VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT

on

Artificial Intelligence (23CS5PCAIN)

Submitted by

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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)

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B.M.S. College of Engineering,

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(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 **DAIVYA PRIYANKKUMAR SHAH (1BM23CS084),** who is a 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.

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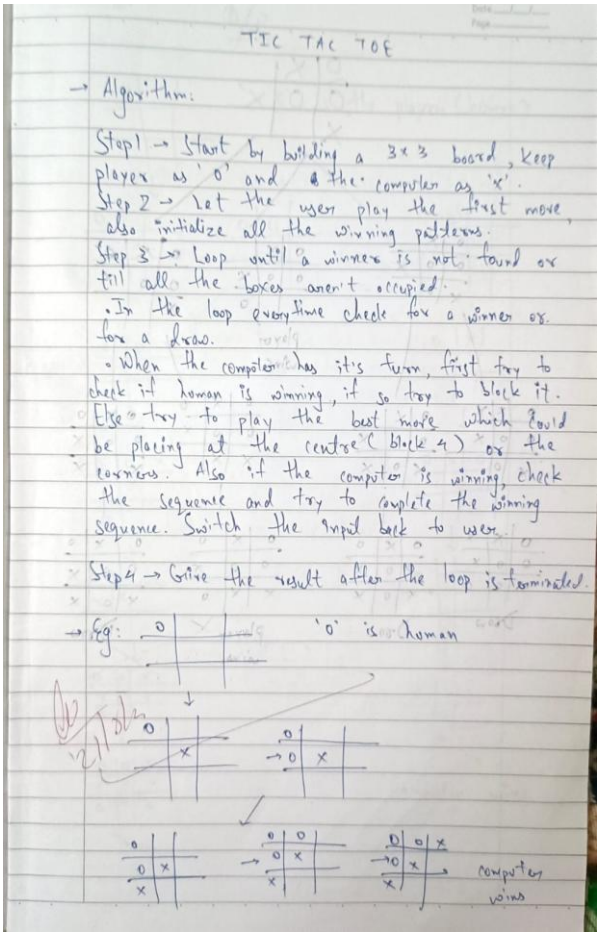
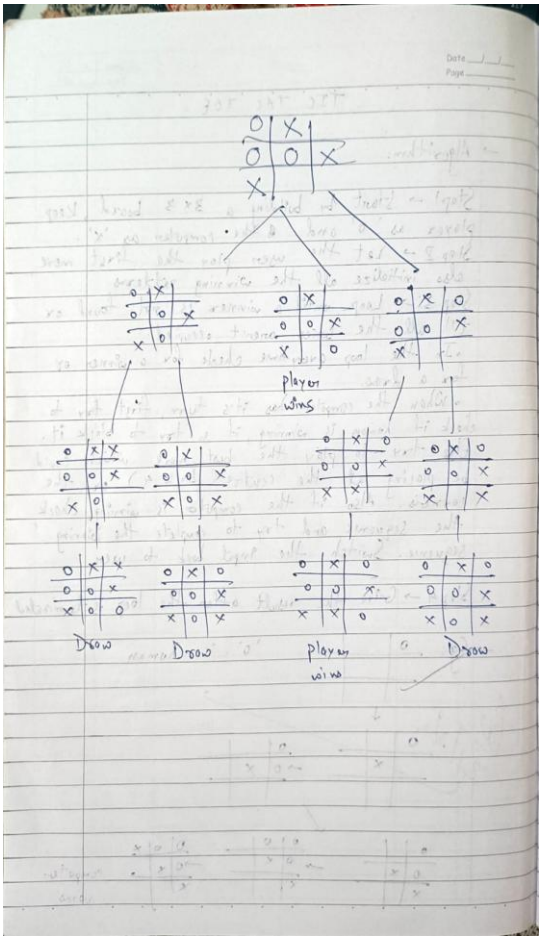
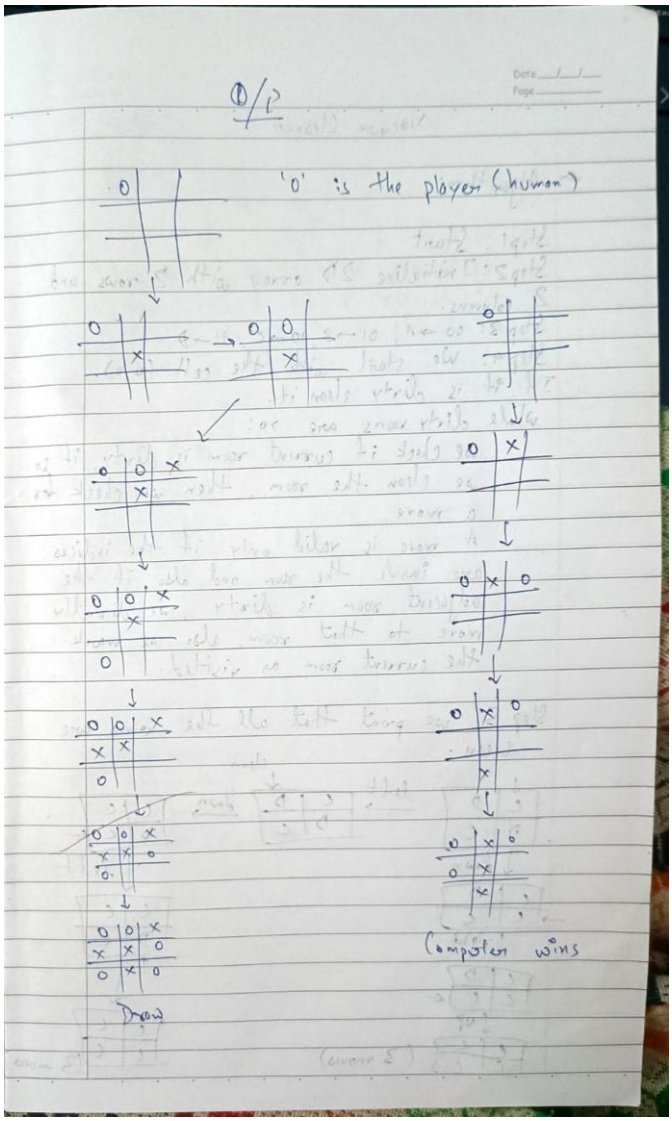
GITHUB: https://github.com/daivya17/AI_Lab

Program 1: Implement Tic –Tac –Toe Game & Implement vacuum cleaner agent.

ALGORITHM (Tic-Tac-Toe) :






'O' is the player (human)
Draw
Computer wins

CODE (Tic-Tac-Toe) :

```
import math
import random
def print_board(board):
    """Prints the current state of the game board."""
    for row in [board[i:i+3] for i in range(0, 9, 3)]:
        print('| ' + ' | '.join(row) + ' |')
def available_moves(board):
    """Returns a list of available spots on the board."""
    return [i for i, spot in enumerate(board) if spot == ' ']
def check_winner(board, player):
    """Checks if the given player has won the game."""
    # Check for winning rows
    for i in range(0, 9, 3):
        if all(s == player for s in board[i:i+3]):
            return True

    # Check for winning columns
    for i in range(3):
        if board[i] == board[i+3] == board[i+6] == player:
            return True

    # Check for winning diagonals
    if board[0] == board[4] == board[8] == player:
        return True
    if board[2] == board[4] == board[6] == player:
        return True

    return False

def minimax(board, is_maximizing):
    """
    Minimax algorithm to find the best move.
```

```
'X' is the maximizing player (computer), 'O' is the minimizing player (human).
"""
ai_player = 'X'
human_player = 'O'

if check_winner(board, ai_player):
    return 1, None
if check_winner(board, human_player):
    return -1, None
if not available_moves(board):
    return 0, None

if is_maximizing:
    best_score = -math.inf
    best_move = None
    for move in available_moves(board):
        board[move] = ai_player
        score, _ = minimax(board, False)
        board[move] = ' '
        if score > best_score:
            best_score = score
            best_move = move
    return best_score, best_move
else:
    best_score = math.inf
    best_move = None
    for move in available_moves(board):
        board[move] = human_player
        score, _ = minimax(board, True)
        board[move] = ' '
        if score < best_score:
            best_score = score
            best_move = move
```

```
        return best_score, best_move

def get_computer_move(board):
    """
    Gets a beatable move for the computer. It finds all moves with a positive
    score and chooses one randomly. If no such moves exist, it chooses a
    random move to prolong the game.
    """
    ai_player = 'X'
    human_player = 'O'

    # If the board is empty, take the center.
    if not available_moves(board):
        return 4

    # Check for an immediate win for the computer
    for move in available_moves(board):
        board[move] = ai_player
        if check_winner(board, ai_player):
            board[move] = ' '
            return move
        board[move] = ' '

    # Check for an immediate block of the human player
    for move in available_moves(board):
        board[move] = human_player
        if check_winner(board, human_player):
            board[move] = ' '
            return move
        board[move] = ' '

    # If no immediate win or block, use a simplified minimax approach.
    # Find all moves that result in a positive score.
```

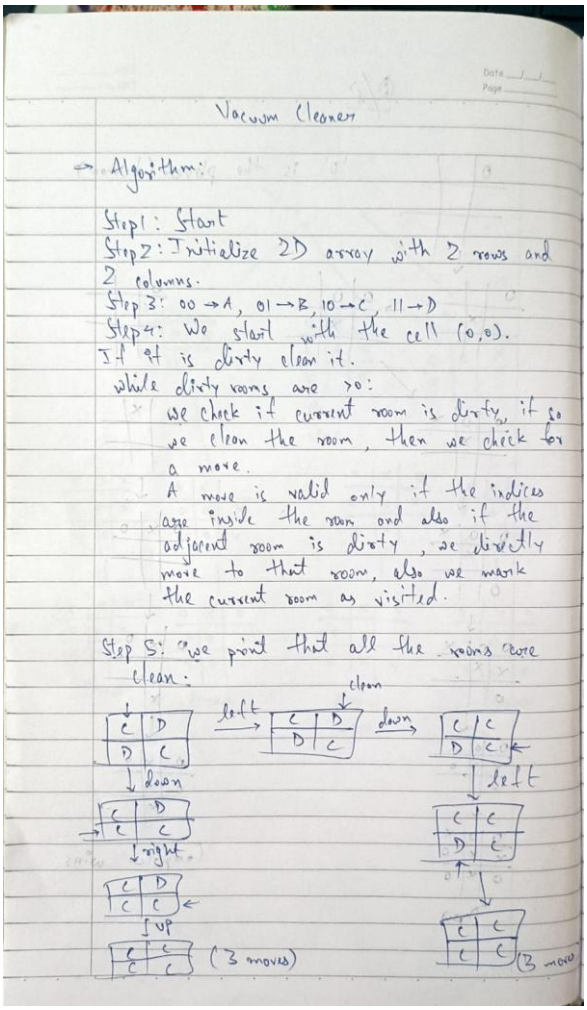
```
    positive_moves = []
    for move in available_moves(board):
        board[move] = ai_player
        score, _ = minimax(board, False)
        board[move] = ' '
        if score > 0:
            positive_moves.append(move)

    # If there are any moves that lead to a win or a draw, pick one at random.
    if positive_moves:
        return random.choice(positive_moves)

    # If all remaining moves lead to a loss, choose a random available move to delay the loss.
    return random.choice(available_moves(board))


def get_player_move(board):
    """Gets a valid move from the human player."""
    while True:
        try:
            move = int(input("Enter your move (1-9): ")) - 1
            if move not in available_moves(board):
                print("Invalid move. Please enter a number from 1-9 that is not taken.")
            else:
                return move
        except ValueError:
            print("Invalid input. Please enter a number.")

def play_game():
    """The main function to run the Tic-Tac-Toe game loop."""
    board = [' '] * 9
    print("Welcome to Tic-Tac-Toe!")
    print_board(board)
```

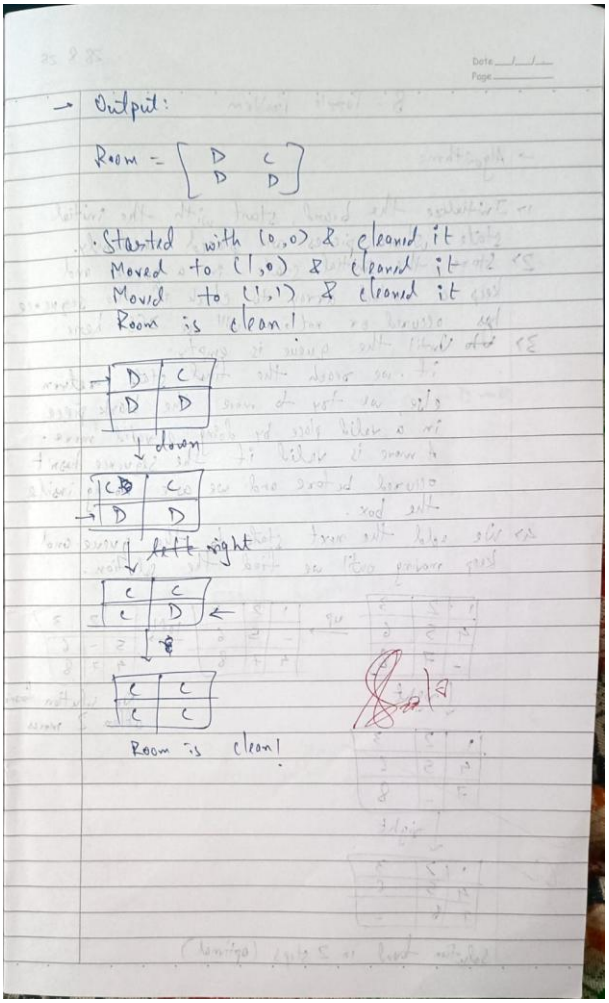
```
    # Let the human player ('O') go first.
    turn = 'O'

    while True:
        if turn == 'O':
            # Human's turn
            move = get_player_move(board)
            board[move] = 'O'
        else:
            # Computer's turn
            print("Computer is thinking...")
            move = get_computer_move(board)
            board[move] = 'X'

        print(f"Player {turn} makes a move to square {move + 1}")
        print_board(board)

        # Check for a winner after the move
        if check_winner(board, turn):
            print(f"{turn} wins!")
            break

        # Check for a tie
        if not available_moves(board):
            print("It's a draw!")
            break

        # Switch turns
        turn = 'X' if turn == 'O' else 'O'

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

OUTPUT:

