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,
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 **Vinayak Sunil Rodd (1WA23CS045),** who is bonafide student of **B.M.S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements in respect of an Artificial Intelligence (23CS5PCAIN) work prescribed for the said degree.

Dr. K R Mamatha Assistant Professor Department of CSE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE

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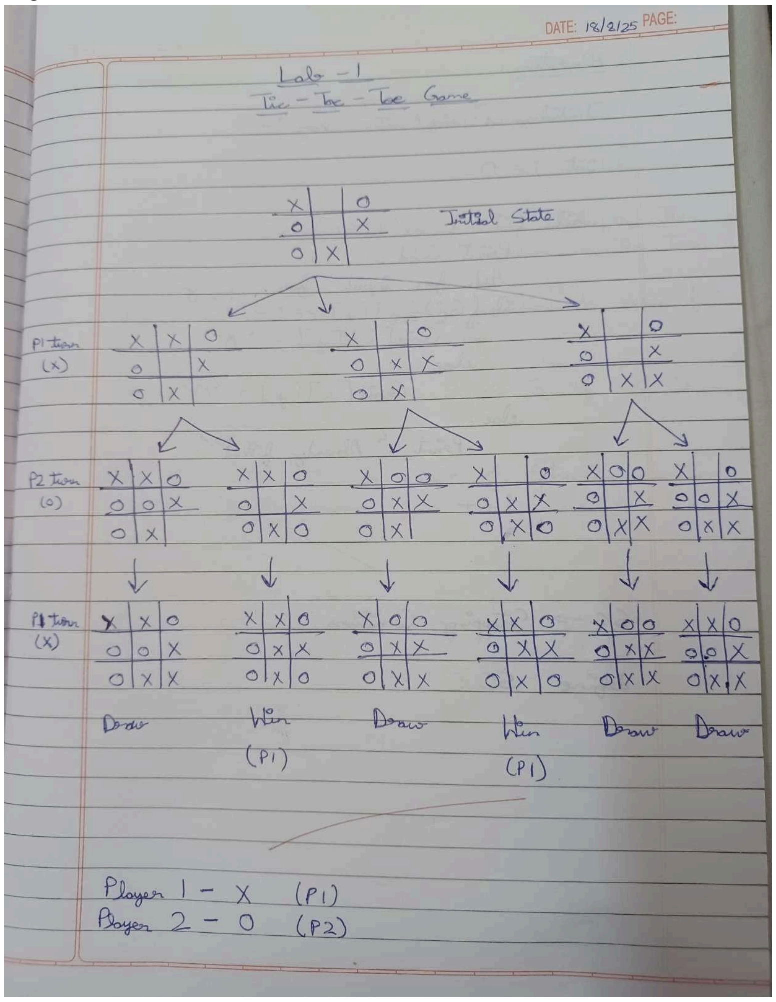
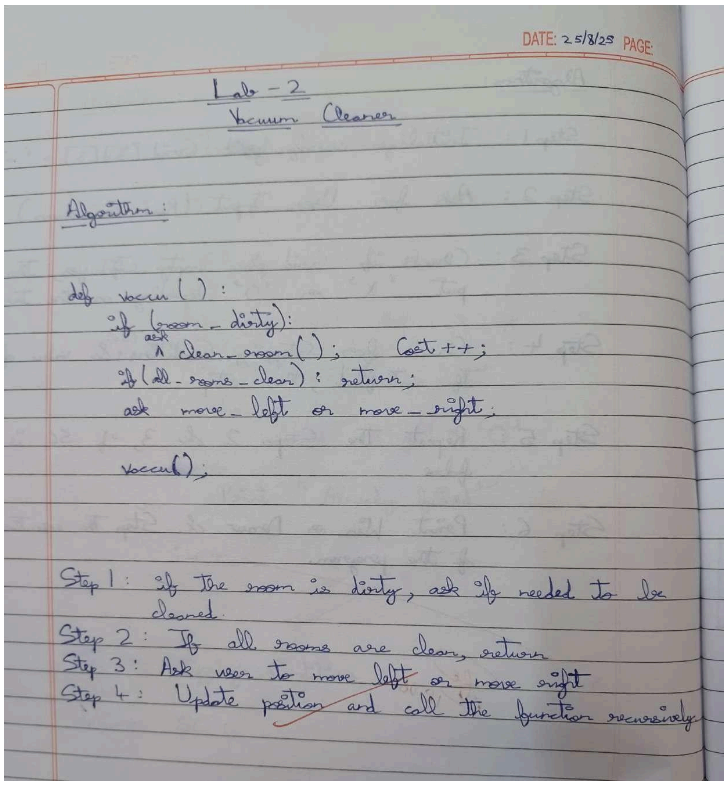
Github Link:
https://github.com/Vinayak1205/AiLab

Program 1

Implement Tic –Tac –Toe Game
Implement vacuum cleaner agent

Algorithm:





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Lab - 2

Vacuum Cleaner

Algorithm :

```
def vaccu ( ) :
    if (room _ dirty):
        ask clear_room( );      Cost ++;
    if (all - rooms _ clean) : return;
    ask  move_ left  or  move _ right;

    vaccu();
```

Step 1 : if the room is dirty, ask if needed to be cleaned.

