# 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**
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**B.M.S. College of Engineering,**
**Bull Temple Road, Bangalore 560019**
(Affiliated To Visvesvaraya Technological University, Belgaum)
**Department of Computer Science and Engineering**

## CERTIFICATE

This is to certify that the Lab work entitled "Artificial Intelligence (23CS5PCAIN)" carried out by **Bhoomi Suresh Kota (1BM23CS065),** 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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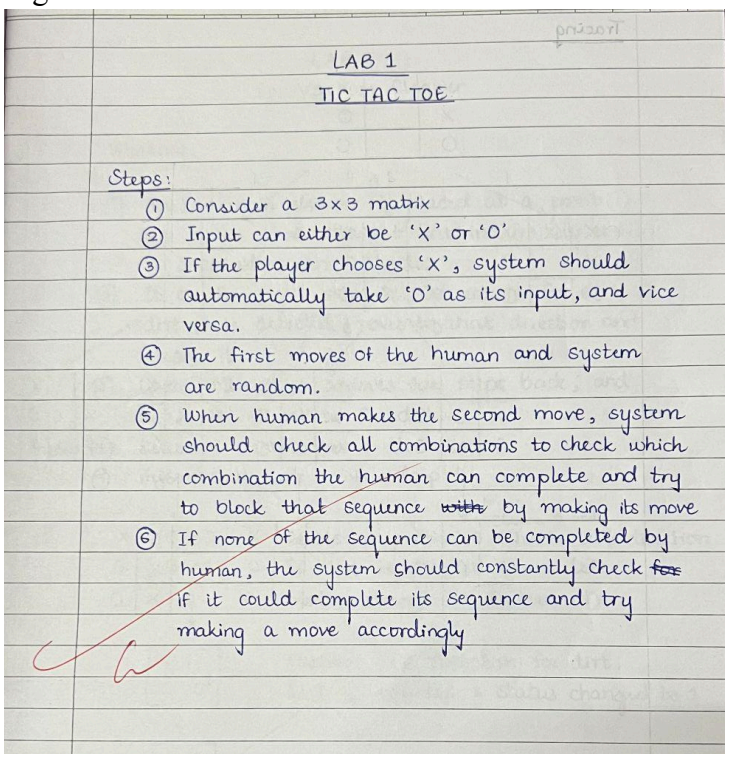
Github Link:
https://github.com/BhoomiSuresh/AI-LAB.git

# Program 1

**Implement Tic –Tac –Toe Game**
**Implement vacuum cleaner agent**

Algorithm:

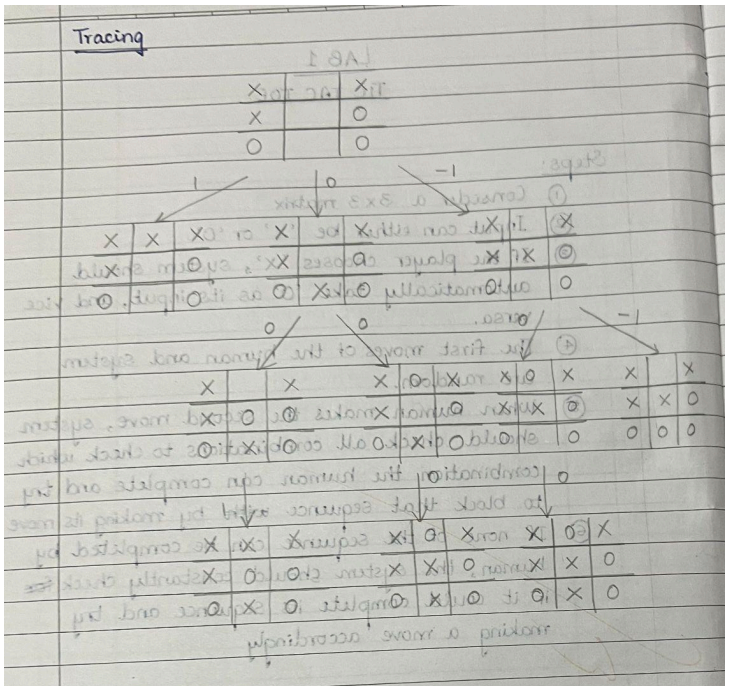


LAB 1

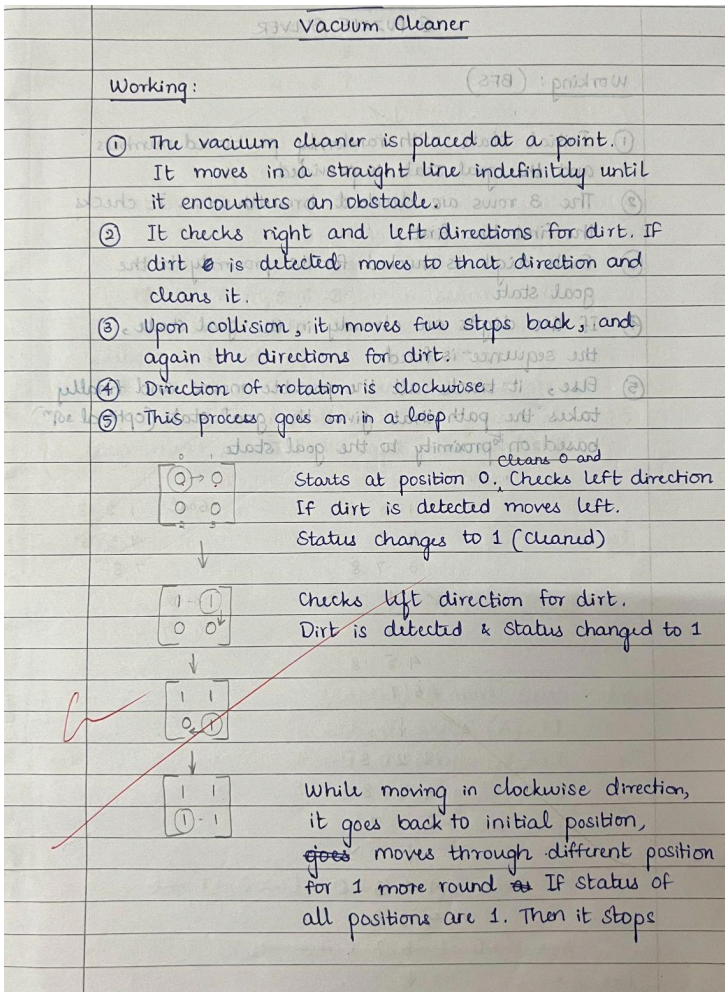
TIC TAC TOE

Steps:

① Consider a 3x3 matrix
② Input can either be 'X' or 'O'
③ If the player chooses 'X', system should automatically take 'O' as its input, and vice versa.
④ The first moves of the human and system are random.
⑤ When human makes the second move, system should check all combinations to check which combination the human can complete and try to block that sequence ~~with~~ by making its move
⑥ If none of the sequence can be completed by human, the system should constantly check ~~for~~ if it could complete its sequence and try making a move accordingly



Tracing




Code:

Tic Tac Toe:

```
def computer_move():
    best_move = minimax_recurse(game_board, active_player, 0)
    print("The best move is ", best_move)
    make_move(game_board, best_move, active_player)

    print("COMPUTER MOVE DONE")

def minimax_recurse(game_board, player, depth):

    winner = is_winner(game_board)
    if winner == active_player:
        return 1
    elif winner is not None and winner != active_player:
        return -1
    elif len(get_move_list(game_board)) == 0:
```

```
        return 0

    if player == player1:
        other_player = player2
    else:
        other_player = player1

    if player == active_player:
        alpha = -1
    else:
        alpha = 1

    movelist = get_move_list(game_board)
    best_move = None

    for move in movelist:
        board2 = [list(row) for row in game_board] # Create a copy of the board

        make_move(board2, move, player)

        subalpha = minimax_recurse(board2, other_player, depth + 1)

        if player == active_player:
            if depth == 0 and alpha <= subalpha:
                best_move = move
            alpha = max(alpha, subalpha)
            if alpha == 1: # Alpha-beta pruning
                if depth == 0:
                  return best_move
                return alpha

        else:
            alpha = min(alpha, subalpha)
            if alpha == -1: # Alpha-beta pruning
                return alpha

    if depth == 0:
      return best_move
    return alpha


# BOARD FUNCTIONS
game_board = [['1','2','3'],['4','5','6'],['7','8','9']] # Changed to strings to avoid confusion with available
moves
def print_board(board) :

    for row in board :
```

```
        print(row)

def make_move(game_board, player_move, active_player):

    x = 0
    y = 0
    try:
        player_move = int(player_move)
    except ValueError:
        print("Invalid input. Please enter a number.")
        return game_board

    if player_move == 1 :
        x = 0
        y = 0
    elif player_move == 2 :
        x = 0
        y = 1
    elif player_move == 3 :
        x = 0
        y = 2
    elif player_move == 4 :
        x = 1
        y = 0
    elif player_move == 5 :
        x = 1
        y = 1
    elif player_move == 6 :
        x = 1
        y = 2
    elif player_move == 7 :
        x = 2
        y = 0
    elif player_move == 8 :
        x = 2
        y = 1
    elif player_move == 9 :
        x = 2
        y = 2
    else :
        print ("value is out of range")
        return game_board


    if game_board[x][y] == "O" or game_board[x][y] == "X" :
        print("move not available")
        return game_board
```

```
    game_board[x][y] = str(active_player)
    return game_board

def is_winner(board):
    for i in range (0,3) :
        if board[i][0] == player1 and board[i][1] == player1 and board[i][2] == player1 :
            return player1

        if board[i][0] == player2 and board[i][1] == player2 and board[i][2] == player2 :
            return player2

    # checking for columns
    for i in range(0,3):
        if board[0][i] == player1 and board[1][i] == player1 and board[2][i] == player1:
            return player1
        if board[0][i] == player2 and board[1][i] == player2 and board[2][i] == player2:
            return player2

    # checking for diagonals
    if board[0][0] == player1 and board[1][1] == player1 and board[2][2] == player1 :
        return player1
    if board[0][0] == player2 and board[1][1] == player2 and board[2][2] == player2 :
        return player2

    if board[2][0] == player1 and board[1][1] == player1 and board[0][2] == player1 :
        return player1
    if board[2][0] == player2 and board[1][1] == player2 and board[0][2] == player2 :
        return player2

    return None

def get_move_list (game_board) :

    move = []

    for row in game_board :
        for i in row :
            if i.isdigit():
                move.append(int(i))
    return move

# Main Loop
player1 = "X"
player2 = "O"
print_board(game_board)
while True :
```

```
    active_player = player1
    # this is for player move
    print(get_move_list(game_board))
    player_move = input("Please insert your move >>> ")
    game_board = make_move(game_board,player_move,active_player)
    print_board(game_board)

    if is_winner(game_board) == player1 :
        print("Player1 is the winner")
        break
    if is_winner(game_board) == player2 :
        print("Player2 is the winner")
        break
    if len(get_move_list(game_board)) == 0:
        print("It's a tie!")
        break

    print(get_move_list(game_board))
    # computer time
    active_player = player2
    computer_move()
    print_board(game_board)

    if is_winner(game_board) == player1 :
        print("Player1 is the winner")
        break
    if is_winner(game_board) == player2 :
        print("Player2 is the winner")
        break
    if len(get_move_list(game_board)) == 0:
        print("It's a tie!")
        break
```