```
Welcome to Tic-Tac-Toe!
|   |   |   |
|   |   |   |
|   |   |   |
Enter your move (1-9): 5
Player O makes a move to square 5
|   |   |   |
|   | O |   |
|   |   |   |
Computer is thinking...
Player X makes a move to square 6
|   |   |   |
|   | O | X |
|   |   |   |
Enter your move (1-9): 1
Player O makes a move to square 1
| O |   |   |
|   | O | X |
|   |   |   |
Computer is thinking...
Player X makes a move to square 9
| O |   |   |
|   | O | X |
|   |   | X |
Enter your move (1-9): 3
Player O makes a move to square 3
| O |   | O |
|   | O | X |
|   |   | X |
Computer is thinking...
Player X makes a move to square 2
| O | X | O |
|   | O | X |
|   |   | X |
Enter your move (1-9): 7
Player O makes a move to square 7
| O | X | O |
|   | O | X |
| O |   | X |
O wins!
```

ALGORITHM (Vacuum Cleaner):





CODE (Vacuum cleaner) :

```
# Initialize room (2x2 grid), each cell could be 'dirty' or 'clean'
room = [
    ['dirty', 'clean'],
    ['dirty', 'dirty']
]
# Starting position
x, y = 0, 0
```

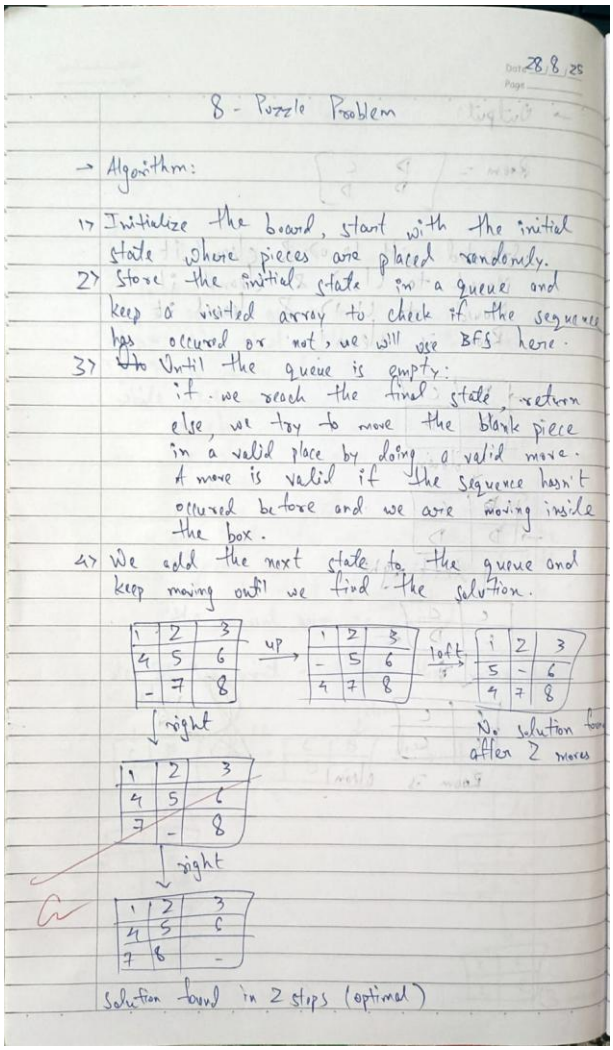
```
# Function to check if the current cell is dirty
def is_dirty(x, y):
    return room[x][y] == 'dirty'

# Function to clean the current cell
def clean(x, y):
    room[x][y] = 'clean'
    print(f"Cleaned cell ({x},{y})")

# Function to move to a new position (up, down, left, or right)
def move_to(new_x, new_y):
    global x, y
    x, y = new_x, new_y
    print(f"Moved to ({x},{y})")

# Function to check if all cells are clean
def all_clean():
    for i in range(2):
        for j in range(2):
            if room[i][j] == 'dirty':
                return False
    return True

# Cleaning path: Visit each cell and clean (left to right, top to bottom)
# The allowed moves are up, down, left, right
cleaning_path = [(0, 0), (0, 1), (1, 1), (1, 0)]

# Start cleaning the room following the path
for cell in cleaning_path:
    move_to(cell[0], cell[1])
    if is_dirty(cell[0], cell[1]):
        clean(cell[0], cell[1])

# Final check to see if the room is clean
if all_clean():
    print("Room is clean!")
else:
    print("Some cells are still dirty.")
```

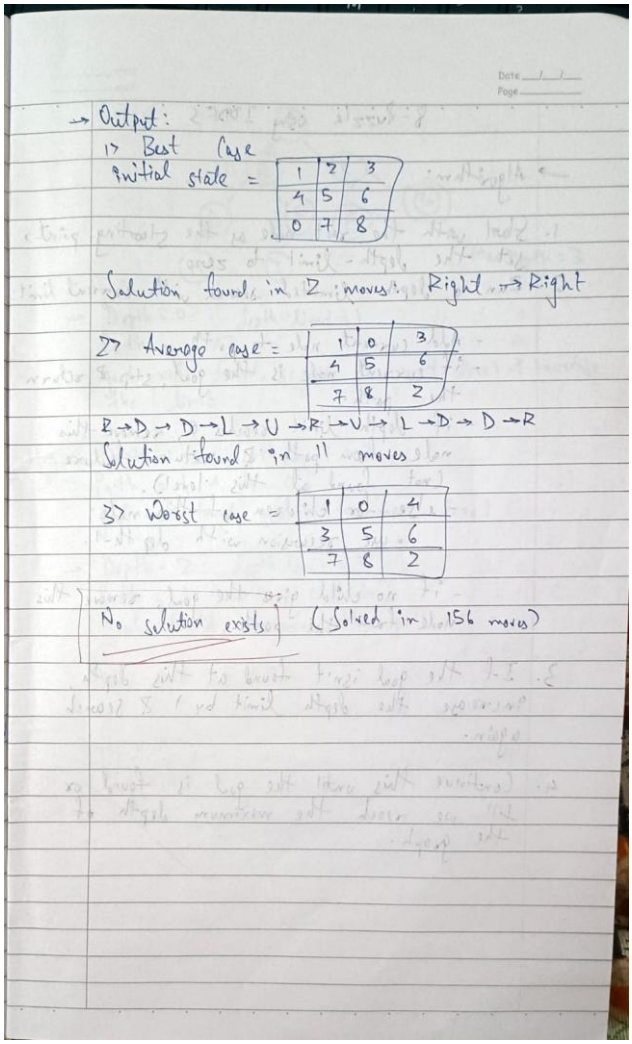
OUTPUT :

```
Moved to (0,0)
Cleaned cell (0,0)
Moved to (0,1)
Moved to (1,1)
Cleaned cell (1,1)
Moved to (1,0)
Cleaned cell (1,0)
Room is clean!
```

Program 2: Implement 8-puzzle

ALGORITHM:





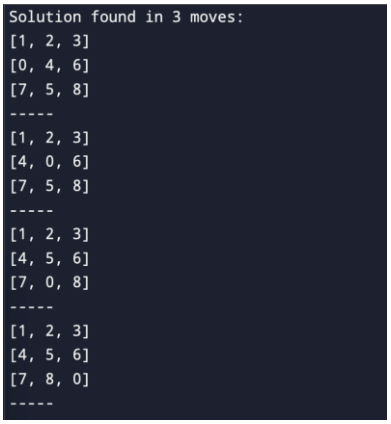
CODE:

```
from collections import deque
import copy

# Define the goal state
GOAL_STATE = [[1, 2, 3],
              [4, 5, 6],
              [7, 8, 0]]
```

```
# Directions for moving the blank tile
DIRECTIONS = {
    'Up': (-1, 0),
    'Down': (1, 0),
    'Left': (0, -1),
    'Right': (0, 1)
}

def find_blank(state):
    for i in range(3):
        for j in range(3):
            if state[i][j] == 0:
                return i, j

def is_valid(x, y):
    return 0 <= x < 3 and 0 <= y < 3

def get_neighbors(state):
    neighbors = []
    x, y = find_blank(state)

    for move, (dx, dy) in DIRECTIONS.items():
        new_x, new_y = x + dx, y + dy
        if is_valid(new_x, new_y):
            new_state = copy.deepcopy(state)
            # Swap blank with adjacent tile
            new_state[x][y], new_state[new_x][new_y] = new_state[new_x][new_y], new_state[x][y]
            neighbors.append((move, new_state))
    return neighbors

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

    while queue:
        current_state, path = queue.popleft()
        state_tuple = tuple(tuple(row) for row in current_state)

        if current_state == GOAL_STATE:
            return path  # Return the solution if we reach the goal state

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

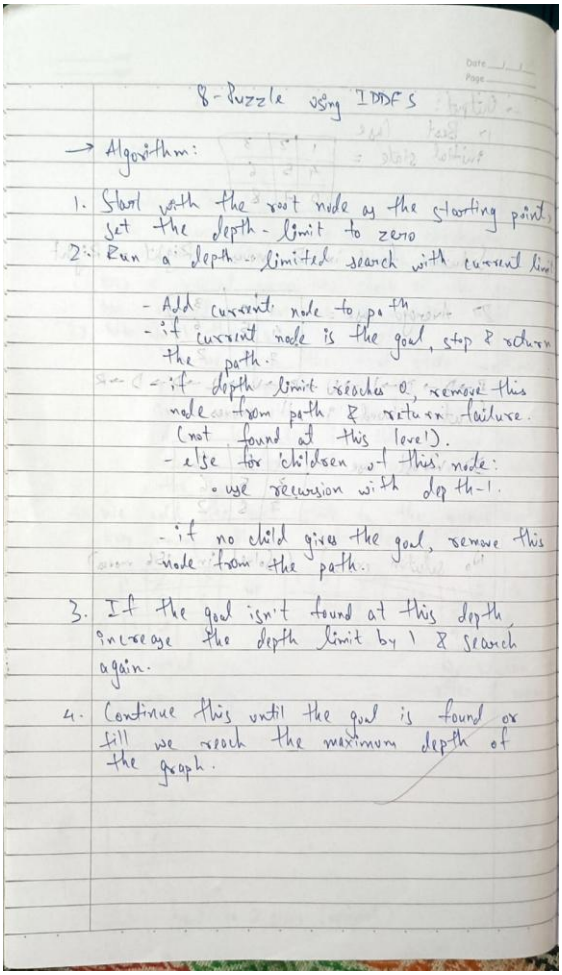
```
        for move, neighbor in get_neighbors(current_state):
            queue.append((neighbor, path + [move]))

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

solution = bfs(start_state)

# Since we removed "no solution" handling, it will keep exploring until it finds the solution
if solution:
    print("Solution found in", len(solution), "moves:")
    print(" -> ".join(solution))
```

OUTPUT:



Program 3: Implement IDDFS

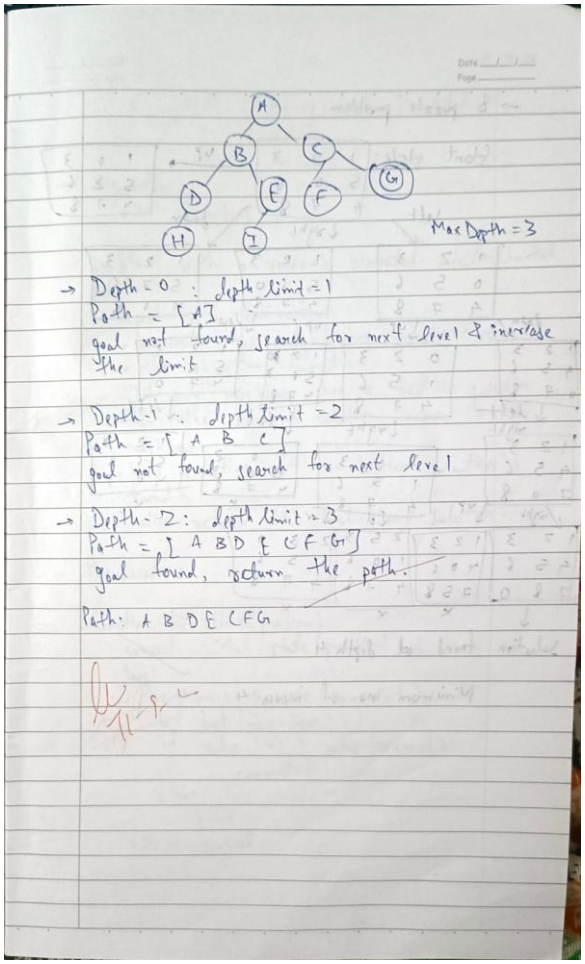
ALGORITHM :



8-Puzzle using IDDFS

→ Algorithm:

1. Start with the root node as the starting point, set the depth-limit to zero
2. Run a depth-limited search with current limit
   - Add current node to path
   - if current node is the goal, stop & return the path.
   - if depth limit reaches 0, remove this node from path & return failure. (not found at this level).
   - else for children of this node:
     - use recursion with depth-1.
   - if no child gives the goal, remove this node from the path.
3. If the goal isn't found at this depth, increase the depth limit by 1 & search again.
4. Continue this until the goal is found or till we reach the maximum depth of the graph.