Step 2 : If all rooms are clean, return

Step 3 : Ask user to move left or move right

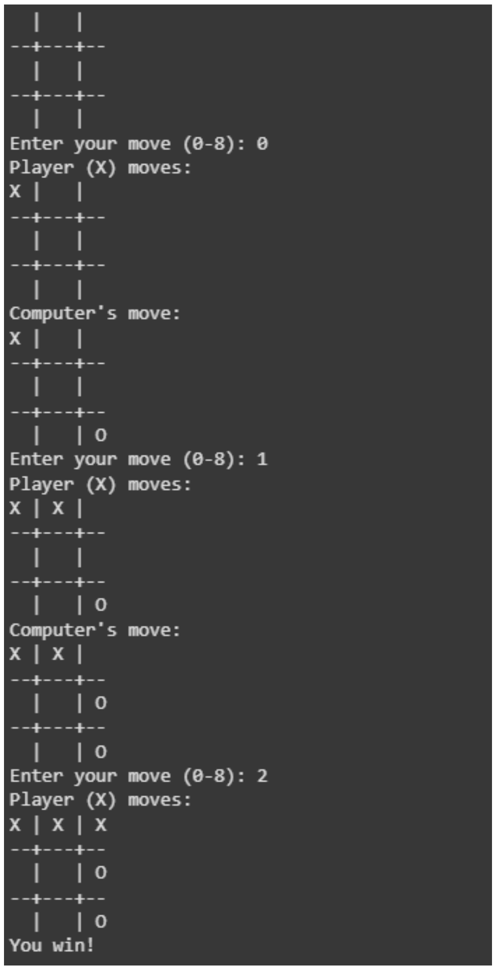
Step 4 : Update position and call the function recursively.

Code:

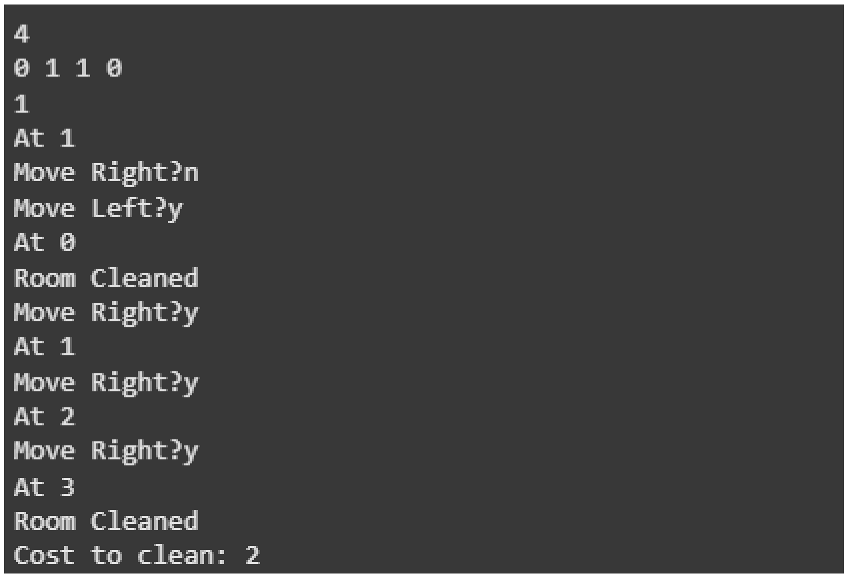
```
# Tic-Tac-Toe game



import random



board = [' ' for _ in range(9)]
current_winner = None



def print_board():
    print(f"{board[0]} | {board[1]} |
    {board[2]}") print("--+---+--")
    print(f"{board[3]} | {board[4]} |
    {board[5]}") print("--+---+--")
    print(f"{board[6]} | {board[7]} | {board[8]}")
```