Vacuum Cleaner:

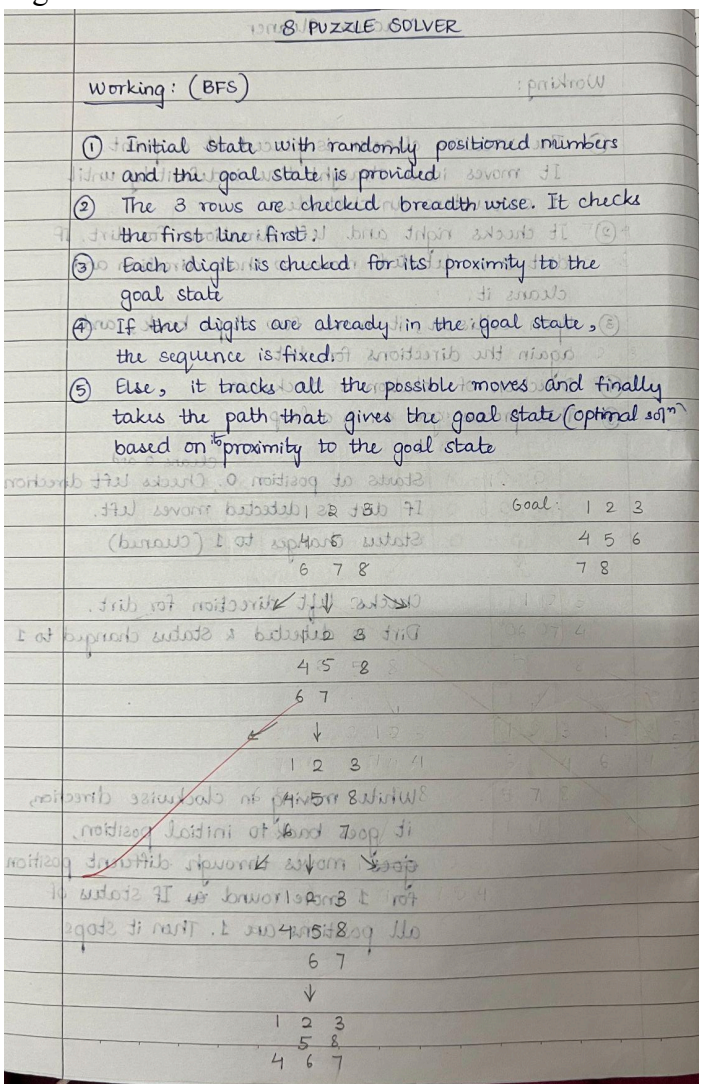
```
import random

def vacuum_cleaner_agent(location, status_A, status_B):
    """
    Simulates a simple vacuum cleaner agent in a two-location environment (A and B).
    Args:
        location (str): The current location of the vacuum ('A' or 'B').
        status_A (str): The cleanliness status of location A ('Dirty' or 'Clean').
        status_B (str): The cleanliness status of location B ('Dirty' or 'Clean').
    Returns:
        tuple: A tuple containing the updated location and statuses after the agent's action.
    """
```

```
    print(f"Vacuum cleaner is at {location}.")

    if location == 'A':
        if status_A == 'Dirty':
            print("Location A is Dirty. Sucking dirt...")
            status_A = 'Clean'
            print("Location A is now Clean.")
            # Move to B after cleaning A
            print("Moving to Location B.")
            return 'B', status_A, status_B
        else:
            print("Location A is Clean. Moving to Location B.")
            return 'B', status_A, status_B
    elif location == 'B':
        if status_B == 'Dirty':
            print("Location B is Dirty. Sucking dirt...")
            status_B = 'Clean'
            print("Location B is now Clean.")
            # Move to A after cleaning B
            print("Moving to Location A.")
            return 'A', status_A, status_B
        else:
            print("Location B is Clean. Moving to Location A.")
            return 'A', status_A, status_B

# Initializing the environment
initial_location = random.choice(['A', 'B'])
initial_status_A = random.choice(['Dirty', 'Clean'])
initial_status_B = random.choice(['Dirty', 'Clean'])

print(f"Initial state: Vacuum at {initial_location}, A is {initial_status_A}, B is {initial_status_B}\n")

current_location, current_status_A, current_status_B = initial_location, initial_status_A,
initial_status_B

# Running the simulation until both locations are clean
while current_status_A == 'Dirty' or current_status_B == 'Dirty':
    current_location, current_status_A, current_status_B = vacuum_cleaner_agent(
        current_location, current_status_A, current_status_B
    )
    print(f"Current state: Vacuum at {current_location}, A is {current_status_A}, B is
{current_status_B}\n")

print("Both locations are clean. Vacuum cleaner has finished its task.")
```

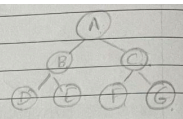
# Program 2

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

Algorithm:



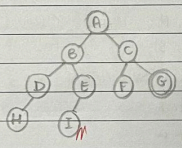
IDDFS ~~Graph~~ Algorithm:




1: Initialize the start and goal node
2: Starting from start node till goal node:
- Start traversing using BFS
- From the first node, traverse to its child nodes in the next depth level (DFS)
- Further, traverse to its child nodes
- Once we reach the end of the child nodes, move to the next node in the previous breadth.

3: IF the goal node is found, return the path
Else, if max_depth is reached, return goal not found.

Eg:




Sol: Start from A (BFS[A])
DFS(A) gives B, C
DFS[B] gives D, E
DFS[C] gives F, G
G is the goal state

∴ Path: A → B → D → E → C → F → G

~~A → B → D → E → C → F → G → H → I~~

For I:
A → B → D → H → E → I → C → F → G

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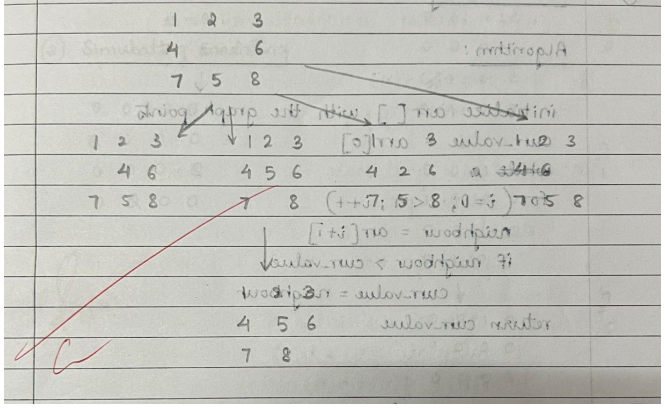
Output:

Tile: 1 2 3 / 4 0 6 / 7 5 8 → 1 2 3 / 4 5 6 / 7 0 8 → 1 2 3 / 4 5 6 / 7 8 0



Code:

BFS

```
# Import necessary libraries
from collections import deque

# Define the dimensions of the puzzle
N = 3

# Class to represent the state of the puzzle
class PuzzleState:
    def __init__(self, board, x, y, depth):
        self.board = board
        self.x = x
        self.y = y
        self.depth = depth

# Possible moves: Left, Right, Up, Down
row = [0, 0, -1, 1]
col = [-1, 1, 0, 0]

# Function to check if the current state is the goal state
def is_goal_state(board):
    goal = [[1, 2, 3], [4, 5, 6], [7, 8, 0]]
    return board == goal

# Function to check if a move is valid
def is_valid(x, y):
    return 0 <= x < N and 0 <= y < N

# Function to print the puzzle board
def print_board(board):
    for row in board:
        print(' '.join(map(str, row)))
    print('--------')

# BFS function to solve the 8-puzzle problem
def solve_puzzle_bfs(start, x, y):
    q = deque()
    visited = set()

    # Enqueue initial state
    q.append(PuzzleState(start, x, y, 0))
    visited.add(tuple(map(tuple, start)))

    while q:
```

```
        curr = q.popleft()

        # Print the current board state
        print(f'Depth: {curr.depth}')
        print_board(curr.board)

        # Check if goal state is reached
        if is_goal_state(curr.board):
            print(f'Goal state reached at depth {curr.depth}')
            return

        # Explore all possible moves
        for i in range(4):
            new_x = curr.x + row[i]
            new_y = curr.y + col[i]

            if is_valid(new_x, new_y):
                new_board = [row[:] for row in curr.board]
                new_board[curr.x][curr.y], new_board[new_x][new_y] = new_board[new_x][new_y],
new_board[curr.x][curr.y]

                # If this state has not been visited before, push to queue
                if tuple(map(tuple, new_board)) not in visited:
                    visited.add(tuple(map(tuple, new_board)))
                    q.append(PuzzleState(new_board, new_x, new_y, curr.depth + 1))

    print('No solution found (BFS Brute Force reached depth limit)')

# Driver Code
if __name__ == '__main__':
    start = [[1, 2, 3], [4, 0, 5], [6, 7, 8]]  # Initial state
    x, y = 1, 1

    print('Initial State:')
    print_board(start)

    solve_puzzle_bfs(start, x, y)
```