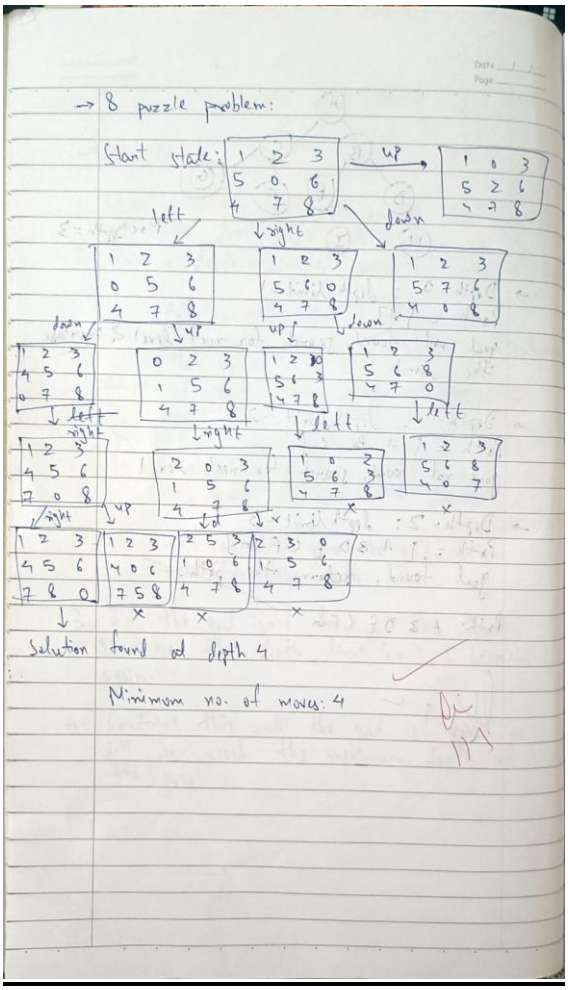


→ Depth-0 : depth limit = 1
Path = [A]
goal not found, search for next level & increase the limit

→ Depth-1 : depth limit = 2
Path = [A B C]
goal not found, search for next level

→ Depth-2 : depth limit = 3
Path = [A B D E C F G]
goal found, return the path.

Path: A B D E C F G



CODE :

```
from collections import deque

# Directions for movement
MOVES = {
   'Up': -3,
   'Down': 3,
   'Left': -1,
   'Right': 1
}

# Define the goal state
GOAL_STATE = (1, 2, 3,
              4, 5, 6,
              7, 8, 0)

# Valid indices for moves
def valid_moves(index):
```

```
    moves = []
    row, col = divmod(index, 3)

    if row > 0: moves.append('Up')
    if row < 2: moves.append('Down')
    if col > 0: moves.append('Left')
    if col < 2: moves.append('Right')

    return moves

# Apply move to a state
def apply_move(state, move):
    idx = state.index(0)
    new_idx = idx + MOVES[move]

    # Special case for left/right edge wrapping
    if move == 'Left' and idx % 3 == 0:
        return None
    if move == 'Right' and idx % 3 == 2:
        return None

    state = list(state)
    state[idx], state[new_idx] = state[new_idx], state[idx]
    return tuple(state)

# DFS with depth limit
def dls(state, depth, visited, path):
    if state == GOAL_STATE:
        return path

    if depth == 0:
        return None

    visited.add(state)
    for move in valid_moves(state.index(0)):
        next_state = apply_move(state, move)
        if next_state and next_state not in visited:
            result = dls(next_state, depth - 1, visited.copy(), path + [(move, next_state)])
            if result:
                return result
    return None

# IDDFS main function
def iddfs(start_state, max_depth=50):
```

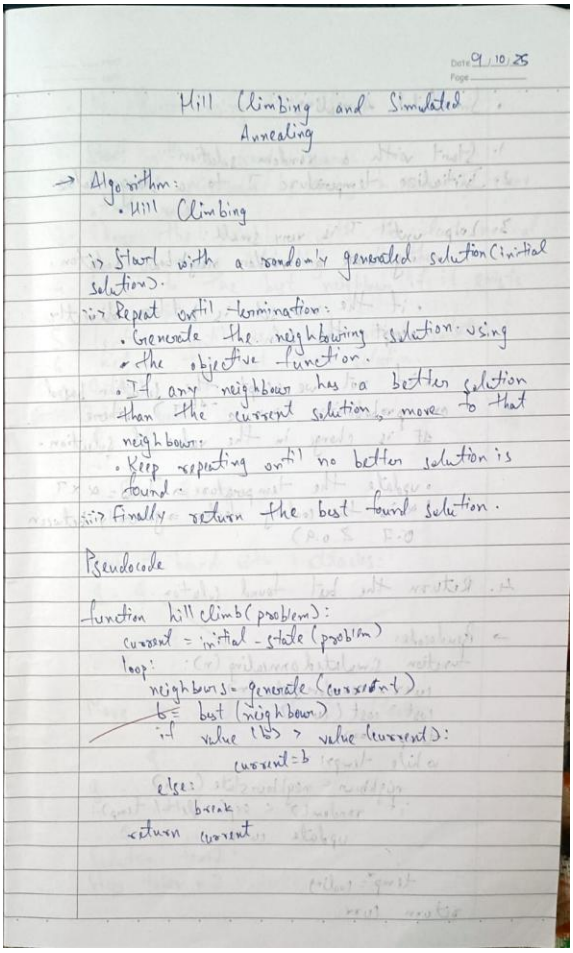
```
    for depth in range(max_depth):
        print(f"\n--- Iteration {depth + 1}: Depth Limit = {depth} ---")
        visited = set()
        path = dls(start_state, depth, visited, [])
        if path is not None:
            return path
    return None

# Function to print the puzzle state in a readable format
def print_state(state):
    for i in range(0, 9, 3):
        print(state[i:i+3])
    print()

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

    print("Initial State:")
    print_state(start)

    solution = iddfs(start)
    if solution:
        print(f"Solution found in {len(solution)} moves:")
        current_state = start
        for move, state in solution:
            print(f"Move: {move}")
            print_state(state)
            current_state = state
    else:
        print("No solution found.")
```

OUTPUT :

```
Initial State:
(1, 2, 3)
(4, 5, 6)
(0, 7, 8)


--- Iteration 1: Depth Limit = 0 ---

--- Iteration 2: Depth Limit = 1 ---

--- Iteration 3: Depth Limit = 2 ---
Solution found in 2 moves:
Move: Right
(1, 2, 3)
(4, 5, 6)
(7, 0, 8)

Move: Right
(1, 2, 3)
(4, 5, 6)
(7, 8, 0)
```

Program 4: Implement Hill Climbing & Simulated Annealing

ALGORITHM:



Hill Climbing and Simulated Annealing

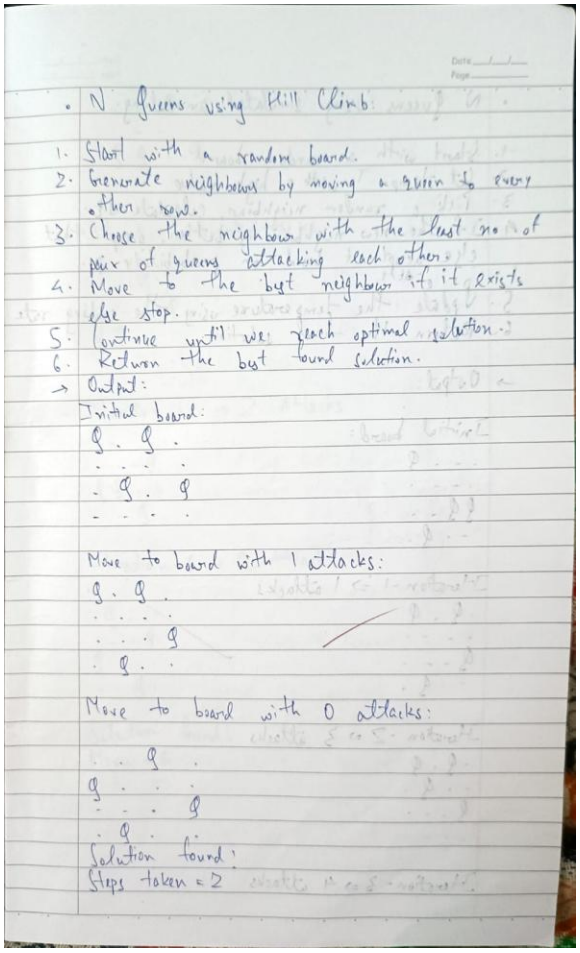
→ Algorithm:
- Hill Climbing

i) Start with a randomly generated solution (initial solution).
ii) Repeat until termination:
- Generate the neighbouring solution using the objective function.
- If any neighbour has a better solution than the current solution, move to that neighbour.
- Keep repeating until no better solution is found.

iii) Finally return the best found solution.

Pseudocode

```
function hillclimb(problem):
    current = initial_state(problem)
    loop:
        neighbours = generate(current)
        b = best(neighbour)
        if value(b) > value(current):
            current = b
        else:
            break
    return current
```



- N Queens using Hill Climb

1. Start with a random board.
2. Generate neighbours by moving a queen to every other row.
3. Choose the neighbour with the least no of pair of queens attacking each other.
4. Move to the best neighbour if it exists else stop.
5. Continue until we reach optimal solution.
6. Return the best found solution.

→ Output:

Initial board:

Q . Q .
. . . .
. Q . Q
. . . .

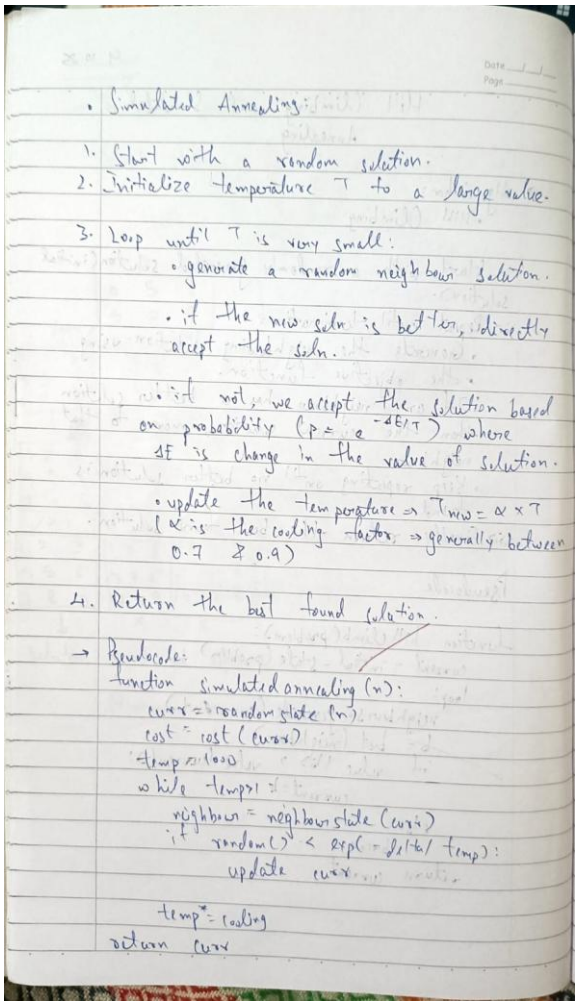
Move to board with 1 attacks:

Q . Q .
. . . .
. . . Q
. Q . .

Move to board with 0 attacks:

. . Q .
Q . . .
. . . Q
. Q . .

Solution found!
Steps taken = 2

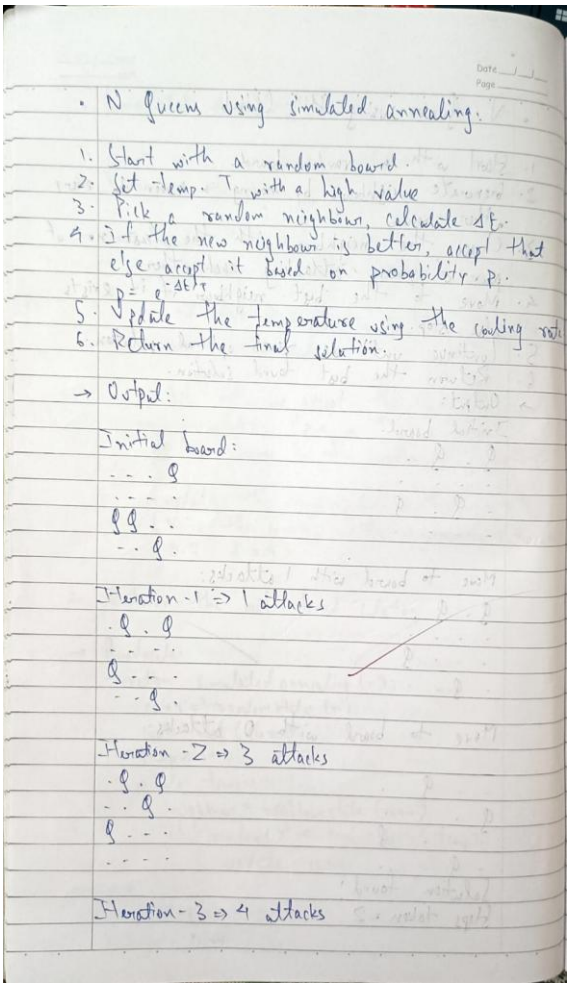


• Simulated Annealing:

1. Start with a random solution.
2. Initialize temperature T to a large value.
3. Loop until T is very small:
   • generate a random neighbour solution.
   • if the new soln is better, directly accept the soln.
   • if not, we accept the solution based on probability ($P = e^{-\Delta E/T}$) where ΔE is change in the value of solution.
   • update the temperature ⇒ $T_{new} = \alpha \times T$ (α is the cooling factor ⇒ generally between 0.7 & 0.9)
4. Return the best found solution.