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

    for condition in win_conditions:
        if all(board[i] == player for i in condition):
            return True
    return False

def check_draw():
    return ' ' not in board

def available_moves():
    return [i for i, spot in enumerate(board) if spot == ' ']

def make_move(position, player):
    if board[position] == ' ':
        board[position] = player
        return True
    return False

def computer_move():
    return random.choice(available_moves())


def play_game():
    global current_winner

    print_board()

    user_player = 'X'
    computer_player = 'O'

    while True:
        user_move = int(input("Enter your move (0-8):
        ")) if make_move(user_move, user_player):
            print("Player (X) moves:")
            print_board()

            if check_winner(user_player):
                current_winner = user_player
                print("You win!")
                break

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

            computer_move_position = computer_move()
            make_move(computer_move_position, computer_player)
            print("Computer's move:")
            print_board()

            if check_winner(computer_player):
                current_winner = computer_player
                print("Computer wins!")
                break

            if check_draw():
                print("It's a draw!")
                break
        else:
            print("Invalid move. Try again.")

if __name__ == "__main__":
    play_game()



# Vacuum Cleaner

def vacuum_cleaner(rooms, position, cost):
    # Base case: If the vacuum is at either end, stop
    if position < 0 or position >= N:
        return cost

    print("At", position);
    if not rooms[position]:
        rooms[position] = True
        cost += 1
        print("Room Cleaned")


    c = input("Move Right?");
    if(c == 'y'):
        return vacuum_cleaner(rooms, position + 1, cost)

    c = input("Move Left?");
    if(c == 'y'):
        return vacuum_cleaner(rooms, position - 1, cost)

    #cost = vacuum_cleaner(rooms, position - 1, cost)
    #cost = vacuum_cleaner(rooms, position + 1, cost)
    return cost


N = int(input())
rooms = [bool(int(x)) for x in input().split()] # Read rooms as booleans
initial_pos = int(input())

total_cost = vacuum_cleaner(rooms, initial_pos, 0)
print("Cost to clean:", total_cost)
```

Output:



```
  |   |
--+---+--
  |   |
--+---+--
  |   |
Enter your move (0-8): 0
Player (X) moves:
X |   |
--+---+--
  |   |
--+---+--
  |   |
Computer's move:
X |   |
--+---+--
  |   |
--+---+--
  |   | O
Enter your move (0-8): 1
Player (X) moves:
X | X |
--+---+--
  |   |
--+---+--
  |   | O
Computer's move:
X | X |
--+---+--
  |   | O
--+---+--
  |   | O
Enter your move (0-8): 2
Player (X) moves:
X | X | X
--+---+--
  |   | O
--+---+--
  |   | O
You win!
```

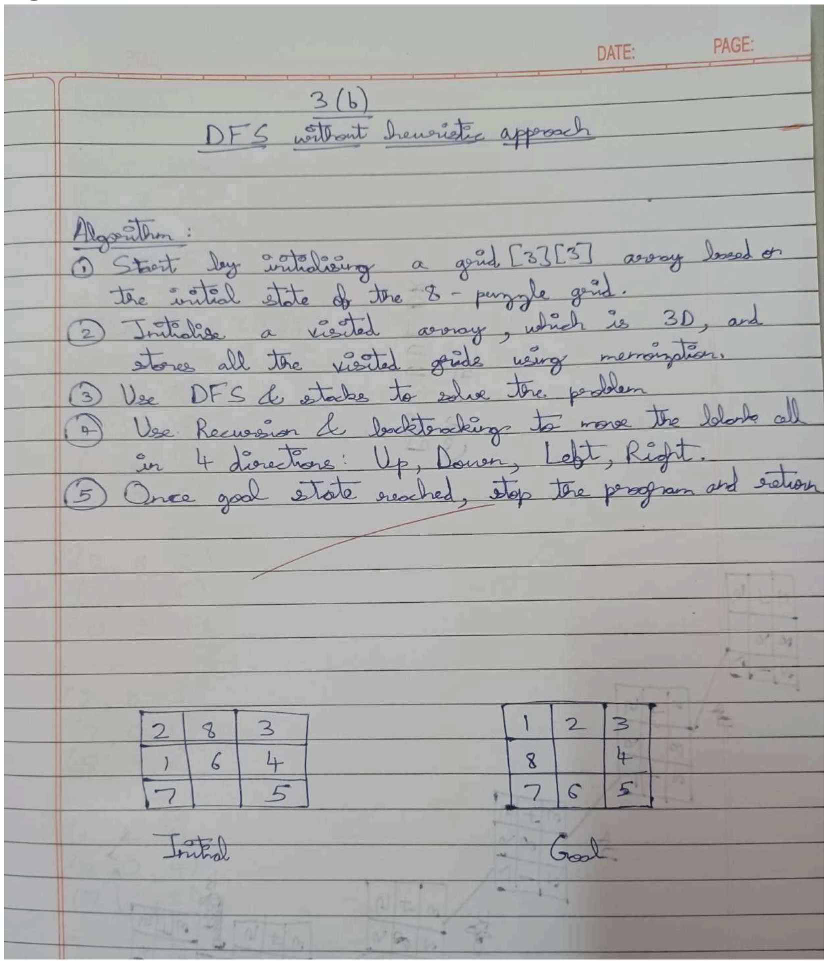