IDDFS:

```
from collections import deque

# Goal state
GOAL = (1, 2, 3,
        4, 5, 6,
        7, 8, 0)
```

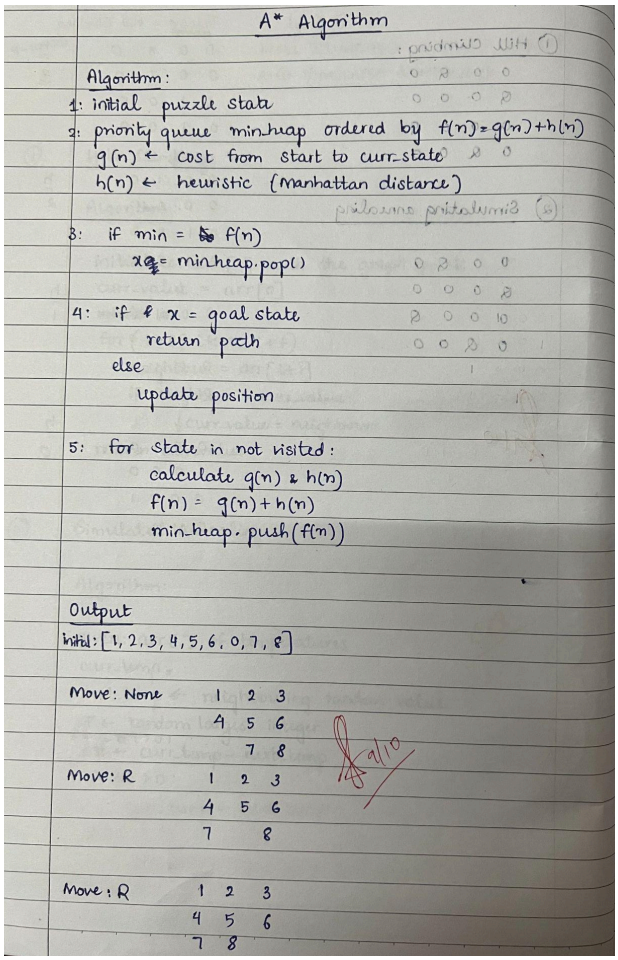
```
# Moves: up, down, left, right
MOVES = {
    'U': -3,
    'D':  3,
    'L': -1,
    'R':  1
}

def is_valid_move(pos, move):
    """Check if blank can move in given direction."""
    if move == 'U' and pos < 3: return False
    if move == 'D' and pos > 5: return False
    if move == 'L' and pos % 3 == 0: return False
    if move == 'R' and pos % 3 == 2: return False
    return True

def neighbors(state):
    """Generate valid neighbor states from current state."""
    new_states = []
    pos = state.index(0)  # blank position
    for move, offset in MOVES.items():
        if is_valid_move(pos, move):
            new_pos = pos + offset
            new_state = list(state)
            new_state[pos], new_state[new_pos] = new_state[new_pos], new_state[pos]
            new_states.append((tuple(new_state), move))
    return new_states

def dls(state, depth, visited, path):
    """Depth-limited DFS."""
    if state == GOAL:
        return path
    if depth == 0:
        return None
    visited.add(state)

    for neighbor, move in neighbors(state):
        if neighbor not in visited:
            result = dls(neighbor, depth - 1, visited, path + [move])
            if result is not None:
                return result
    return None

def iddfs(start, max_depth=50):
    """Iterative Deepening DFS."""
    for depth in range(max_depth):
```

```
        visited = set()
        path = dls(start, depth, visited, [])
        if path is not None:
            return path
    return None

# --- MAIN PROGRAM ---
if __name__ == "__main__":
    print("Enter the start state of the 8-puzzle (use 0 for blank):")
    nums = []
    for i in range(9):
        nums.append(int(input(f"Tile {i+1}: ")))
    start = tuple(nums)

    solution = iddfs(start, max_depth=30)
    if solution:
        print(f"\nSolution found in {len(solution)} moves:")
        print(" -> ".join(solution))
    else:
        print("No solution found within depth limit.")
```

# Program 3

**Implement A* search algorithm**

Algorithm:




Code:

```
import heapq
from termcolor import colored

# Class to represent the state of the 8-puzzle
class PuzzleState:
    def __init__(self, board, parent, move, depth, cost):
        self.board = board  # The puzzle board configuration
        self.parent = parent  # Parent state
        self.move = move  # Move to reach this state
        self.depth = depth  # Depth in the search tree
        self.cost = cost  # Cost (depth + heuristic)
```

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

# Function to display the board in a visually appealing format
def print_board(board):
    print("+---+---+---+")
    for row in range(0, 9, 3):
        row_visual = "|"
        for tile in board[row:row + 3]:
            if tile == 0:  # Blank tile
                row_visual += f" {colored(' ', 'cyan')} |"
            else:
                row_visual += f" {colored(str(tile), 'yellow')} |"
        print(row_visual)
        print("+---+---+---+")

# Goal state for the puzzle
goal_state = [1, 2, 3, 4, 5, 6, 7, 8, 0]

# Possible moves for the blank tile (up, down, left, right)
moves = {
    'U': -3,  # Move up
    'D': 3,   # Move down
    'L': -1,  # Move left
    'R': 1    # Move right
}

# Function to calculate the heuristic (Manhattan distance)
def heuristic(board):
    distance = 0
    for i in range(9):
        if board[i] != 0:
            x1, y1 = divmod(i, 3)
            x2, y2 = divmod(board[i] - 1, 3)
            distance += abs(x1 - x2) + abs(y1 - y2)
    return distance

# Function to get the new state after a move
def move_tile(board, move, blank_pos):
    new_board = board[:]
    new_blank_pos = blank_pos + moves[move]
    new_board[blank_pos], new_board[new_blank_pos] = new_board[new_blank_pos],
new_board[blank_pos]
    return new_board

# A* search algorithm
def a_star(start_state):
```

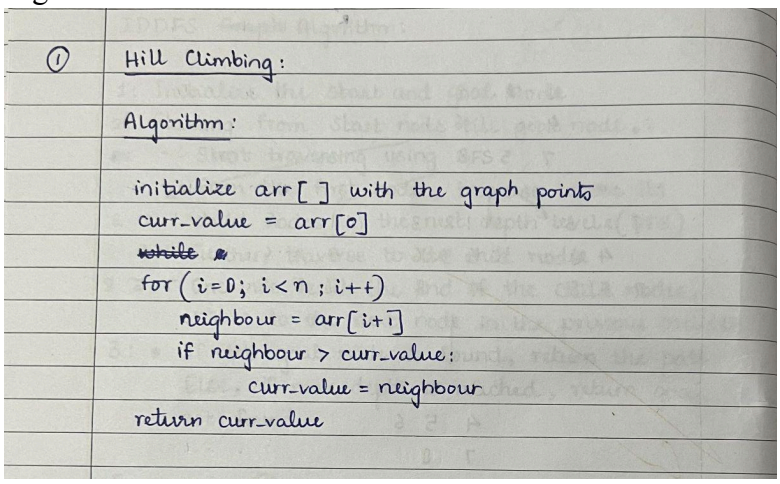
```
    open_list = []
    closed_list = set()
    heapq.heappush(open_list, PuzzleState(start_state, None, None, 0, heuristic(start_state)))

    while open_list:
        current_state = heapq.heappop(open_list)

        if current_state.board == goal_state:
            return current_state

        closed_list.add(tuple(current_state.board))

        blank_pos = current_state.board.index(0)

        for move in moves:
            if move == 'U' and blank_pos < 3:  # Invalid move up
                continue
            if move == 'D' and blank_pos > 5:  # Invalid move down
                continue
            if move == 'L' and blank_pos % 3 == 0:  # Invalid move left
                continue
            if move == 'R' and blank_pos % 3 == 2:  # Invalid move right
                continue

            new_board = move_tile(current_state.board, move, blank_pos)

            if tuple(new_board) in closed_list:
                continue

            new_state = PuzzleState(new_board, current_state, move, current_state.depth + 1,
current_state.depth + 1 + heuristic(new_board))
            heapq.heappush(open_list, new_state)

    return None

# Function to print the solution path
def print_solution(solution):
    path = []
    current = solution
    while current:
        path.append(current)
        current = current.parent
    path.reverse()

    for step in path:
        print(f"Move: {step.move}")
        print_board(step.board)
```

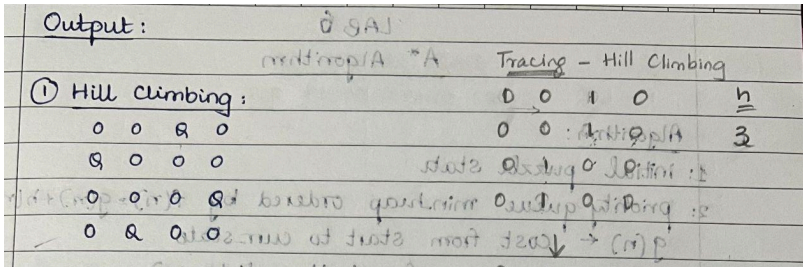
```
# Initial state of the puzzle
initial_state = [1, 2, 3, 4, 0, 5, 6, 7, 8]