→ Pseudocode:

```
function simulatedannealing(n):
    curr = randomstate(n)
    cost = cost(curr)
    temp = 1000
    while temp>1:
        neighbour = neighbourstate(curr)
        if random() < exp(-delta/temp):
            update curr
        temp *= cooling
    return curr
```



• N Queens using simulated annealing.

1. Start with a random board.
2. Set temp. T with a high value
3. Pick a random neighbour, calculate ΔE.
4. If the new neighbour is better, accept that else accept it based on probability P.
   $P = e^{-\Delta E/T}$
5. Update the temperature using the cooling rate
6. Return the final solution.

→ Output:

Initial board:

. . . Q
. . . .
Q Q . .
. . Q .

Iteration-1 ⇒ 1 attacks

. Q . Q
. . . .
Q . . .
. . Q .

Iteration-2 ⇒ 3 attacks

. Q . Q
. . Q .
Q . . .
. . . .

Iteration-3 ⇒ 4 attacks

CODE (Hill Climbing) :

```
import random
def heuristic(board):
    h = 0
    n = len(board)
    for i in range(n):
        for j in range(i+1, n):
            if board[i] == board[j] or abs(board[i]-board[j]) == abs(i-j):
                h += 1
    return h

def hill_climbing_restart(initial_board, max_restarts=100):
    N = len(initial_board)
    board = [x-1 for x in initial_board]  # 0-based
    h = heuristic(board)

    restart_count = 0
```

```
    while h != 0 and restart_count < max_restarts:
        steps = 0
        while True:
            best_board = board[:]
            best_h = h
            for col in range(N):
                for row in range(N):
                    if row != board[col]:
                        neighbor = board[:]
                        neighbor[col] = row
                        h_neighbor = heuristic(neighbor)
                        if h_neighbor < best_h:
                            best_board = neighbor
                            best_h = h_neighbor
            steps += 1
            if best_h >= h:  # stuck
                break
            board = best_board
            h = best_h
            if h == 0:
                break
        if h == 0:
            print(f"Solution found after {restart_count} restarts and {steps} steps.")
            break
        # Random restart
        board = [random.randint(0, N-1) for _ in range(N)]
        h = heuristic(board)
        restart_count += 1

    return [x+1 for x in board], h

# User input
N = int(input("Enter number of queens (N): "))
print(f"Enter the initial positions of {N} queens (row numbers 1 to {N}):")
initial_board = list(map(int, input().split()))

solution, h_val = hill_climbing_restart(initial_board)
print("Final board:", solution)
print("Heuristic H =", h_val)
```

OUTPUT (Hill Climbing) :

```
Enter number of queens (N): 4
Enter the initial positions of 4 queens (row numbers 1 to 4):
3 4 1 2
Solution found after 0 restarts and 3 steps.
Final board: [2, 4, 1, 3]
Heuristic H = 0

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

CODE (Simulated Annealing):

```
from datetime import datetime
import random, time, math
from copy import deepcopy, copy
import decimal

class Board:
    def __init__(self, queen_count=4):
        self.queen_count = queen_count
        self.reset()

    def reset(self):
        self.queens = [-1 for i in range(0, self.queen_count)]

        for i in range(0, self.queen_count):
            self.queens[i] = random.randint(0, self.queen_count - 1)
            # self.queens[row] = column


    def calculateCost(self):
        threat = 0

        for queen in range(0, self.queen_count):
            for next_queen in range(queen+1, self.queen_count):
                if self.queens[queen] == self.queens[next_queen] or abs(queen - next_queen) ==
abs(self.queens[queen] - self.queens[next_queen]):
                    threat += 1

        return threat

    @staticmethod
    def calculateCostWithQueens(queens):
        threat = 0
```

```
        queen_count = len(queens)

        for queen in range(0, queen_count):
            for next_queen in range(queen+1, queen_count):
                if queens[queen] == queens[next_queen] or abs(queen - next_queen) ==
abs(queens[queen] - queens[next_queen]):
                    threat += 1

        return threat

    @staticmethod
    def toString(queens):
        board_string = ""

        for row, col in enumerate(queens):
            board_string += "(%s, %s)\n" % (row, col)

        return board_string

    def getLowerCostBoard(self):
        displacement_count = 0
        temp_queens = self.queens
        lowest_cost = self.calculateCost(temp_queens)

        for i in range(0, self.queen_count):
            temp_queens[i] = (temp_queens[i] + 1) % (self.queen_count - 1)

            for j in range(queen+1, self.queen_count):
                temp_queens[j] = (temp_queens[j] + 1) % (self.queen_count - 1)

    def __str__(self):
        board_string = ""

        for row, col in enumerate(self.queens):
            board_string += "(%s, %s)\n" % (row, col)

        return board_string

class SimulatedAnnealing:
    def __init__(self, board):
        self.elapsedTime = 0;
        self.board = board
        self.temperature = 4000
        self.sch = 0.99
```

```
        self.startTime = datetime.now()


    def run(self):
        board = self.board
        board_queens = self.board.queens[:]
        solutionFound = False

        for k in range(0, 170000):
            self.temperature *= self.sch
            board.reset()
            successor_queens = board.queens[:]
            dw = Board.calculateCostWithQueens(successor_queens) -
Board.calculateCostWithQueens(board_queens)
            exp = decimal.Decimal(decimal.Decimal(math.e) ** (decimal.Decimal(-dw) *
decimal.Decimal(self.temperature)))

            if dw > 0 or random.uniform(0, 1) < exp:
                board_queens = successor_queens[:]

            if Board.calculateCostWithQueens(board_queens) == 0:
                print("Solution:")
                print(Board.toString(board_queens))
                self.elapsedTime = self.getElapsedTime()
                print("Success, Elapsed Time: %sms" % (str(self.elapsedTime)))
                solutionFound = True
                break

        if solutionFound == False:
            self.elapsedTime = self.getElapsedTime()
            print("Unsuccessful, Elapsed Time: %sms" % (str(self.elapsedTime)))

        return self.elapsedTime

    def getElapsedTime(self):
        endTime = datetime.now()
        elapsedTime = (endTime - self.startTime).microseconds / 1000
        return elapsedTime


if __name__ == '__main__':
    board = Board()
    print("Board:")
    print(board)
```

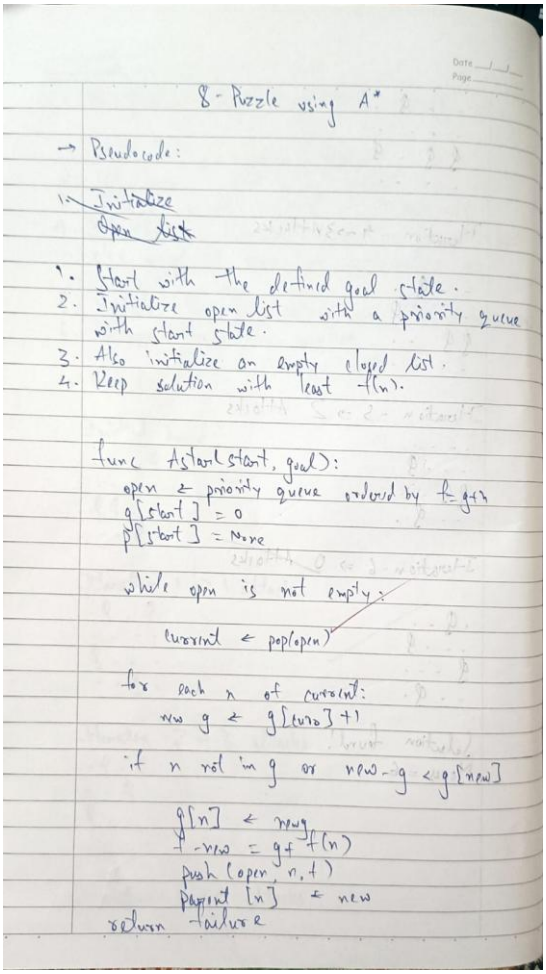
SimulatedAnnealing(board).run()

OUTPUT (Simulated Annealing):

```
Board:
(0, 1)
(1, 0)
(2, 1)
(3, 3)

Solution:
(0, 2)
(1, 0)
(2, 3)
(3, 1)

Success, Elapsed Time: 7.9ms
```

Program 5: A* Algorithm

ALGORITHM :



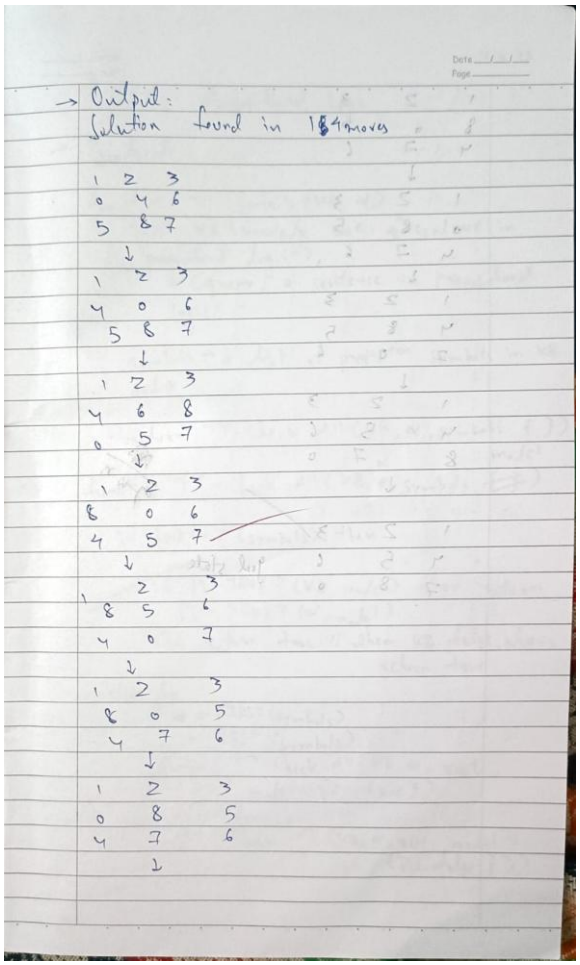
8- Puzzle using A*

→ Pseudocode:

1. Initialize ~~Open list~~

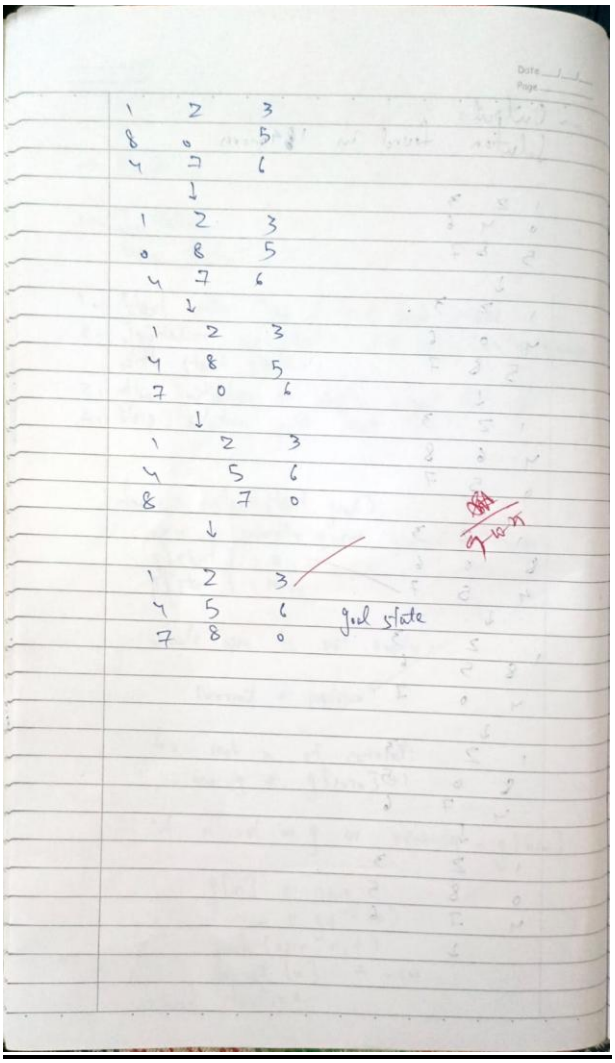
1. Start with the defined goal state.
2. Initialize open list with a priority queue with start state.
3. Also initialize an empty closed list.
4. Keep solution with least f(n).

