0] == li.split("(")[0]:
                subs = unify(lj[1:], li)
                if subs:
                    new_clause = substitute([x for x in ci if x != li] + [x for x in cj if x != lj], subs)
                    resolvents.append((list(set(new_clause)), subs, (li, lj)))
    return resolvents

def resolution(kb, query):
    clauses = deepcopy(kb)
    negated_query = [negate(q) for q in query]
    clauses.append(negated_query)
    print_step("Initial Clauses", clauses)

    steps = []
    new = []
    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:
            for r, subs, pair in resolve(ci, cj):
                if not r:
                    steps.append({
                        "parents": (ci, cj),
                        "resolvent": r,
                        "subs": subs
                    })
                    print_tree(steps)
                    print("\n☑ Empty clause derived — query proven.")
                    return True
                if r not in clauses and r not in new:
                    new.append(r)
                    steps.append({
                        "parents": (ci, cj),
                        "resolvent": r,
                        "subs": subs
                    })
        if all(r in clauses for r in new):
            print_step("No New Clauses", "Query cannot be proven ✗")
            print_tree(steps)
            return False
        clauses.extend(new)

def print_tree(steps):
```

```
    print("\n" + "="*45)
    print("Resolution Proof Trace")
    print("="*45)
    for i, s in enumerate(steps, 1):
        p1, p2 = s["parents"]
        r = s["resolvent"]
        subs = s["subs"]
        subs_text = f"  Substitution: {subs}" if subs else ""

        print(f"  Resolve {p1} and {p2}")
        if subs_text:
            print(subs_text)
        if r:
            print(f"  ⇒ {r}")
        else:
            print("  ⇒ {} (empty clause)")
        print("-"*45)

def main():
    print_step("Knowledge Base in CNF", KB)
    print_step("Negated Query", [negate(q) for q in QUERY])
    proven = resolution(KB, QUERY)
    if proven:
        print("\n☑ Query Proven by Resolution: John likes peanuts.")
    else:
        print("\n❌ Query cannot be proven from KB.")

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

```
Unifying: P(f(x),g(y),y)  and  P(f(g(z)),g(f(a)),f(a
    ))
=> Substitution: x : g(z), y : f(a)

Unifying: Q(x,f(x))  and  Q(f(y),y)
=> Not unifiable.

Unifying: H(x,g(x))  and  H(g(y),g(g(z)))
=> Substitution: x : g(y), y : z

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

Program 10

Implement Alpha-Beta Pruning




```
# Simplified Tic-Tac-Toe with Unification + Alpha-Beta
# No parsing layer, direct symbolic unification and minimax

def unify(a, b):
    """Very simple unification for small terms like ('line', [X,O,X])"""
    if a == b:
        return {}
    if isinstance(a, str) and a.islower():  # variable
        return {a: b}
    if isinstance(b, str) and b.islower():
        return {b: a}
    if isinstance(a, tuple) and isinstance(b, tuple):
        if a[0] != b[0] or len(a[1]) != len(b[1]):
            return None
```

```
        subs = {}
        for x, y in zip(a[1], b[1]):
            s = unify(x, y)
            if s is None:
                return None
            subs.update(s)
        return subs
    return None


# Winning triples (rows, cols, diagonals)
WIN_TRIPLES = [(0,1,2),(3,4,5),(6,7,8),(0,3,6),(1,4,7),(2,5,8),(0,4,8),(2,4,6)]

def winner(board):
    pattern = ('line', ['X','X','X'])
    for i,j,k in WIN_TRIPLES:
        term = ('line', [board[i], board[j], board[k]])
        if unify(term, pattern):
            return 'X'
        if unify(term, ('line',['O','O','O'])):
            return 'O'
    return None

def is_full(board): return all(c != '_' for c in board)

def evaluate(board):
    w = winner(board)
    if w == 'X': return 1
    if w == 'O': return -1
    if is_full(board): return 0
    return None

def alpha_beta(board, player, alpha=-float('inf'), beta=float('inf')):
    val = evaluate(board)
    if val is not None:
        return val, None

    moves = [i for i,c in enumerate(board) if c == '_']
    best_move = None
    if player == 'X':
        max_eval = -float('inf')
        for m in moves:
            new_board = board[:]
            new_board[m] = 'X'
            eval_, _ = alpha_beta(new_board, 'O', alpha, beta)
            if eval_ > max_eval:
                max_eval, best_move = eval_, m
```

```
            alpha = max(alpha, eval_)
            if beta <= alpha: break
        return max_eval, best_move
    else:
        min_eval = float('inf')
        for m in moves:
            new_board = board[:]
            new_board[m] = 'O'
            eval_, _ = alpha_beta(new_board, 'X', alpha, beta)
            if eval_ < min_eval:
                min_eval, best_move = eval_, m
            beta = min(beta, eval_)
            if beta <= alpha: break
        return min_eval, best_move

def print_board(b):
    for i in range(0,9,3):
        print(' '.join(b[i:i+3]))
    print()

# --- Example usage ---
board = ['_']*9
score, move = alpha_beta(board, 'X')
print("Best first move for X:", move)
board[move] = 'X'
print_board(board)
```

```
Best first move for X: 0
X _ _
_ _ _
_ _ _
```