# Solve the puzzle using A* algorithm
solution = a_star(initial_state)

# Print the solution
if solution:
    print(colored("Solution found:", "green"))
    print_solution(solution)
else:
    print(colored("No solution exists.", "red"))
```

# Program 4

**Implement Hill Climbing search algorithm to solve N-Queens problem**

Algorithm:




Code:

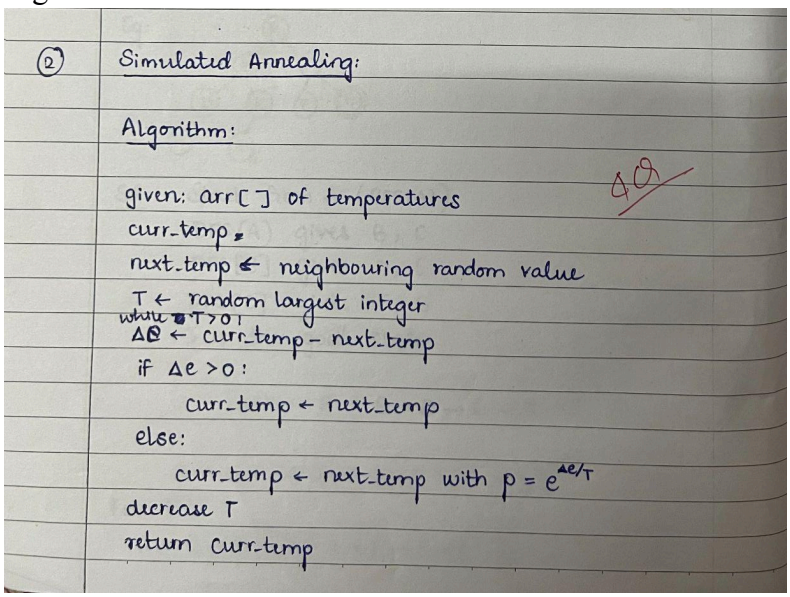
```
import random

def calculate_attacks(board):
    """Calculates the number of attacking pairs on the board."""
    n = len(board)
    attacks = 0
    for i in range(n):
        for j in range(i + 1, n):
            # Check row attacks
            if board[i] == board[j]:
                attacks += 1
            # Check diagonal attacks
            elif abs(board[i] - board[j]) == abs(i - j):
                attacks += 1
    return attacks

def hill_climbing_n_queens(n):
    """Solves the N-Queens problem using Hill Climbing."""
```

```
    # Initialize with a random board
    current_board = [random.randint(0, n - 1) for _ in range(n)]
    current_attacks = calculate_attacks(current_board)

    while current_attacks > 0:
        best_neighbor_board = list(current_board)
        best_neighbor_attacks = current_attacks

        found_better_neighbor = False
        for col_to_move in range(n):
            for row_new_pos in range(n):
                if current_board[col_to_move] == row_new_pos:
                    continue  # Don't move to the same position

                temp_board = list(current_board)
                temp_board[col_to_move] = row_new_pos
                temp_attacks = calculate_attacks(temp_board)

                if temp_attacks < best_neighbor_attacks:
                    best_neighbor_attacks = temp_attacks
                    best_neighbor_board = list(temp_board)
                    found_better_neighbor = True
                elif temp_attacks == best_neighbor_attacks and not found_better_neighbor:
                    # If multiple neighbors have the same best attack count,
                    # choose one randomly to avoid always picking the same one
                    if random.random() < 0.5: # Simple tie-breaking
                        best_neighbor_board = list(temp_board)

        if not found_better_neighbor:
            # Stuck in a local optimum or reached a solution
            break
        current_board = best_neighbor_board
        current_attacks = best_neighbor_attacks

    return current_board, current_attacks

# Example for 4-Queens
n = 4
solution, attacks = hill_climbing_n_queens(n)

print(f"Final board: {solution}")
print(f"Number of attacks: {attacks}")

if attacks == 0:
    print("Solution found!")
else:
    print("Stuck in a local optimum.")
```

# Program 5

**Simulated Annealing to Solve 8-Queens problem**

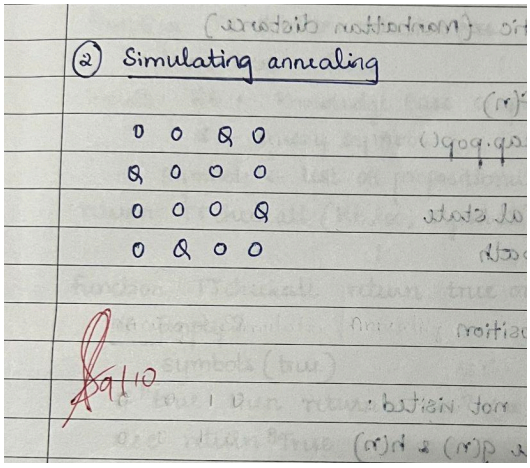
Algorithm:



② Simulated Annealing:

Algorithm:

given: arr[ ] of temperatures
curr_temp,
next_temp ← neighbouring random value
T ← random largest integer
while T > 0 :
ΔE ← curr_temp − next_temp
if Δe > 0 :
curr_temp ← next_temp
else:
curr_temp ← next_temp with $p = e^{\Delta e/T}$
decrease T
return curr_temp



② Simulating annealing

Q 0 0 0
0 0 0 Q
0 Q 0 0
0 0 Q 0

Code:

```
import random
import math

def calculate_attacks(board):
    """Calculates the number of attacking queen pairs on the board."""
    n = len(board)
    attacks = 0
    for i in range(n):
```

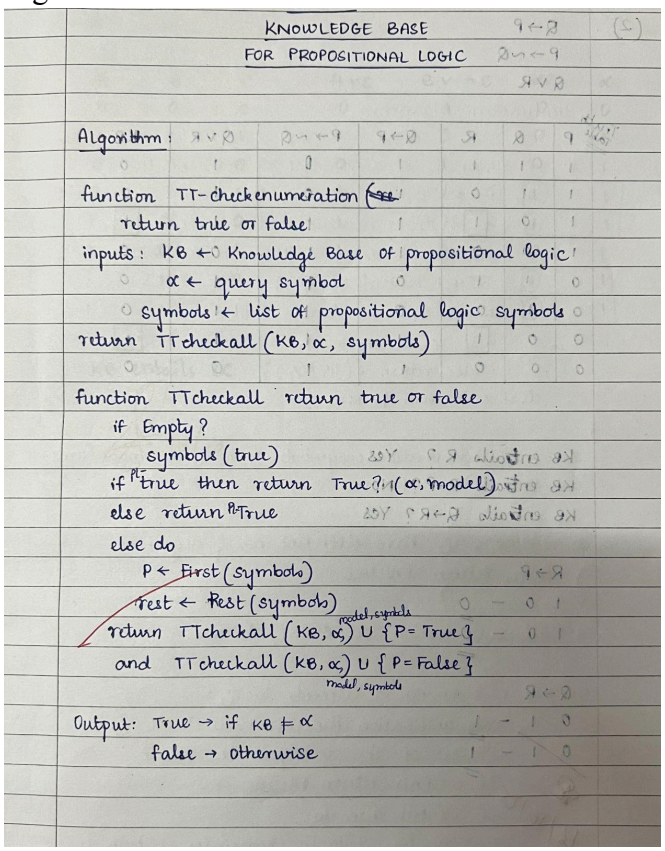
```
        for j in range(i + 1, n):
            # Check horizontal attacks
            if board[i] == board[j]:
                attacks += 1
            # Check diagonal attacks
            if abs(board[i] - board[j]) == abs(i - j):
                attacks += 1
    return attacks

def get_neighbor(board):
    """Generates a neighboring state by randomly moving one queen."""
    n = len(board)
    new_board = list(board)
    queen_to_move = random.randint(0, n - 1)
    new_position = random.randint(0, n - 1)
    new_board[queen_to_move] = new_position
    return tuple(new_board)

def simulated_annealing(n, initial_temperature, cooling_rate, iterations):
    """Solves the N-Queens problem using Simulated Annealing."""
    current_board = tuple(random.randint(0, n - 1) for _ in range(n))
    current_energy = calculate_attacks(current_board)
    best_board = current_board
    best_energy = current_energy
    temperature = initial_temperature

    for i in range(iterations):
        if temperature <= 0:
            break

        neighbor_board = get_neighbor(current_board)
        neighbor_energy = calculate_attacks(neighbor_board)

        # If neighbor is better, accept it
        if neighbor_energy < current_energy:
            current_board = neighbor_board
            current_energy = neighbor_energy
            if current_energy < best_energy:
                best_energy = current_energy
                best_board = current_board
        # If neighbor is worse, accept with a probability
        else:
            probability = math.exp((current_energy - neighbor_energy) / temperature)
            if random.random() < probability:
                current_board = neighbor_board
                current_energy = neighbor_energy
```

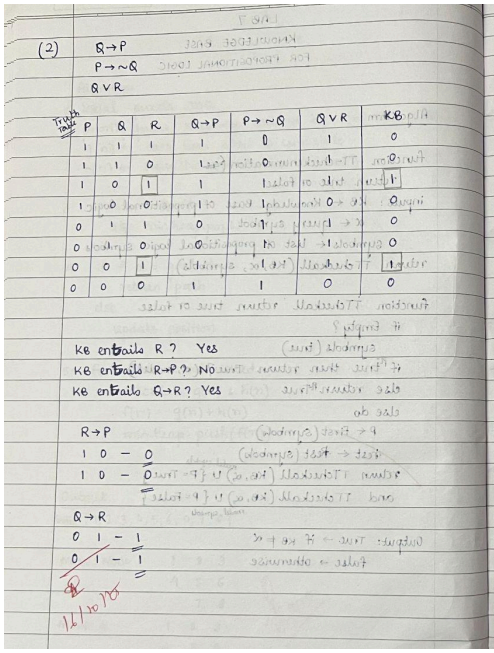
```
        temperature *= cooling_rate