```
func AStar(start, goal):
    open ← priority queue ordered by f = g+h
    g[start] = 0
    p[start] = None

    while open is not empty:
        current ← pop(open)

        for each n of current:
            new_g ← g[current] + 1

            if n not in g or new_g < g[n]:
                g[n] ← new_g
                f ← new_g + h(n)
                push(open, n, f)
                parent[n] ← new
    return failure
```



→ Output:
Solution found in 18 moves

```
1 2 3
0 4 6
5 8 7
  ↓
1 2 3
4 0 6
5 8 7
  ↓
1 2 3
4 6 8
0 5 7
  ↓
1 2 3
8 0 6
4 5 7
  ↓
1 2 3
8 5 6
4 0 7
  ↓
1 2 3
8 0 5
4 7 6
  ↓
1 2 3
0 8 5
4 7 6
  ↓
```



CODE :

```
import heapq

class PuzzleState:
    def __init__(self, board, parent=None, move="", depth=0, cost=0):
        self.board = board
        self.parent = parent
        self.move = move
        self.depth = depth
        self.cost = cost

    def __lt__(self, other):
        return self.cost < other.cost

    def blank_pos(self):
        return self.board.index(0)
```

```
    def expand(self):
        b = self.blank_pos()
        row, col = divmod(b, 3)
        dirs = {
            "Up": (row - 1, col),
            "Down": (row + 1, col),
            "Left": (row, col - 1),
            "Right": (row, col + 1)
        }
        nxt = []
        for mv, (r, c) in dirs.items():
            if 0 <= r < 3 and 0 <= c < 3:
                idx = r * 3 + c
                nb = self.board[:]
                nb[b], nb[idx] = nb[idx], nb[b]
                nxt.append(PuzzleState(nb, self, mv, self.depth + 1))
        return nxt

    def build_path(self):
        p, node = [], self
        while node:
            p.append((node.move, node.board, node.depth))
            node = node.parent
        return list(reversed(p))

def misplaced_tiles(state, goal):
    return sum(1 for i in range(9) if state.board[i] not in (0, goal[i]))

def manhattan_distance(state, goal):
    d = 0
    for i, v in enumerate(state.board):
        if v != 0:
            r1, c1 = divmod(i, 3)
            r2, c2 = divmod(goal.index(v), 3)
            d += abs(r1 - r2) + abs(c1 - c2)
    return d

def a_star(start, goal, h):
    opened = []
    closed = set()
    nodes = 0
    s = PuzzleState(start)
    s.cost = h(s, goal)
```

```
    heapq.heappush(opened, s)

    while opened:
        cur = heapq.heappop(opened)
        nodes += 1

        if cur.board == goal:
            return cur.build_path(), nodes

        closed.add(tuple(cur.board))

        for nxt in cur.expand():
            if tuple(nxt.board) in closed:
                continue
            nxt.cost = nxt.depth + h(nxt, goal)
            heapq.heappush(opened, nxt)

    return None, nodes

def print_solution(path, total_nodes):
    print("Steps:\n")
    for mv, st, d in path:
        label = "Start" if mv == "" else f"Move {mv}"
        print(f"{label} | Depth {d}")
        for i in range(0, 9, 3):
            print(" ".join(str(x) if x != 0 else " " for x in st[i:i+3]))
        print()
    print(f"Total Moves: {len(path)-1}")
    print(f"Nodes Expanded: {total_nodes}")

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

    goal = [1, 2, 3,
            4, 5, 6,
            7, 8, 0]

    print("A* (Misplaced Tiles)\n")
    sol1, n1 = a_star(start, goal, misplaced_tiles)
    if sol1:
        print_solution(sol1, n1)
    else:
```

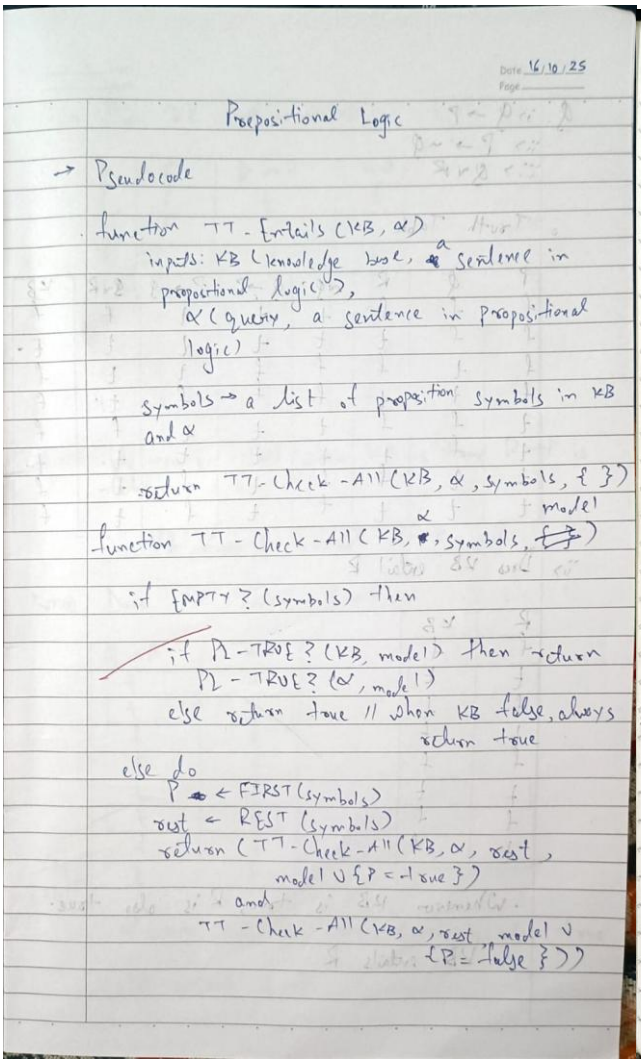
```
    print("No solution.")

print("\nA* (Manhattan Distance)\n")
sol2, n2 = a_star(start, goal, manhattan_distance)
if sol2:
    print_solution(sol2, n2)
else:
    print("No solution.")
```

OUTPUT :

```
A* (Misplaced Tiles)

Steps:

Start | Depth 0
1 2 3
4   6
7 5 8

Move Down | Depth 1
1 2 3
4 5 6
7   8

Move Right | Depth 2
1 2 3
4 5 6
7 8

Total Moves: 2
Nodes Expanded: 3

A* (Manhattan Distance)

Steps:

Start | Depth 0
1 2 3
4   6
7 5 8

Move Down | Depth 1
1 2 3
4 5 6
7   8

Move Right | Depth 2
1 2 3
4 5 6
7 8

Total Moves: 2
Nodes Expanded: 3
```

Program 6: Propositional Logic

ALGORITHM :



Propositional Logic

→ Pseudocode

function TT-Entails(KB, α)
inputs: KB (knowledge base, a sentence in propositional logic),
α (query, a sentence in propositional logic)

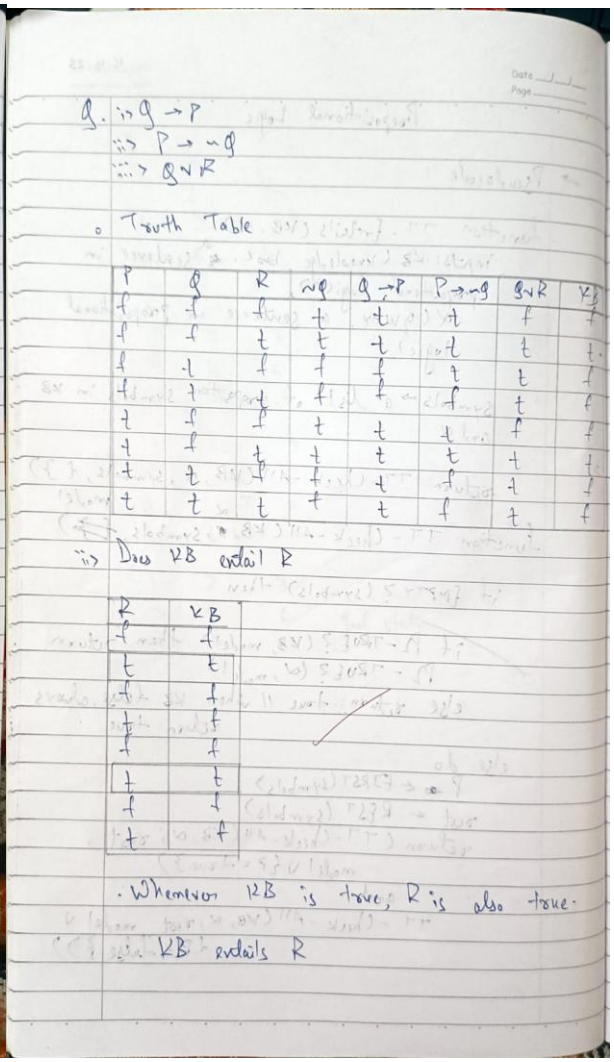
symbols → a list of proposition symbols in KB and α

return TT-Check-All(KB, α, symbols, { })

function TT-Check-All(KB, α, symbols, model)

if EMPTY?(symbols) then
if PL-TRUE?(KB, model) then return PL-TRUE?(α, model)
else return true // when KB false, always return true

else do
P ← FIRST(symbols)
rest ← REST(symbols)
return (TT-Check-All(KB, α, rest, model ∪ {P = true})
and
TT-Check-All(KB, α, rest, model ∪ {P = false}))



Q. i) Q → P
ii) P → ¬Q
iii) Q ∨ R

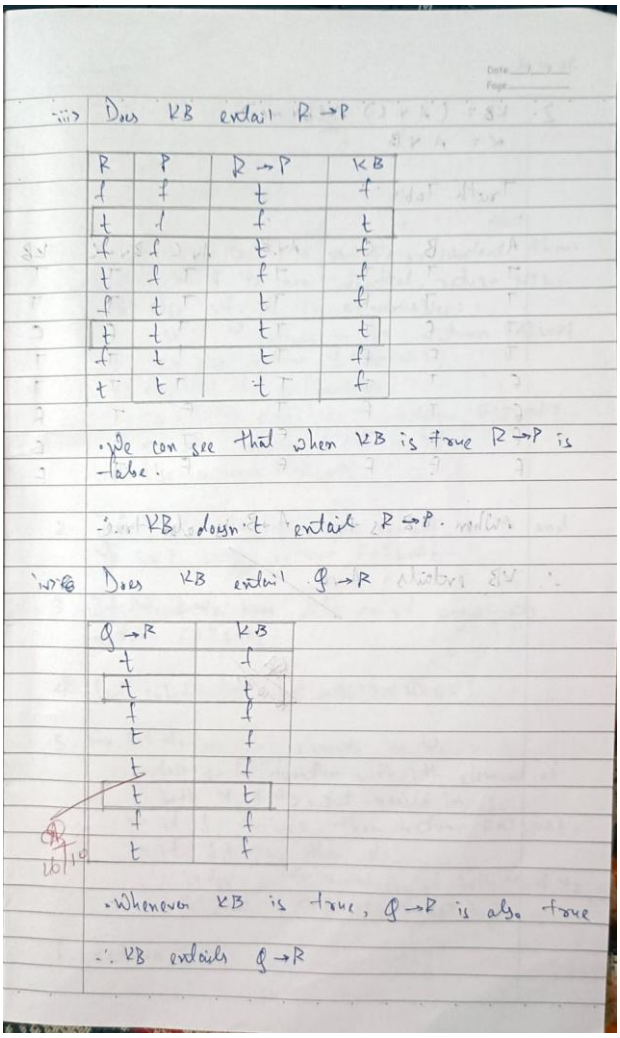
Truth Table

P	Q	R	¬Q	Q→P	P→¬Q	Q∨R	KB
f	f	f	t	t	t	f	f
f	f	t	t	t	t	t	t
f	t	f	f	t	t	t	f
f	t	t	f	f	t	t	f
t	f	f	t	t	t	f	f
t	f	t	t	t	t	t	t
t	t	f	f	t	f	t	f
t	t	t	f	t	f	t	f

ii) Does KB entail R

R	KB
f	f
t	t
f	f
f	f
f	f
t	t
f	f
t	f

. Whenever KB is true, R is also true.
∴ KB entails R



Does KB entail R → P

R	P	R → P	KB
f	f	t	f
t	f	f	t
f	f	t	f
t	f	f	f
f	t	t	f
t	t	t	t
f	t	t	f
t	t	t	f

- We can see that when KB is true R → P is false.
- ∴ KB doesn't entail R → P.

Does KB entail Q → R

Q → R	KB
t	f
t	t
f	f
t	f
t	f
t	t
f	f
t	f

- Whenever KB is true, Q → R is also true
- ∴ KB entails Q → R

CODE :

```
import itertools

# Logical operations
def implies(a, b):
    return not a or b

def or_operator(a, b):
    return a or b

def not_operator(a):
    return not a

# Constructing the truth table
def construct_truth_table():
    truth_values = [True, False]
```

```
    truth_table = []

    # Generate all combinations for Q, P, R
    for values in itertools.product(truth_values, repeat=3):
        Q, P, R = values

        # Evaluate KB sentences
        q_implies_p = implies(Q, P)
        p_implies_not_q = implies(P, not_operator(Q))
        q_or_r = or_operator(Q, R)

        # KB = (Q → P) ∧ (P → ¬Q) ∧ (Q ∨ R)
        kb_is_true = q_implies_p and p_implies_not_q and q_or_r

        # Entailment expressions
        entail_r = R
        entail_r_implies_p = implies(R, P)
        entail_q_implies_r = implies(Q, R)

        # Add row to truth table
        truth_table.append((
            Q, P, R,
            q_implies_p, p_implies_not_q, q_or_r,
            kb_is_true,
            entail_r, entail_r_implies_p, entail_q_implies_r
        ))
    return truth_table