        if current_energy == 0:  # Found a solution
            break

    return best_board, best_energy

def print_board(board):
    """Prints the N-Queens board."""
    n = len(board)
    for row in range(n):
        line = ["Q" if board[col] == row else "." for col in range(n)]
        print(" ".join(line))

if __name__ == "__main__":
    N = 4  # For the 4-Queens problem
    initial_temp = 100
    cooling_rate = 0.99
    num_iterations = 10000

    solution_board, solution_attacks = simulated_annealing(N, initial_temp, cooling_rate,
num_iterations)

    print(f"Final board configuration: {solution_board}")
    print(f"Number of attacks: {solution_attacks}")

    if solution_attacks == 0:
        print("\nSolution found:")
        print_board(solution_board)
    else:
        print("\nNo perfect solution found within iterations. Best found:")
        print_board(solution_board)
```

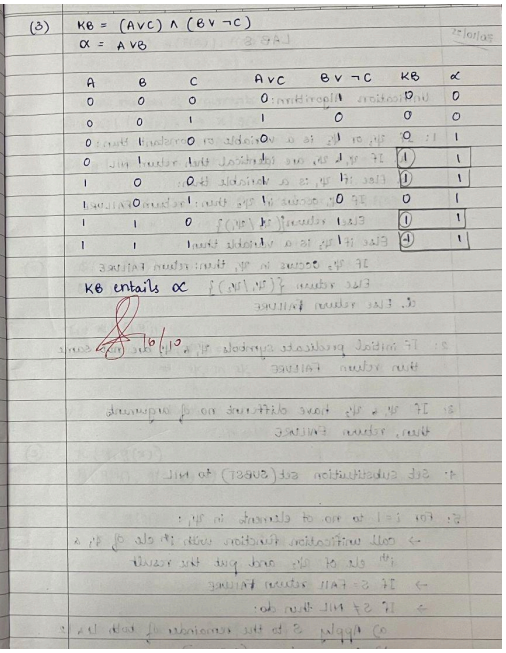
# Program 6

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

Algorithm:



Code:

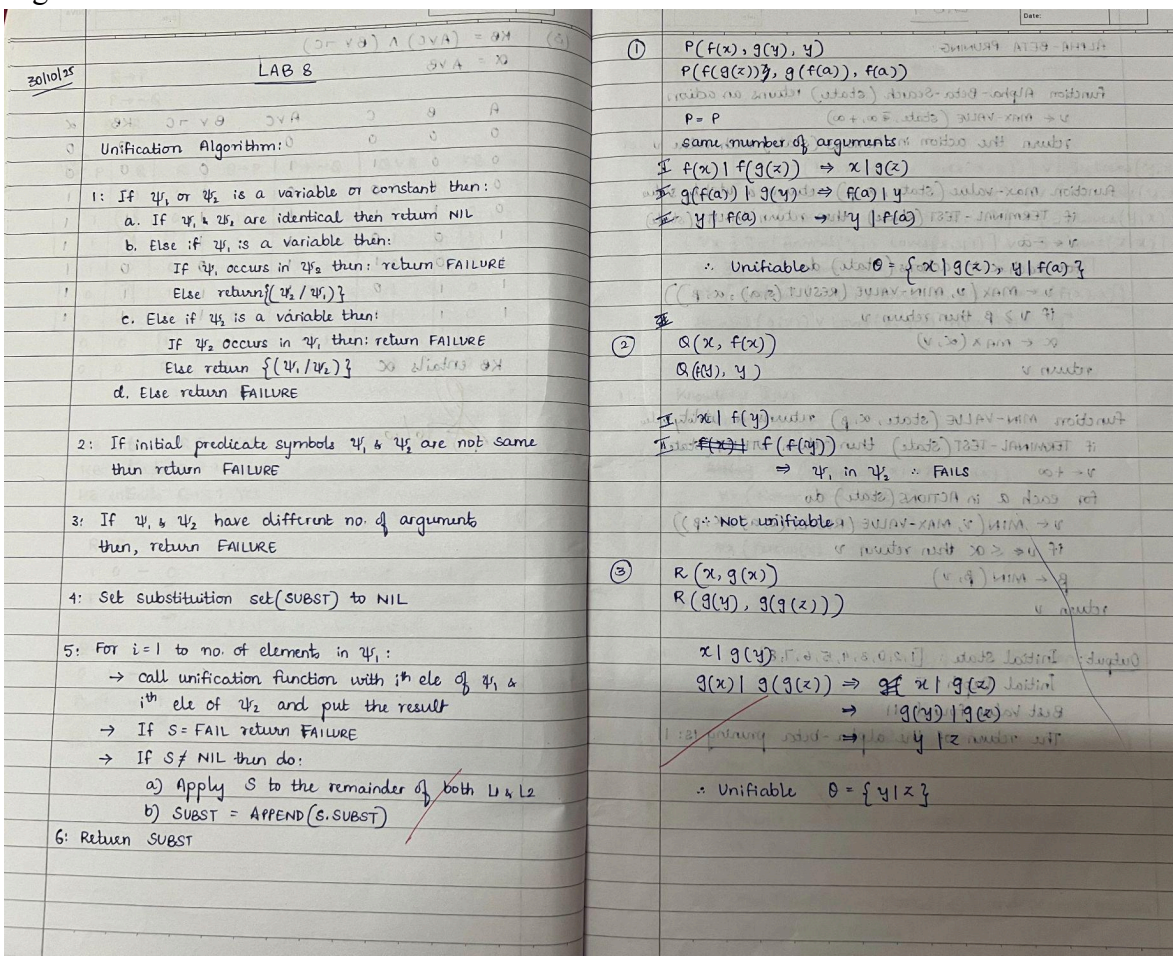
```
import pandas as pd
import itertools

# Define propositions
props = ['P', 'Q', 'R']

# Generate all truth assignments for P, Q, R
truth_values = list(itertools.product([False, True], repeat=3))

def implies(a, b):
    return (not a) or b

# Evaluate KB sentences and entailments
rows = []
for (P, Q, R) in truth_values:
    sentence1 = implies(Q, P)         # Q -> P
    sentence2 = implies(P, not Q)    # P -> ¬Q
    sentence3 = Q or R               # Q ∨ R

    kb_true = sentence1 and sentence2 and sentence3

    entail_R = R
    entail_R_implies_P = implies(R, P)
    entail_Q_implies_R = implies(Q, R)

    rows.append({
        'P': P, 'Q': Q, 'R': R,
        'Q->P': sentence1,
        'P->¬Q': sentence2,
        'Q∨R': sentence3,
        'KB True': kb_true,
        'Entail R': entail_R,
        'Entail R->P': entail_R_implies_P,
        'Entail Q->R': entail_Q_implies_R
    })

# Create DataFrame
df = pd.DataFrame(rows)

# Filter models where KB is true
models_where_KB_true = df[df['KB True']]

# Print full truth table
print("Full Truth Table:\n")
```

```
print(df.to_string(index=False))

# Checking entailments (whether KB entails each sentence)
# KB entails a sentence if the sentence is true in all models where KB is true
entail_R_result = models_where_KB_true['Entail R'].all()
entail_R_implies_P_result = models_where_KB_true['Entail R->P'].all()
entail_Q_implies_R_result = models_where_KB_true['Entail Q->R'].all()

print("\nModels where KB is True:")
print(models_where_KB_true.to_string(index=False))

print("\nEntailment Results:")
print(f"Does KB entail R? {'Yes' if entail_R_result else 'No'}")
print(f"Does KB entail R -> P? {'Yes' if entail_R_implies_P_result else 'No'}")
print(f"Does KB entail Q -> R? {'Yes' if entail_Q_implies_R_result else 'No'}")
```

# Program 7

**Implement unification in first order logic**

Algorithm:



LAB 8

Unification Algorithm:

1: If $\Psi_1$ or $\Psi_2$ is a variable or constant then:
   a. If $\Psi_1$ & $\Psi_2$ are identical then return NIL
   b. Else if $\Psi_1$ is a variable then:
      If $\Psi_1$ occurs in $\Psi_2$ then: return FAILURE
      Else return $\{(\Psi_2 / \Psi_1)\}$
   c. Else if $\Psi_2$ is a variable then:
      If $\Psi_2$ occurs in $\Psi_1$ then: return FAILURE
      Else return $\{(\Psi_1 / \Psi_2)\}$
   d. Else return FAILURE

2: If initial predicate symbols $\Psi_1$ & $\Psi_2$ are not same then return FAILURE

3: If $\Psi_1$ & $\Psi_2$ have different no. of arguments then, return FAILURE

4: Set substitution set(SUBST) to NIL

5: For i = 1 to no. of elements in $\Psi_1$:
   → Call unification function with $i^{th}$ ele of $\Psi_1$ & $i^{th}$ ele of $\Psi_2$ and put the result
   → If S = FAIL return FAILURE
   → If S ≠ NIL then do:
      a) Apply S to the remainder of both L1 & L2
      b) SUBST = APPEND(S, SUBST)

6: Return SUBST

① P(f(x), g(y), y)
P(f(g(z)), g(f(a)), f(a))
P = P
same number of arguments
I f(x) | f(g(z)) ⇒ x | g(z)
II g(f(a)) | g(y) ⇒ f(a) | y
III y | f(a)

∴ Unifiable θ = {x | g(z), y | f(a)}

② Q(x, f(x))
Q(f(y), y)
I x | f(y)
II f(x) | f(f(y))
⇒ $\Psi_1$ in $\Psi_2$ ∴ FAILS
∴ Not unifiable

③ R(x, g(x))
R(g(y), g(g(z)))
x | g(y)
g(x) | g(g(z)) ⇒ x | g(z)
⇒ g(y) | g(z)
⇒ y | z
∴ Unifiable θ = {y | z}

Code:

```
import re

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

def parse_term(term):
    # Parses a function or constant or variable into structured form
    term = term.strip()
    if '(' not in term:
        return term
    functor, args_str = term.split('(', 1)
    args = []
    depth = 0
```

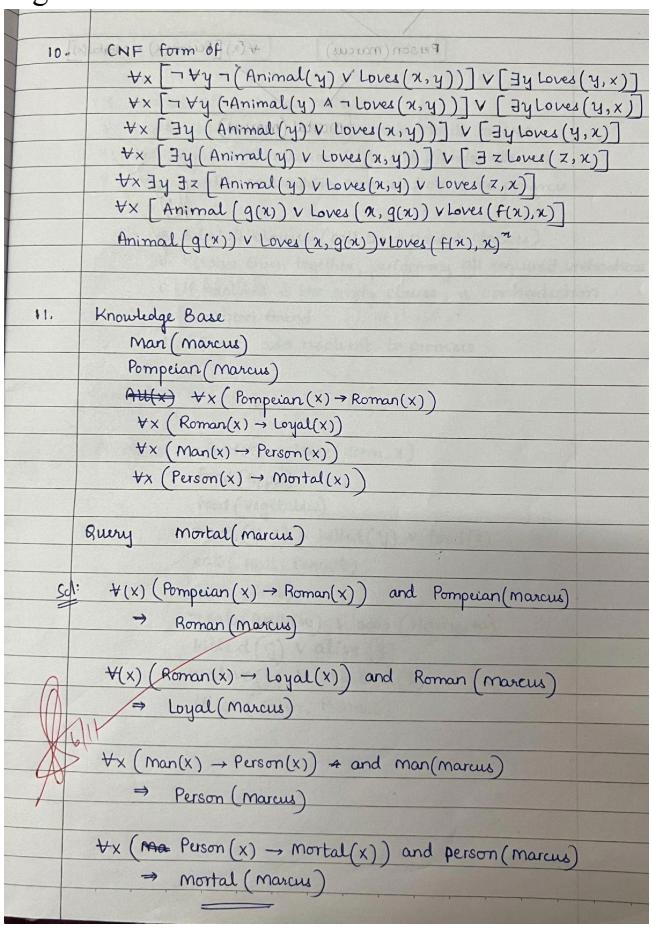
```
    current = ''
    for ch in args_str[:-1]:  # skip last ')'
        if ch == ',' and depth == 0:
            args.append(parse_term(current.strip()))
            current = ''
        else:
            if ch == '(':
                depth += 1
            elif ch == ')':
                depth -= 1
            current += ch
    if current:
        args.append(parse_term(current.strip()))
    return (functor.strip(), args)

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

def substitute(x, subst):
    if isinstance(x, str):
        # If x is a variable and has a substitution, apply it recursively.
        # This handles chained substitutions like x -> y, y -> f(z).
        if x in subst:
            return substitute(subst[x], subst)
        else:
            # If it's not in the substitution, it's either a constant string
            # or a variable that hasn't been substituted yet.
            return x
    elif isinstance(x, tuple):
        functor, args = x
        return (functor, [substitute(arg, subst) for arg in args])
    return x

def unify(x, y, subst=None):
    if subst is None:
        subst = {}
    x = substitute(x, subst)
    y = substitute(y, subst)
    if x == y:
```

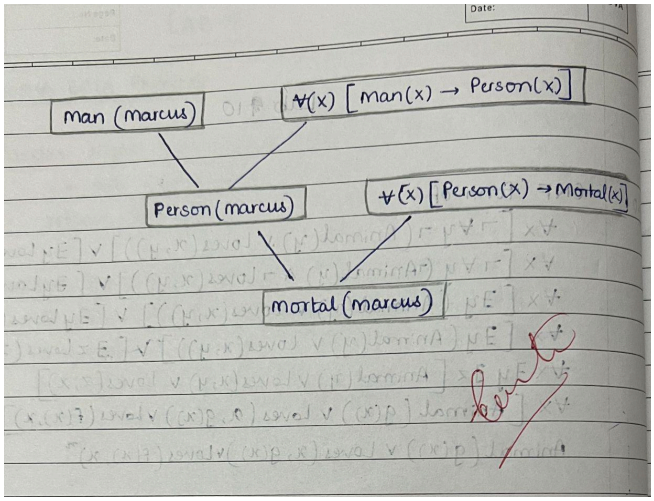
```
        return subst
    elif is_variable(x):
        if occurs_check(x, y, subst):
            raise ValueError(f"Occurs check failed for {x} in {y}")
        subst[x] = y
        return subst
    elif is_variable(y):
        if occurs_check(y, x, subst):
            raise ValueError(f"Occurs check failed for {y} in {x}")
        subst[y] = x
        return subst
    elif isinstance(x, tuple) and isinstance(y, tuple):
        if x[0] != y[0] or len(x[1]) != len(y[1]):
            raise ValueError(f"Functor mismatch: {x[0]} vs {y[0]}")
        for a, b in zip(x[1], y[1]):
            subst = unify(a, b, subst)
        return subst
    else:
        raise ValueError(f"Cannot unify {x} with {y}")

# ----- Test -----
x = parse_term("P(f(x), g(y), y)")
y = parse_term("P(f(g(z)), g(f(a)), f(a))")

print("Parsed terms:")
print("x =", x)
print("y =", y)

try:
    result = unify(x, y)
    print("\nUnification successful!")
    print("Substitution set:")
    for var, val in result.items():
        print(f"  {var} = {val}")
except ValueError as e:
    print("\nUnification failed:", e)
```

# Program 8

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

Algorithm:



Code:

```
import re

# -------------------------
# Helper functions
# -------------------------

def eliminate_implications(expr):
    """Eliminate implications (A -> B becomes ~A | B)."""
    expr = re.sub(r'\((.*?)\)->\((.*?)\)', r'(~(\1)|(\2))', expr)
    return expr

def move_not_inwards(expr):
    """Apply De Morgan's laws and double negation elimination."""
    expr = expr.replace("~~", "")
    expr = expr.replace("~(A&B)", "(~A|~B)")
    expr = expr.replace("~(A|B)", "(~A&~B)")
    return expr

def standardize_variables(expr):
    """Rename variables to avoid clashes."""
    # For demo, just ensure lowercase vars get unique suffixes
    var_map = {}
    count = 0
    new_expr = ""
    for ch in expr:
        if ch.islower() and ch.isalpha():
            if ch not in var_map:
                var_map[ch] = chr(ord('a') + count)
                count += 1
            new_expr += var_map[ch]
        else:
            new_expr += ch
    return new_expr

def skolemize(expr):
    """Replace existential quantifiers with Skolem constants/functions."""
    expr = re.sub(r'∃[a-z]\.', '', expr)  # Remove existential quantifier
    return expr.replace("x", "c")  # Replace var with Skolem constant (simple demo)

def drop_universal(expr):
    """Remove universal quantifiers (implicit in CNF)."""
    expr = re.sub(r'∀[a-z]\.', '', expr)
    return expr

def distribute_or_over_and(expr):
```

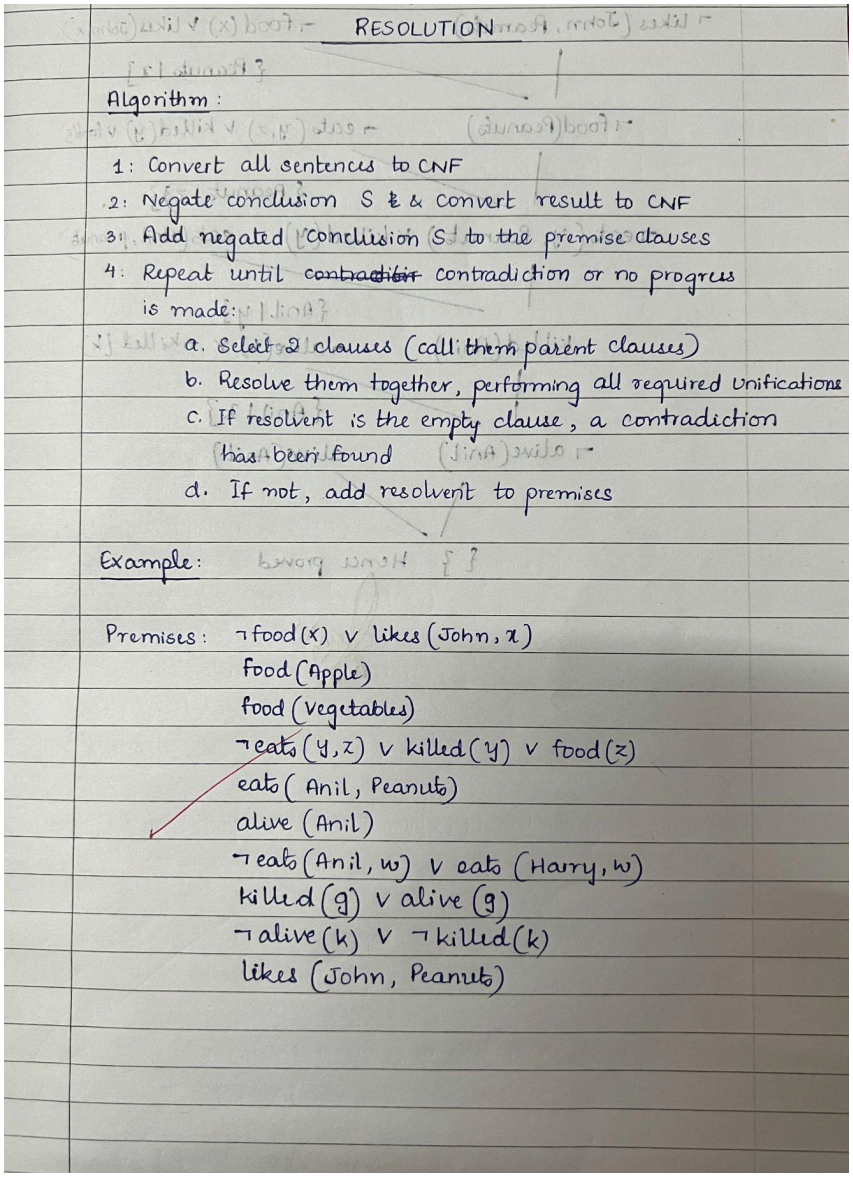
```
    """Simplified distribution (only handles basic patterns)."""
    # In a full implementation you'd need a tree structure, not regex.
    return expr.replace("|", "∨").replace("&", "∧")