# Print the truth table nicely
def print_truth_table(truth_table):
    header = [
        "Q", "P", "R",
        "Q → P", "P → ¬Q", "Q ∨ R",
        "KB (all true)",
        "R", "R → P", "Q → R"
    ]
    print(" | ".join(header))
    print("-" * 85)

    for row in truth_table:
        # Format True/False as T/F for compactness
        formatted_row = [("T" if val else "F") for val in row]
        print(" | ".join(formatted_row))
```

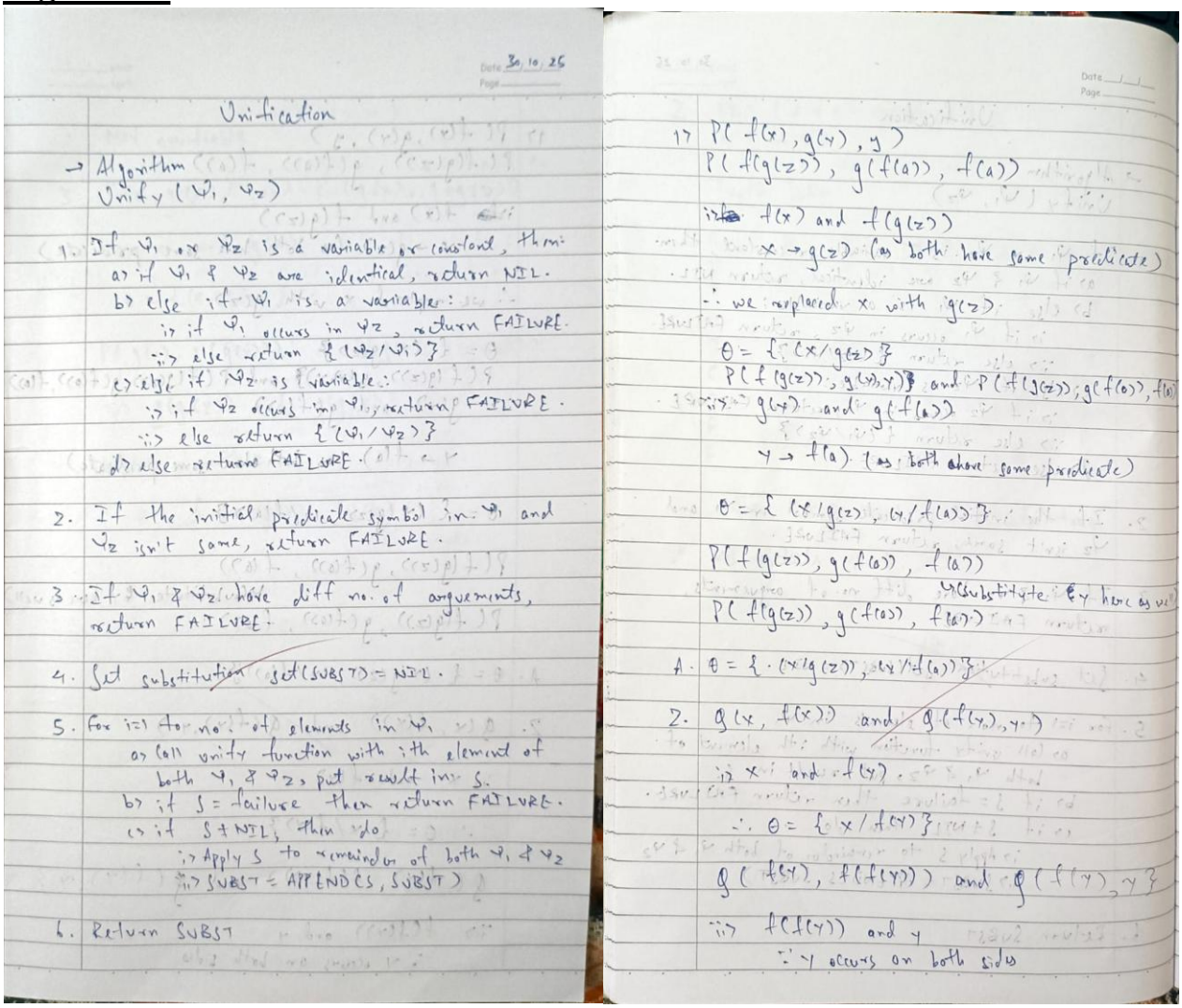
```
# Generate and print truth table
truth_table = construct_truth_table()
print_truth_table(truth_table)

# Additionally, check entailment by verifying if for all models where KB is true, entailment is
true

def check_entailment(truth_table, entailment_index):
    for row in truth_table:
        kb_true = row[6]
        entailment_val = row[entailment_index]
        if kb_true and not entailment_val:
            return False
    return True

print("\nEntailment Results:")
print(f"Does KB entail R? {check_entailment(truth_table, 7)}")
print(f"Does KB entail R → P? {check_entailment(truth_table, 8)}")
print(f"Does KB entail Q → R? {check_entailment(truth_table, 9)}")
```

OUTPUT :

```
Q | P | R | Q → P | P → ¬Q | Q v R | KB (all true) | R | R → P | Q → R
-------------------------------------------------------------------------------------
T | T | T | T | F | T | F | T | T | T
T | T | F | T | F | T | F | F | T | F
T | F | T | F | T | T | F | T | F | T
T | F | F | F | T | T | F | F | T | F
F | T | T | T | T | T | T | T | T | T
F | T | F | T | T | F | F | F | T | T
F | F | T | T | T | T | T | T | F | T
F | F | F | T | T | F | F | F | T | T

Entailment Results:
Does KB entail R? True
Does KB entail R → P? False
Does KB entail Q → R? True
```

Program 7: Unification

Algorithm:



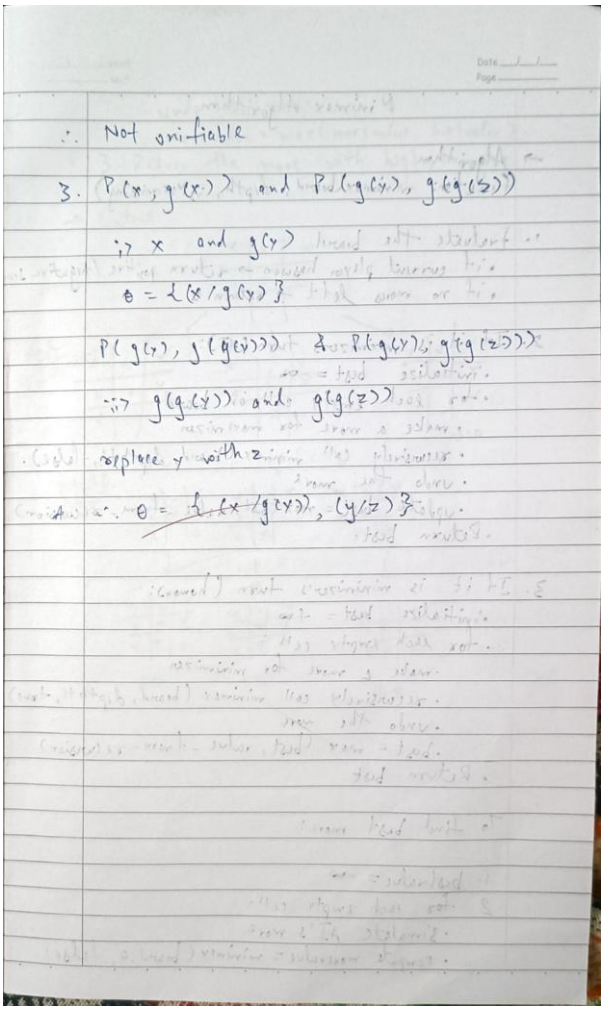
Unification

→ Algorithm
Unify (Ψ_1, Ψ_2)

1. If Ψ_1 or Ψ_2 is a variable or constant, then:
   a) if Ψ_1 & Ψ_2 are identical, return NIL.
   b) else if Ψ_1 is a variable:
      i) if Ψ_1 occurs in Ψ_2, return FAILURE.
      ii) else return $\{(\Psi_2 / \Psi_1)\}$
   c) else if Ψ_2 is variable:
      i) if Ψ_2 occurs in Ψ_1, return FAILURE.
      ii) else return $\{(\Psi_1 / \Psi_2)\}$
   d) else return FAILURE.
2. If the initial predicate symbol in Ψ_1 and Ψ_2 isn't same, return FAILURE.
3. If Ψ_1 & Ψ_2 have diff no. of arguements, return FAILURE.
4. Set substitution set(SUBST) = NIL.
5. For i=1 to no. of elements in Ψ_1
   a) call unify function with ith element of both Ψ_1 & Ψ_2, put result in S.
   b) if S = failure then return FAILURE.
   c) if S ≠ NIL, then do
      i) Apply S to remainder of both Ψ_1 & Ψ_2
      ii) SUBST = APPEND(S, SUBST)
6. Return SUBST

1) $P(f(x), g(y), y)$
$P(f(g(z)), g(f(a)), f(a))$

i) $f(x)$ and $f(g(z))$
$x \rightarrow g(z)$ (as both have same predicate)
∴ we replaced x with $g(z)$
$\theta = \{(x / g(z))\}$
$P(f(g(z)), g(y), y)$ and $P(f(g(z)), g(f(a)), f(a))$
ii) $g(y)$ and $g(f(a))$
$y \rightarrow f(a)$ (as both above same predicate)
$\theta = \{(x / g(z)), (y / f(a))\}$
$P(f(g(z)), g(f(a)), f(a))$
Substitute $f(a)$ for y here as well
$P(f(g(z)), g(f(a)), f(a))$
4. $\theta = \{(x / g(z)), (y / f(a))\}$
2. $g(x, f(x))$ and $g(f(y), y)$
i) x and $f(y)$.
∴ $\theta = \{x / f(y)\}$
$g(f(y), f(f(y)))$ and $g(f(y), y)$
ii) $f(f(y))$ and y
∴ y occurs on both sides



CODE :

```
class Variable:
    def __init__(self, name):
        self.name = name

    def __eq__(self, other):
        return isinstance(other, Variable) and self.name == other.name

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

    def __repr__(self):
        return self.name

class Constant:
    def __init__(self, value):
        self.value = value
```

```
    def __eq__(self, other):
        return isinstance(other, Constant) and self.value == other.value

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

    def __repr__(self):
        return str(self.value)

class Function:
    def __init__(self, name, args):
        self.name = name
        self.args = args

    def __eq__(self, other):
        return (isinstance(other, Function) and
                self.name == other.name and
                len(self.args) == len(other.args) and
                all(a == b for a, b in zip(self.args, other.args)))

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

    def __repr__(self):
        return f"{self.name}({', '.join(map(str, self.args))})"

def unify(term1, term2, substitution=None):
    """
    Unifies two first-order logic terms and returns the MGU (substitution)
    or None if unification is not possible.
    """
    if substitution is None:
        substitution = {}

    # Apply existing substitutions
    term1 = substitute(term1, substitution)
    term2 = substitute(term2, substitution)

    if term1 == term2:
        return substitution
    elif isinstance(term1, Variable):
        return unify_var(term1, term2, substitution)
    elif isinstance(term2, Variable):
```

```
        return unify_var(term2, term1, substitution)
    elif isinstance(term1, Function) and isinstance(term2, Function):
        if term1.name != term2.name or len(term1.args) != len(term2.args):
            return None  # Function symbols or arity don't match
        for arg1, arg2 in zip(term1.args, term2.args):
            substitution = unify(arg1, arg2, substitution)
            if substitution is None:
                return None  # Sub-unification failed
        return substitution
    else:
        return None  # Cannot unify different types (e.g., Constant and Function)

def unify_var(var, x, substitution):
    """Handles unification when one of the terms is a variable."""
    if var in substitution:
        return unify(substitution[var], x, substitution)
    elif x in substitution:
        return unify(var, substitution[x], substitution)
    elif occurs_check(var, x, substitution):
        return None  # Occurs check fails
    else:
        substitution[var] = x
        return substitution

def occurs_check(var, term, substitution):
    """Checks if a variable occurs within a term, preventing infinite substitutions."""
    term = substitute(term, substitution)  # Apply current substitutions
    if var == term:
        return True
    elif isinstance(term, Function):
        return any(occurs_check(var, arg, substitution) for arg in term.args)
    return False

def substitute(term, substitution):
    """Applies a given substitution to a term."""
    if isinstance(term, Variable):
        return substitution.get(term, term)
    elif isinstance(term, Function):
        return Function(term.name, [substitute(arg, substitution) for arg in term.args])
    return term

# Example Usage:
if __name__ == "__main__":
    # Define terms
```

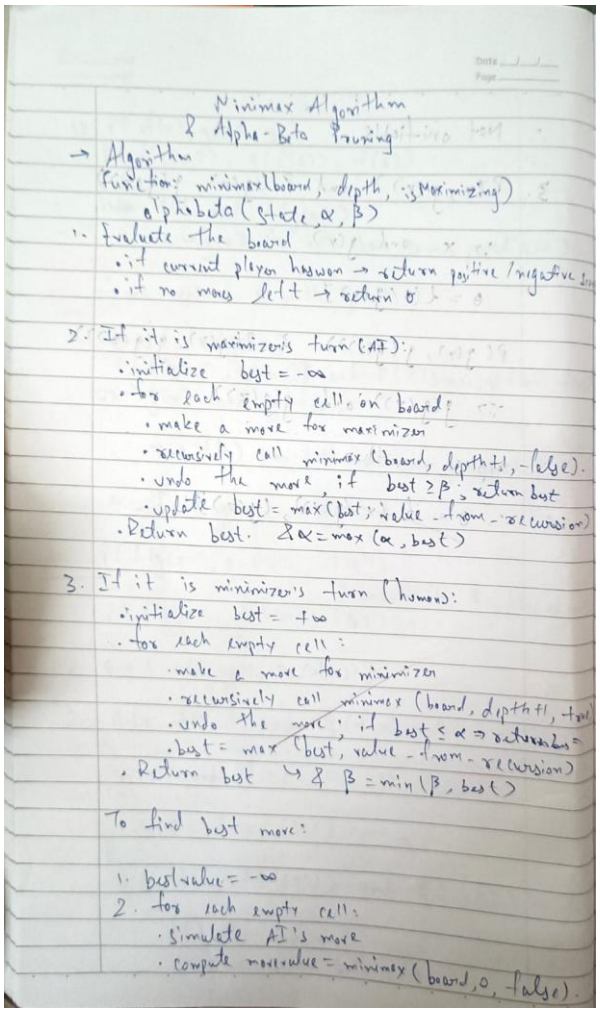
```
    x, y, z = Variable('x'), Variable('y'), Variable('z')
    a, b = Constant('a'), Constant('b')
    f = Function('f', [x, Constant('b')])
    g = Function('g', [Constant('a'), y])
    h = Function('h', [z])

    print(f"Unify(f(x, b), f(a, y)): {unify(Function('f', [x, b]), Function('f', [a, y]))}")
    print(f"Unify(g(a, y), g(a, b)): {unify(Function('g', [a, y]), Function('g', [a, b]))}")
    print(f"Unify(x, f(x, b)): {unify(x, Function('f', [x, b]))}") # Occurs check failure
    print(f"Unify(f(x, y), f(a, g(z))): {unify(Function('f', [x, y]), Function('f', [a, Function('g',
[z])]))}")
    print(f"Unify(P(x, A), P(B, y)): {unify(Function('P', [x, Constant('A')]), Function('P',
[Constant('B'), y]))}")

    print("\n--- Your Requested Tests ---")

    # 1. p(f(x), g(y), y) and p(f(g(z)), g(f(a)), f(a))
    term1_1 = Function('p', [Function('f', [x]), Function('g', [y]), y])
    term1_2 = Function('p', [Function('f', [Function('g', [z])]), Function('g', [Function('f', [a])]),
Function('f', [a])])
    print(f"Unify(p(f(x), g(y), y), p(f(g(z)), g(f(a)), f(a))): {unify(term1_1, term1_2)}")

    # 2. q(x, f(x)) and q(f(y), y)
    term2_1 = Function('q', [x, Function('f', [x])])
    term2_2 = Function('q', [Function('f', [y]), y])
    print(f"Unify(q(x, f(x)), q(f(y), y)): {unify(term2_1, term2_2)}")

    # 3. p(x, g(x)) and p(g(y), g(g(z)))
    term3_1 = Function('p', [x, Function('g', [x])])
    term3_2 = Function('p', [Function('g', [y]), Function('g', [Function('g', [z])])])
    print(f"Unify(p(x, g(x)), p(g(y), g(g(z)))): {unify(term3_1, term3_2)}")
```

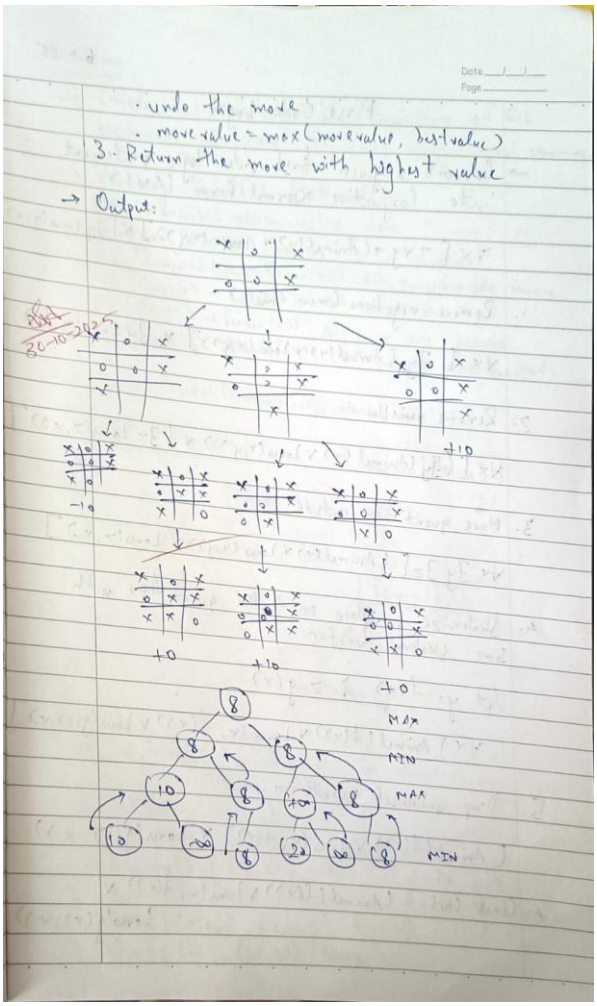
OUTPUT :

```
Unify(f(x, b), f(a, y)): {x: a, y: b}
Unify(g(a, y), g(a, b)): {y: b}
Unify(x, f(x, b)): None
Unify(f(x, y), f(a, g(z))): {x: a, y: g(z)}
Unify(P(x, A), P(B, y)): {x: B, y: A}

--- Your Requested Tests ---
Unify(p(f(x), g(y), y), p(f(g(z)), g(f(a)), f(a))): {x: g(z), y: f(a)}
Unify(q(x, f(x)), q(f(y), y)): None
Unify(p(x, g(x)), p(g(y), g(g(z)))): {x: g(y), y: z}
```

Program 8: MinMax & AlphaBeta

ALGORITHM :





CODE :

```
def alpha_beta(node, depth, alpha, beta, maximizing_player, path):
    # Base case: if node is a leaf (integer), return its value and path
    if isinstance(node, int):
        return node, path

    if maximizing_player:
        value = float('-inf')
        best_path = None
```

```
        for i, child in enumerate(node):
            child_value, child_path = alpha_beta(
                child, depth + 1, alpha, beta, False, path + [i]
            )

            if child_value > value:
                value = child_value
                best_path = child_path

            # Artifact '62' removed here
            alpha = max(alpha, value)

            if alpha >= beta:
                print(f"  [PRUNE] MAX (Depth {depth}): Alpha ({alpha}) >= Beta ({beta})")
                break

        return value, best_path

    else:
        value = float('inf')
        best_path = None

        for i, child in enumerate(node):
            child_value, child_path = alpha_beta(
                child, depth + 1, alpha, beta, True, path + [i]
            )

            if child_value < value:
                value = child_value
                best_path = child_path

            beta = min(beta, value)

            if beta <= alpha:
                print(f"  [PRUNE] MIN (Depth {depth}): Beta ({beta}) <= Alpha ({alpha})")
                break

        return value, best_path

if __name__ == "__main__":
    # Tree structure with artifact '63' removed
    tree = [
        [
            [
```

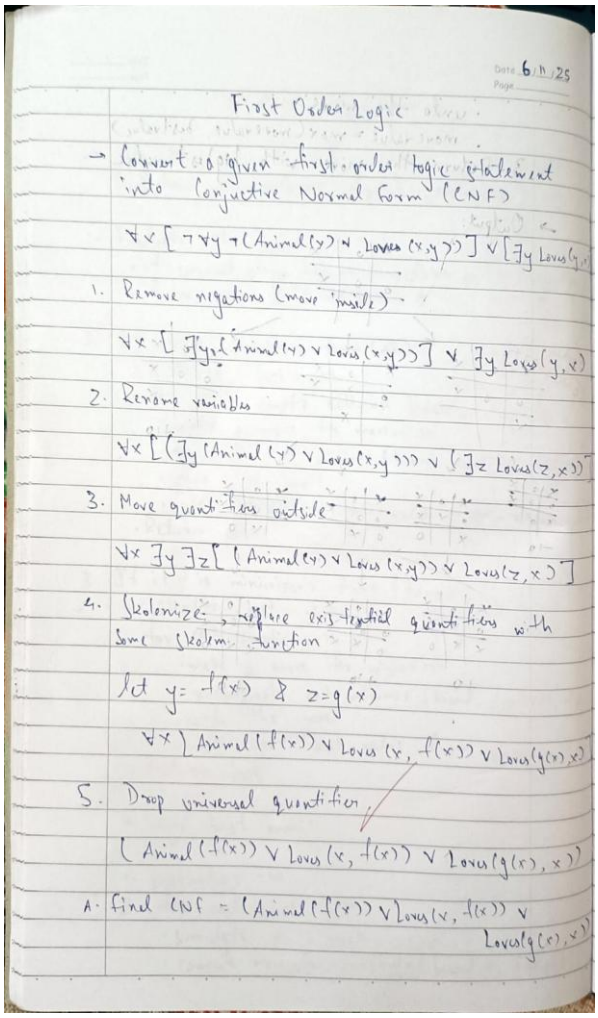
```
            [10, 11],
            [9, 12]
        ],
        [
            [14, 15],
            [13, 14]
        ],
    ],
    [
        [
            [5, 2],
            [4, 1]
        ],
        [
            [3, 22],
            [20, 21]
        ],
    ]
]

print("Starting Alpha-Beta Pruning...\n" + "-"*30)

value, best_path = alpha_beta(tree, 0, float('-inf'), float('inf'), True, [])

print("-" * 30)
print(f"FINAL MINIMAX VALUE AT ROOT: {value}")
print(f"BEST PATH INDICES: {best_path}")
```

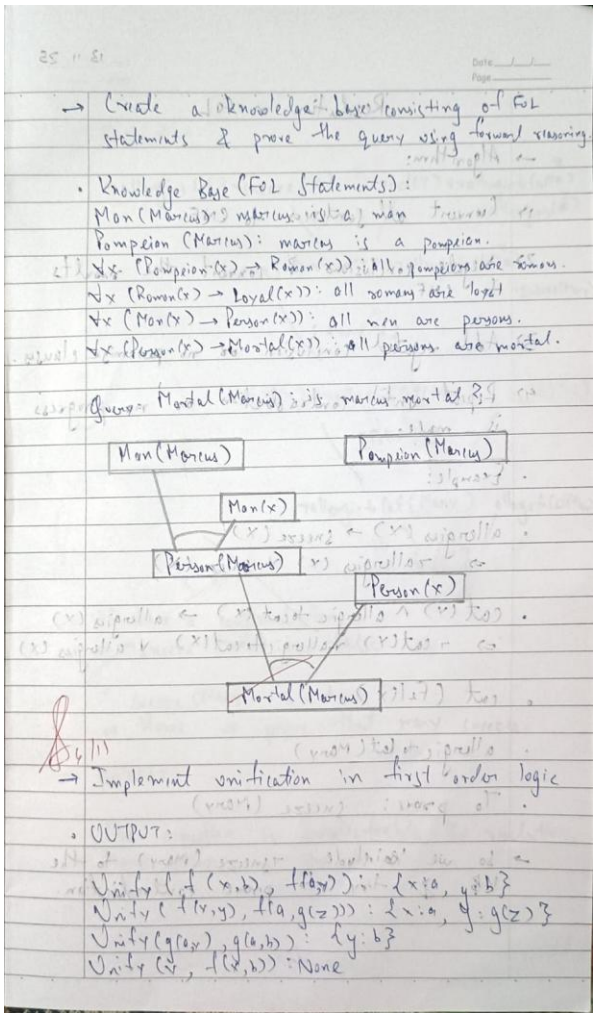
OUTPUT :

```
Starting Alpha-Beta Pruning...
------------------------------
  [PRUNE] MIN (Depth 3): Beta (9) <= Alpha (10)
  [PRUNE] MAX (Depth 2): Alpha (14) >= Beta (10)
  [PRUNE] MIN (Depth 3): Beta (5) <= Alpha (10)
  [PRUNE] MIN (Depth 3): Beta (4) <= Alpha (10)
  [PRUNE] MIN (Depth 1): Beta (5) <= Alpha (10)
------------------------------
FINAL MINIMAX VALUE AT ROOT: 10
BEST PATH INDICES: [0, 0, 0, 0]
```

Program 9: Forward Chaining & Conversion to CNF

ALGORITHM :





CODE (Forward Chaining) :

```
import re

def isVariable(x):
    return len(x) == 1 and x.islower() and x.isalpha()

def getAttributes(string):
    expr = r'\([^)]+\)'
    matches = re.findall(expr, string)
    return matches

def getPredicates(string):
```

```
    expr = r'([a-zA-Z~]+)\([^&|]+\)'
    return re.findall(expr, string)

class Fact:
    def __init__(self, expression):
        self.expression = expression.strip()
        predicate, params = self.splitExpression(expression)
        self.predicate = predicate
        self.params = params

    def splitExpression(self, expression):
        predicate = getPredicates(expression)[0]
        params = getAttributes(expression)[0].strip('()').split(',')
        return [predicate, [p.strip() for p in params]]

    def substitute(self, var_map):
        params = [var_map.get(p, p) for p in self.params]
        return Fact(f"{self.predicate}({','.join(params)})")

    def __repr__(self):
        return self.expression

class Implication:
    def __init__(self, expression):
        self.expression = expression.strip()
        lhs, rhs = expression.split('=>')
        self.lhs = [Fact(f.strip()) for f in lhs.split('&')]
        self.rhs = Fact(rhs.strip())

    def infer(self, known_facts):
        substitutions = {}

        for fact in self.lhs:
            matched = False
            for known in known_facts:
                if known.predicate == fact.predicate:
                    mapping = {}
                    for i, param in enumerate(fact.params):
                        if isVariable(param):
                            mapping[param] = known.params[i]
                        elif param != known.params[i]:
                            break
                    else:
                        substitutions.update(mapping)
```

```
                    matched = True
                    break
            if not matched:
                return None

        return self.rhs.substitute(substitutions)

class KB:
    def __init__(self):
        self.facts = set()
        self.implications = set()

    def tell(self, expr):
        if '=>' in expr:
            self.implications.add(Implication(expr))
        else:
            self.facts.add(Fact(expr))

    def infer_all(self):
        added = True
        while added:
            added = False
            for rule in self.implications:
                new_fact = rule.infer(self.facts)
                if new_fact and new_fact.expression not in [f.expression for f in self.facts]:
                    print(f"Derived: {new_fact.expression}")
                    self.facts.add(new_fact)
                    added = True

    def ask(self, query):
        print(f"\nQuerying {query}:")
        self.infer_all()
        facts = [f.expression for f in self.facts]
        if query in facts:
            print(f"Yes, {query.split('(')[1].strip(')')} is {query.split('(')[0]}.")
        else:
            print(f"No, cannot infer {query}.")

    def display(self):
        print("\nAll facts in Knowledge Base:")
        for i, f in enumerate(sorted([f.expression for f in self.facts])):
            print(f"\t{i+1}. {f}")

def main():
```

```
    kb = KB()
    n = int(input("Enter number of FOL expressions: "))
    print("Enter expressions:")
    for _ in range(n):
        kb.tell(input().strip())

    query = input("Enter query: ").strip()
    kb.ask(query)
    kb.display()