# -------------------------
# Main CNF conversion function
# -------------------------

def fol_to_cnf(expr):
    print("Original:", expr)
    expr = eliminate_implications(expr)
    print("→ No implications:", expr)
    expr = move_not_inwards(expr)
    print("→ Negations inward:", expr)
    expr = standardize_variables(expr)
    print("→ Standardized vars:", expr)
    expr = skolemize(expr)
    print("→ Skolemized:", expr)
    expr = drop_universal(expr)
    print("→ Dropped universals:", expr)
    expr = distribute_or_over_and(expr)
    print("→ CNF form:", expr)
    return expr

# -------------------------
# Example usage
# -------------------------

formula = "∀x.(P(x) -> ∃y.(Q(y) & R(x,y)))"
cnf = fol_to_cnf(formula)
print("\nFinal CNF:", cnf)

# Simple Forward Reasoning (Forward Chaining) in FOL

# Knowledge Base (Facts + Rules)
# Rules are written in the form: (premises, conclusion)
# Facts are just single statements

def forward_chaining(kb, query):
    facts = set()
    rules = []

    # Separate facts and rules
    for statement in kb:
        if "=>" in statement:
            premises, conclusion = statement.split("=>")
            premises = set(p.strip() for p in premises.split("&"))
```

```
            rules.append((premises, conclusion.strip()))
        else:
            facts.add(statement.strip())

    print("Initial Facts:", facts)
    print("Rules:", rules)
    print("Query:", query)

    inferred = True
    while inferred:
        inferred = False
        for premises, conclusion in rules:
            # Check if all premises are in facts
            if premises.issubset(facts) and conclusion not in facts:
                facts.add(conclusion)
                print(f"Inferred: {conclusion}")
                inferred = True
                if conclusion == query:
                    print("Query proven!")
                    return True

    print("Query cannot be proven.")
    return False


# Example Knowledge Base
kb = [
    "A",                    # Fact
    "A & B => C",           # Rule 1
    "C => D",               # Rule 2
    "D & E => F",           # Rule 3
    "B"                     # Fact
]

query = "D"

# Run forward chaining
forward_chaining(kb, query)
```

# Program 9

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

Algorithm:



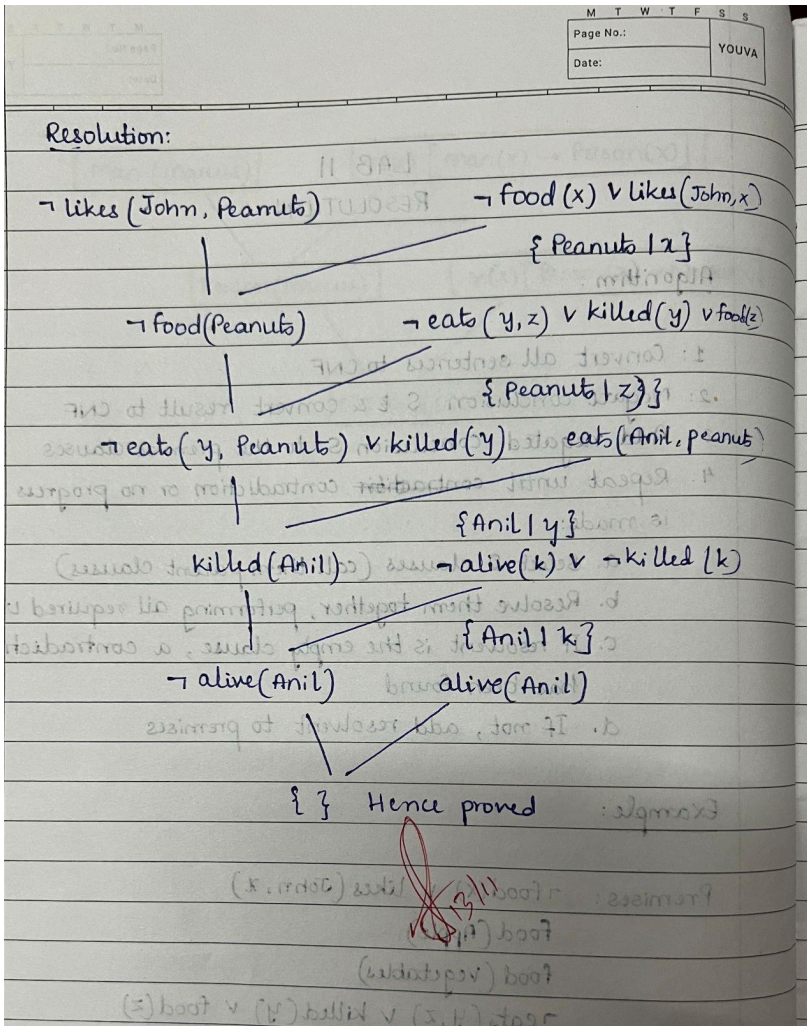
RESOLUTION

Algorithm:

1: Convert all sentences to CNF
2: Negate conclusion S & convert result to CNF
3: Add negated conclusion S to the premise clauses
4: Repeat until ~~contradiction~~ contradiction or no progress is made:
   a. Select 2 clauses (call them parent clauses)
   b. Resolve them together, performing all required unifications
   c. If resolvent is the empty clause, a contradiction has been found
   d. If not, add resolvent to premises

Example:

Premises: $\neg food(x) \vee likes(John, x)$
$food(Apple)$
$food(vegetables)$
$\neg eats(y,z) \vee killed(y) \vee food(z)$
$eats(Anil, Peanuts)$
$alive(Anil)$
$\neg eats(Anil, w) \vee eats(Harry, w)$
$killed(g) \vee alive(g)$
$\neg alive(k) \vee \neg killed(k)$
$likes(John, Peanuts)$




Code:

```
# Simple Forward Reasoning (Forward Chaining) in FOL
# Knowledge Base (Facts + Rules)
# Rules are written in the form: (premises, conclusion)
# Facts are just single statements

def forward_chaining(kb, query):
    facts = set()
    rules = []

    # Separate facts and rules
    for statement in kb:
        if "=>" in statement:
            premises, conclusion = statement.split("=>")
            premises = set(p.strip() for p in premises.split("&"))
            rules.append((premises, conclusion.strip()))
        else:
            facts.add(statement.strip())
```

```
    print("Initial Facts:", facts)
    print("Rules:", rules)
    print("Query:", query)

    inferred = True
    while inferred:
        inferred = False
        for premises, conclusion in rules:
            # Check if all premises are in facts
            if premises.issubset(facts) and conclusion not in facts:
                facts.add(conclusion)
                print(f"Inferred: {conclusion}")
                inferred = True
                if conclusion == query:
                    print("Query proven!")
                    return True

    print("Query cannot be proven.")
    return False


# Example Knowledge Base
kb = [
    "A",                    # Fact
    "A & B => C",           # Rule 1
    "C => D",               # Rule 2
    "D & E => F",           # Rule 3
    "B"                     # Fact
]

query = "D"

# Run forward chaining
forward_chaining(kb, query)
```

Resolution:

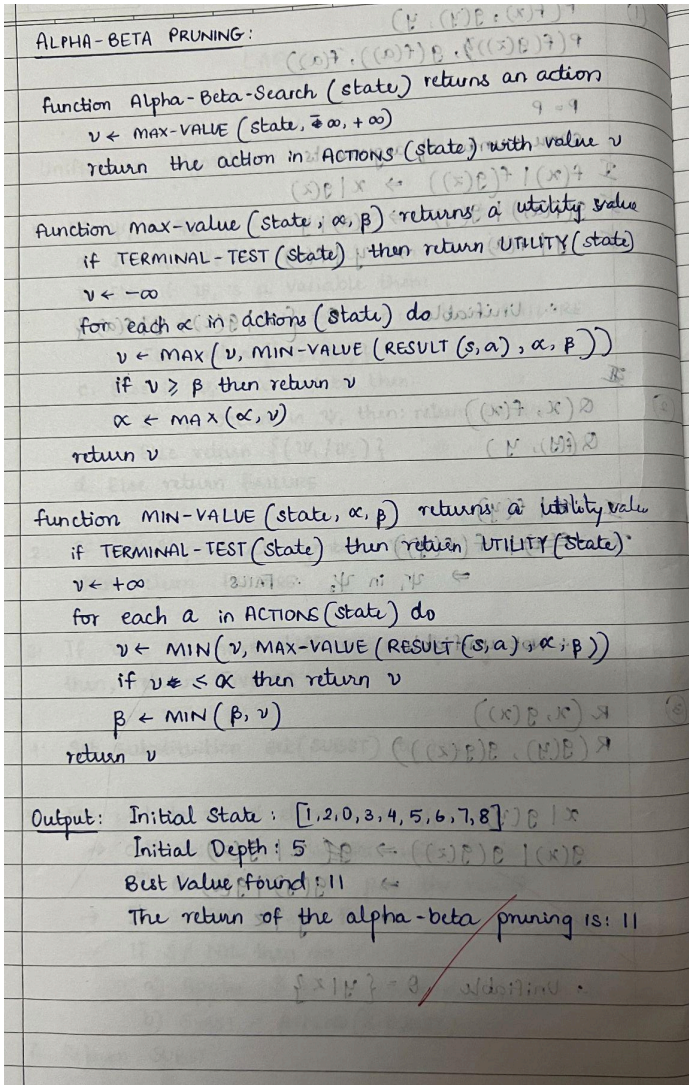
```
!pip install sympy

from sympy import symbols, Or, Not, And
from sympy.logic.inference import satisfiable

# Define propositional atoms (grounded)
food_Apple, food_Veg, food_Peanuts = symbols('food_Apple food_Veg food_Peanuts')
likes_John_Apple, likes_John_Veg, likes_John_Peanuts = symbols('likes_John_Apple
likes_John_Veg likes_John_Peanuts')
eats_Anil_Peanuts, killed_Anil, alive_Anil = symbols('eats_Anil_Peanuts killed_Anil alive_Anil')
```

```
# --- Knowledge Base (grounded CNF clauses) ---
KB = [
    Or(Not(food_Peanuts), likes_John_Peanuts),      # a. ¬food(Peanuts) ∨ likes(John, Peanuts)
    food_Apple,                                     # b. food(Apple)
    food_Veg,                                       # c. food(vegetables)
    Or(Not(eats_Anil_Peanuts), killed_Anil, food_Peanuts), # d. ¬eats(Anil, Peanuts) ∨ killed(Anil)
∨ food(Peanuts)
    eats_Anil_Peanuts,                              # e. eats(Anil, Peanuts)
    alive_Anil,                                     # f. alive(Anil)
    Or(killed_Anil, Not(alive_Anil)),               # h. killed(Anil) ∨ ¬alive(Anil)
    Or(Not(alive_Anil), Not(killed_Anil))           # i. ¬alive(Anil) ∨ ¬killed(Anil)
]

# --- Negated conclusion ---
negated_conclusion = Not(likes_John_Peanuts)
KB.append(negated_conclusion)

# --- Check satisfiability ---
result = satisfiable(And(*KB))

if result is False:
    print("Conclusion PROVED by resolution: likes(John, Peanuts)")
else:
    print("Conclusion NOT proved.")
    print("Satisfying model (means no contradiction):")
    print(result)
```

# Program 10

**Implement Alpha-Beta Pruning.**

Algorithm:



ALPHA-BETA PRUNING:

function Alpha-Beta-Search (state) returns an action
    v ← MAX-VALUE (state, -∞, +∞)
    return the action in ACTIONS (state) with value v

function max-value (state, α, β) returns a utility value
    if TERMINAL-TEST (state) then return UTILITY (state)
    v ← -∞
    for each α in actions (state) do
        v ← MAX (v, MIN-VALUE (RESULT (s, a), α, β))
        if v ≥ β then return v
        α ← MAX (α, v)
    return v

function MIN-VALUE (state, α, β) returns a utility value
    if TERMINAL-TEST (state) then return UTILITY (state)
    v ← +∞
    for each a in ACTIONS (state) do
        v ← MIN (v, MAX-VALUE (RESULT (s, a), α, β))
        if v ≤ α then return v
        β ← MIN (β, v)
    return v

Output: Initial State : [1,2,0,3,4,5,6,7,8]
Initial Depth : 5
Best Value found : 11
The return of the alpha-beta pruning is: 11

Code:

```
import math

def alpha_beta_pruning(state, depth, alpha, beta, maximizing_player):
    # Base case: leaf node or maximum depth reached
    if depth == 0 or is_goal_state(state):
        return heuristic_value(state)
```

```
    if maximizing_player:
        max_eval = -math.inf
        for child_state in get_possible_moves(state):
            eval = alpha_beta_pruning(child_state, depth - 1, alpha, beta, False)
            max_eval = max(max_eval, eval)
            alpha = max(alpha, eval)
            if beta <= alpha:
                break  # Beta cutoff
        return max_eval
    else:  # Minimizing player
        min_eval = math.inf
        for child_state in get_possible_moves(state):
            eval = alpha_beta_pruning(child_state, depth - 1, alpha, beta, True)
            min_eval = min(min_eval, eval)
            beta = min(beta, eval)
            if beta <= alpha:
                break  # Alpha cutoff
        return min_eval

def is_goal_state(state):
    """Checks if the current state is the solved 8-puzzle."""
    # Assuming the goal state is a flattened list [1, 2, 3, 4, 5, 6, 7, 8, 0]
    return state == [1, 2, 3, 4, 5, 6, 7, 8, 0]

def heuristic_value(state):
    """Calculates the Manhattan distance heuristic for the 8-puzzle."""
    goal_state = {
        1: (0, 0), 2: (0, 1), 3: (0, 2),
        4: (1, 0), 5: (1, 1), 6: (1, 2),
        7: (2, 0), 8: (2, 1), 0: (2, 2)
    }
    manhattan_distance = 0
    for i in range(3):
        for j in range(3):
            tile = state[i * 3 + j]
            if tile != 0:
                goal_pos = goal_state[tile]
                manhattan_distance += abs(i - goal_pos[0]) + abs(j - goal_pos[1])
    return manhattan_distance

def get_possible_moves(state):
    """Returns a list of all possible next states from the current state."""
    possible_moves = []
    zero_index = state.index(0)
    zero_row, zero_col = divmod(zero_index, 3)

    # Define possible movements (up, down, left, right)
```

```
    movements = [(-1, 0), (1, 0), (0, -1), (0, 1)]

    for move_row, move_col in movements:
        new_row, new_col = zero_row + move_row, zero_col + move_col

        # Check if the new position is within the board boundaries
        if 0 <= new_row < 3 and 0 <= new_col < 3:
            new_state = list(state)  # Create a mutable copy of the state
            swap_index = new_row * 3 + new_col
            # Swap the blank tile with the tile at the new position
            new_state[zero_index], new_state[swap_index] = new_state[swap_index],
new_state[zero_index]
            possible_moves.append(new_state)

    return possible_moves
initial_state = [1, 2, 0, 3, 4, 5, 6, 7, 8]
initial_depth = 5

print(f"Initial State: {initial_state}")
print(f"Initial Depth: {initial_depth}")
best_value = alpha_beta_pruning(initial_state, initial_depth, -math.inf, math.inf, True)
print(f"Best value found: {best_value}")
print(f"The result of the alpha-beta pruning (best value from the initial state) is: {best_value}")
```

Minimax:

```
import math

# Represents the players
X = 'X'
O = 'O'
EMPTY = ' '

def check_winner(board):
    """
    Checks if there's a winner on the board.
    Returns X if X wins, O if O wins, None if no winner yet, or 'Tie' if full and no winner.
    """
    # Check rows
    for row in board:
        if row[0] == row[1] == row[2] and row[0] != EMPTY:
            return row[0]
    # Check columns
    for col in range(3):
        if board[0][col] == board[1][col] == board[2][col] and board[0][col] != EMPTY:
            return board[0][col]
    # Check diagonals
```

```
    if board[0][0] == board[1][1] == board[2][2] and board[0][0] != EMPTY:
        return board[0][0]
    if board[0][2] == board[1][1] == board[2][0] and board[0][2] != EMPTY:
        return board[0][2]

    # Check for tie (no winner and board is full)
    if all(cell != EMPTY for row in board for cell in row):
        return 'Tie'

    return None

def minimax(board, is_maximizing_player):
    """
    Implements the Minimax algorithm to find the optimal move.
    is_maximizing_player is True for 'X' (AI), False for 'O' (opponent).
    """
    winner = check_winner(board)
    if winner == X:
        return 1  # X wins, maximizing player gets a high score
    elif winner == O:
        return -1 # O wins, minimizing player gets a low score
    elif winner == 'Tie':
        return 0 # Tie game

    if is_maximizing_player:
        best_score = -math.inf
        for r in range(3):
            for c in range(3):
                if board[r][c] == EMPTY:
                    board[r][c] = X # Make the move
                    score = minimax(board, False)
                    board[r][c] = EMPTY # Undo the move
                    best_score = max(best_score, score)
        return best_score
    else: # Minimizing player
        best_score = math.inf
        for r in range(3):
            for c in range(3):
                if board[r][c] == EMPTY:
                    board[r][c] = O # Make the move
                    score = minimax(board, True)
                    board[r][c] = EMPTY # Undo the move
                    best_score = min(best_score, score)
        return best_score

def find_best_move(board):
    """
```

```
    Finds the best move for the AI (X) using the Minimax algorithm.
    """
    best_score = -math.inf
    best_move = None

    for r in range(3):
        for c in range(3):
            if board[r][c] == EMPTY:
                board[r][c] = X # Try the move
                score = minimax(board, False) # Evaluate the board state
                board[r][c] = EMPTY # Undo the move

                if score > best_score:
                    best_score = score
                    best_move = (r, c)
    return best_move

def print_board(board):
    """Prints the Tic-Tac-Toe board."""
    for row in board:
        print("|".join(row))
        print("-----")

# Example usage:
if __name__ == "__main__":
    # Initial empty board
    board = [[EMPTY, EMPTY, EMPTY],
             [EMPTY, EMPTY, EMPTY],
             [EMPTY, EMPTY, EMPTY]]

    current_player = X

    while check_winner(board) is None:
        print_board(board)
        if current_player == X:
            print("AI's turn (X)")
            move = find_best_move(board)
            if move:
                board[move[0]][move[1]] = X
            else:
                print("No valid moves left for AI.")
                break
        else:
            print("Human's turn (O)")
            while True:
                try:
                    row = int(input("Enter row (0-2): "))
```

```
            col = int(input("Enter column (0-2): "))
            if 0 <= row <= 2 and 0 <= col <= 2 and board[row][col] == EMPTY:
                board[row][col] = O
                break
            else:
                print("Invalid move. Try again.")
        except ValueError:
            print("Invalid input. Please enter numbers.")

    current_player = O if current_player == X else X

print_board(board)
final_result = check_winner(board)
if final_result == 'Tie':
    print("It's a Tie!")
elif final_result:
    print(f"Player {final_result} wins!")
else:
    print("Game ended unexpectedly.")
```