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

OUTPUT (Forward Chaining) :

```
Enter number of FOL expressions: 6
Enter expressions:
Man(Marcus)
Pompeian(Marcus)
Pompeian(x) => Roman(x)
Roman(x) => Loyal(x)
Man(x) => Person(x)
Person(x) => Mortal(x)
Enter query: Mortal(Marcus)

Querying Mortal(Marcus):
Derived: Person(Marcus)
Derived: Roman(Marcus)
Derived: Mortal(Marcus)
Derived: Loyal(Marcus)
Yes, Marcus is Mortal.

All facts in Knowledge Base:
    1. Loyal(Marcus)
    2. Man(Marcus)
    3. Mortal(Marcus)
    4. Person(Marcus)
    5. Pompeian(Marcus)
    6. Roman(Marcus)
```

CODE (CNF) :

```
import re
def getAttributes(string):
    expr = r'\([^)]+\)'
    matches = re.findall(expr, string)
    return [m for m in str(matches) if m.isalpha()]


def getPredicates(string):
```

```
    expr = r'[A-Za-z~]+\([A-Za-z,]+\)'
    return re.findall(expr, string)

def DeMorgan(sentence):
    string = ''.join(list(sentence).copy())
    string = string.replace('~~', '')
    flag = '[' in string
    string = string.replace('~[', '')
    string = string.strip(']')

    for predicate in getPredicates(string):
        string = string.replace(predicate, f'~{predicate}')

    s = list(string)
    for i, c in enumerate(s):
        if c == 'V':
            s[i] = '^'
        elif c == '^':
            s[i] = 'V'

    string = ''.join(s)
    string = string.replace('~~', '')
    return f'[{string}]' if flag else string

def Skolemization(sentence):
    SKOLEM_CONSTANTS = [f'{chr(c)}' for c in range(ord('A'), ord('Z')+1)]
    statement = ''.join(list(sentence).copy())
    matches = re.findall('[∀∃].', statement)

    for match in matches[::-1]:
        statement = statement.replace(match, '')
```

```
    statements = re.findall(r'\[\[^]]+\]\]', statement)
    for s in statements:
        statement = statement.replace(s, s[1:-1])

    for predicate in getPredicates(statement):
        attributes = getAttributes(predicate)
        if ''.join(attributes).islower():
            statement = statement.replace(predicate, predicate)
        else:
            aL = [a for a in attributes if a.islower()]
            aU = [a for a in attributes if not a.islower()][0] if attributes else ''
            if aU:
                statement = statement.replace(aU, f'{SKOLEM_CONSTANTS.pop(0)}({aL[0] if
len(aL) else match[1]})')
    return statement

def clean_output(expr):
    # Remove multiple brackets and redundant negations
    expr = expr.replace('~~', '')
    while '[[' in expr or ']]' in expr:
        expr = expr.replace('[[', '[').replace(']]', ']')

    expr = expr.strip('[] ')

    # Remove redundant outer brackets like [(p | q)] -> p | q
    if expr.startswith('(') and expr.endswith(')'):
        expr = expr[1:-1]

    # Replace internal redundant patterns
    expr = re.sub(r'\s+', ' ', expr)
    return expr
```

```
def fol_to_cnf(fol):
    statement = fol.replace("<=>", "_")
    while '_' in statement:
        i = statement.index('_')
        new_statement = '[' + statement[:i] + '=>' + statement[i+1:] + ']^[' + statement[i+1:] + '=>' +
statement[:i] + ']'
        statement = new_statement

    statement = statement.replace("=>", "-")

    expr = r'\[([^]]+)\]'
    statements = re.findall(expr, statement)
    for i, s in enumerate(statements):
        if '[' in s and ']' not in s:
            statements[i] += ']'
    for s in statements:
        statement = statement.replace(s, fol_to_cnf(s))

    while '-' in statement:
        i = statement.index('-')
        br = statement.index('[') if '[' in statement else 0
        new_statement = '~' + statement[br:i] + 'V' + statement[i+1:]
        statement = statement[:br] + new_statement if br > 0 else new_statement

    while '~∀' in statement:
        i = statement.index('~∀')
        statement = list(statement)
        statement[i], statement[i+1], statement[i+2] = '∃',
statement[i+2], '~'
        statement = ''.join(statement)
```

```
    while '~∃' in statement:
        i = statement.index('~∃')
        s = list(statement)
        s[i], s[i+1], s[i+2] = '∀', s[i+2], '~'
        statement = ''.join(s)

    statement = statement.replace('~[∀', '[~∀')
    statement = statement.replace('~[∃', '[~∃')

    expr = r'(~[∀V∃].)'
    statements = re.findall(expr, statement)
    for s in statements:
        statement = statement.replace(s, fol_to_cnf(s))

    expr = r'~\[[^]]+\]'
    statements = re.findall(expr, statement)
    for s in statements:
        statement = statement.replace(s, DeMorgan(s))

    return statement

def main():
    print("\n" + "="*50)
    print("   FOL to CNF Converter (Simplified Output)")
    print("="*50)
    print("Supports: ∀, ∃, ~, &, |, >>, <=>, brackets [] () {}")
    print("NOTE: Use 'V' for OR inside the formula if needed.")
    print("-" * 50)
    fol = input("Enter FOL formula: ").strip()
        print("-" * 50)
```

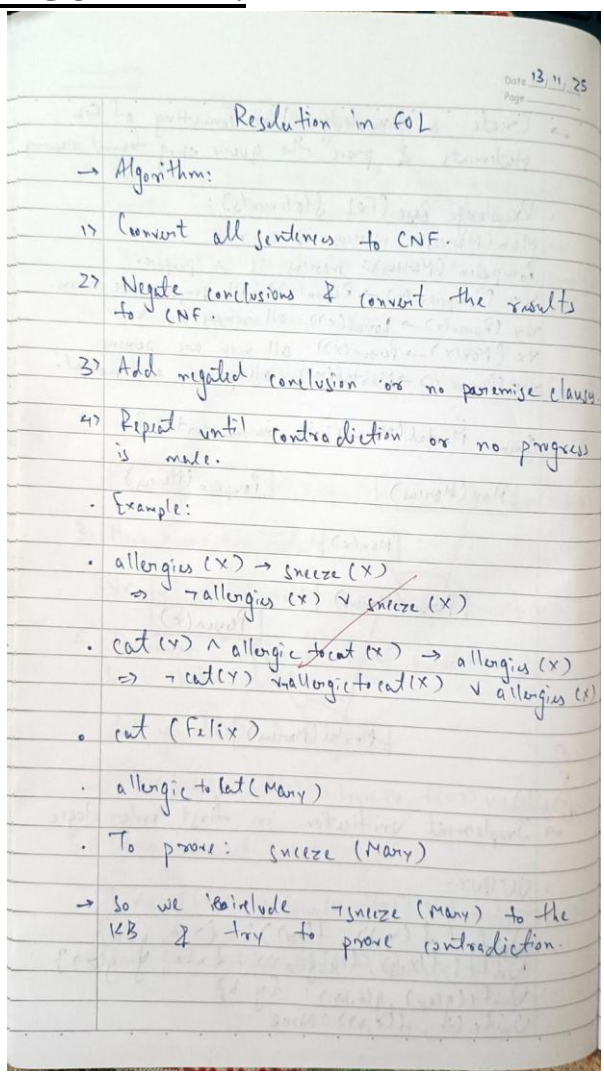
```
    try:
        raw_cnf = fol_to_cnf(fol)
        result = Skolemization(raw_cnf)
        cleaned = clean_output(result)
        print(f"Original:   {fol}")
        print(f"CNF Form:   {cleaned}")
    except Exception as e:
        print("\nError: Could not parse the formula.")
        print("Details:", e)
    print("="*50 + "\n")
if __name__ == "__main__":
    main()
```

OUTPUT (CNF);

```
==================================================
   FOL to CNF Converter (Simplified Output)
==================================================
Supports: ∀, ∃, ~, &, |, >>, <=>, brackets [] () {}
NOTE: Use 'V' for OR inside the formula if needed.
--------------------------------------------------
Enter FOL formula: ∀x[~∀y~(Animal(y)VLoves(x,y))]V[∃y Loves(y,x)]
--------------------------------------------------
Original:   ∀x[~∀y~(Animal(y)VLoves(x,y))]V[∃y Loves(y,x)]
CNF Form:   Animal(y)VLoves(x,y))]V[ Loves(y,x
==================================================
```

Program 10: Resolution

ALGORITHM :



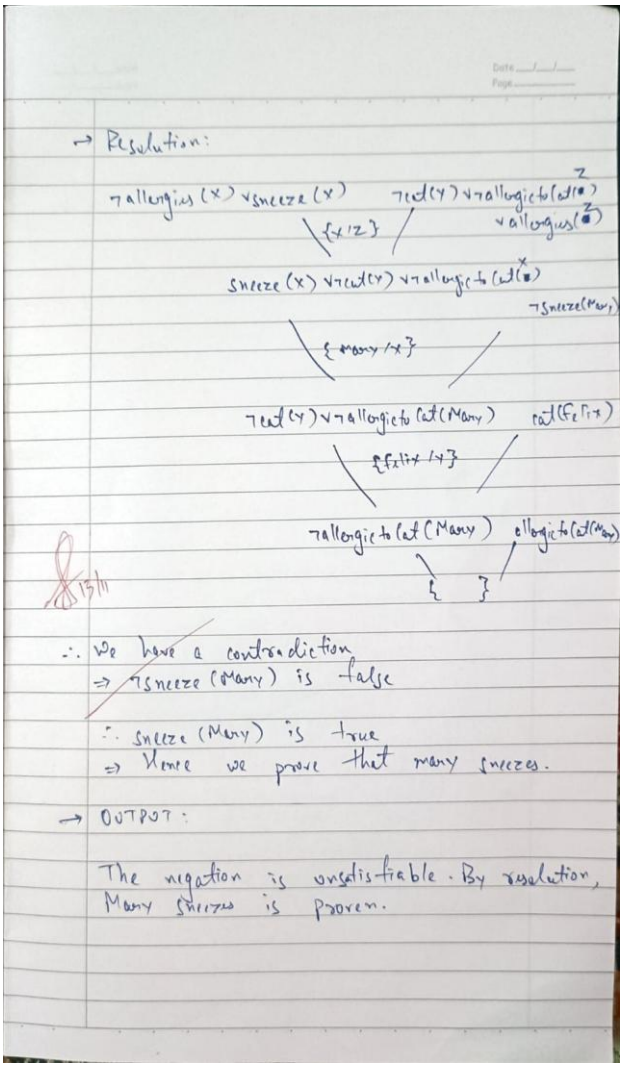
Resolution in FOL

→ Algorithm:

1) Convert all sentences to CNF.
2) Negate conclusions & convert the results to CNF.
3) Add negated conclusion or no parenmise clause.
4) Repeat until contradiction or no progress is made.

- Example:
- allergies (x) → sneeze (x)
  ⇒ ¬allergies (x) ∨ sneeze (x)
- cat (y) ∧ allergic to cat (x) → allergies (x)
  ⇒ ¬cat(y) ∨ allergic to cat(x) ∨ allergies (x)
- cat (Felix)
- allergic to cat (Mary)
- To prove: sneeze (Mary)

→ So we include ¬sneeze (Mary) to the KB & try to prove contradiction.



→ Resolution:

¬allergies (x) ∨ sneeze (x) ¬cat(y) ∨ ¬allergic to (cat(z)) ∨ allergies(z)

{x/z}

sneeze (x) ∨ ¬cat(y) ∨ ¬allergic to (cat(x)) ¬sneeze(Mary)

{mary/x}

¬cat(y) ∨ ¬allergic to cat(Mary) cat(Felix)

{Felix/y}

¬allergic to cat (Mary) allergic to (cat(Mary))

{ }

∴ We have a contradiction
⇒ ¬sneeze (Mary) is false

∴ sneeze (Mary) is true
⇒ Hence we prove that mary sneezes.

→ OUTPUT:

The negation is unsatisfiable. By resolution, Mary sneezes is proven.

CODE :

```
from sympy import symbols
from sympy.logic.boolalg import Implies, And, Or, Not, to_cnf
from sympy.logic.inference import satisfiable

# Define symbols
Food = symbols('Food')
Apple = symbols('Apple')
Vegetables = symbols('Vegetables')
Peanuts = symbols('Peanuts')
```

```
John_likes_x = symbols('John_likes_x')
Anil_eats_x = symbols('Anil_eats_x')
Harry_eats_x = symbols('Harry_eats_x')
Alive_x = symbols('Alive_x')
Killed_x = symbols('Killed_x')

# Knowledge Base in propositional logic
# a. John likes all kind of food -> For each food x, John_likes_x if Food(x)
kb = And(
    Implies(Food, John_likes_x),  # a
    Implies(Or(Apple, Vegetables), Food),  # b
    Implies(And(Anil_eats_x, Not(Killed_x)), Food),  # c
    And(Anil_eats_x, Alive_x),  # d
    Implies(Anil_eats_x, Harry_eats_x),  # e
    Implies(Alive_x, Not(Killed_x)),  # f
    Implies(Not(Killed_x), Alive_x)  # g
)

# We want to prove: John likes peanuts -> John_likes_x for Peanuts
# Assume the negation of the goal for resolution
goal_negation = Not(John_likes_x)

# Combine KB with negated goal
combined = And(kb, goal_negation)

# Check satisfiability
sat_result = satisfiable(combined)

if sat_result:
    print("The negation is satisfiable. Cannot prove John likes peanuts from KB.")
else:
    print("The negation is unsatisfiable. By resolution, John likes peanuts is proven!")
```

OUTPUT :