```
4
0 1 1 0
1
At 1
Move Right?n
Move Left?y
At 0
Room Cleaned
Move Right?y
At 1
Move Right?y
At 2
Move Right?y
At 3
Room Cleaned
Cost to clean: 2
```

Program 2

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

Algorithm:



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3(b)

DFS without heuristic approach

Algorithm:

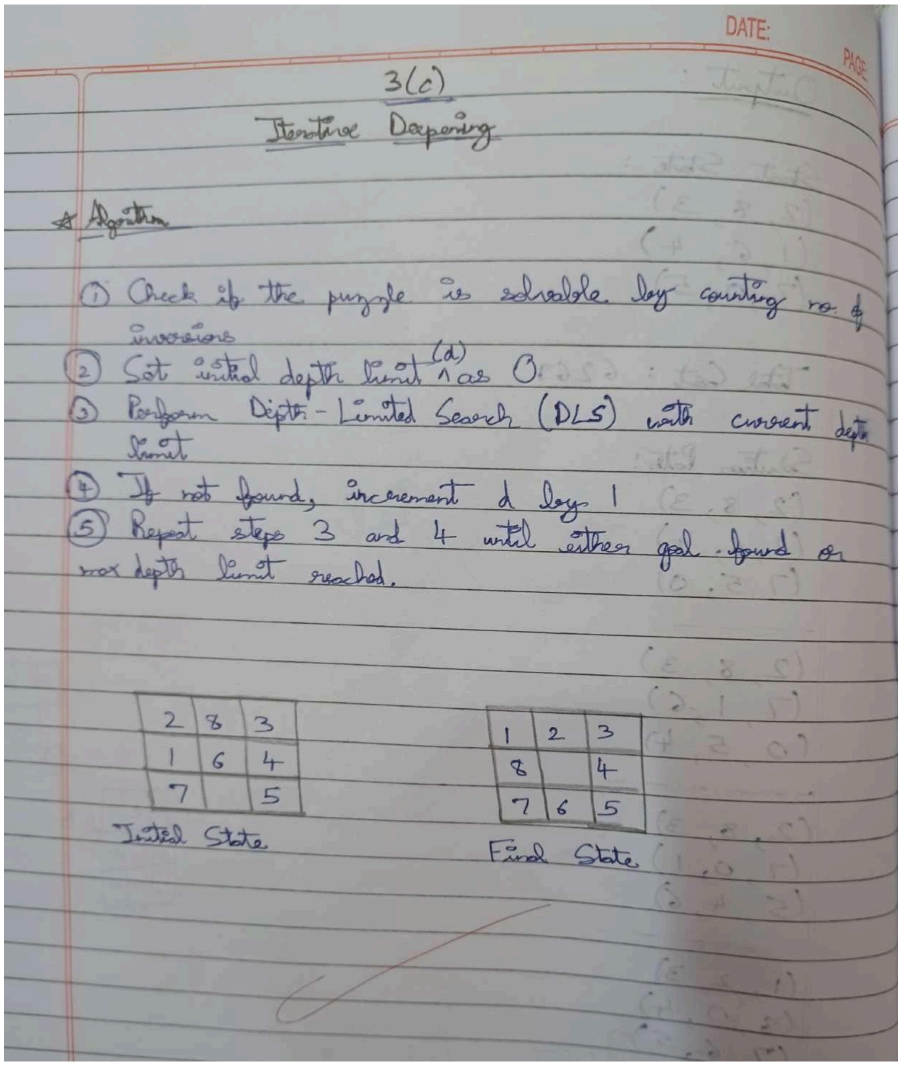
① Start by initialising a grid [3][3] array based on the initial state of the 8-puzzle grid.
② Initialise a visited array, which is 3D, and stores all the visited grids using memoization.
③ Use DFS & stacks to solve the problem
④ Use Recursion & backtracking to move the blank cell in 4 directions: Up, Down, Left, Right.
⑤ Once goal state reached, stop the program and return

2	8	3
1	6	4
7		5

Initial

1	2	3
8		4
7	6	5

Goal



3(c)

Iterative Deepening

* Algorithm

1. Check if the puzzle is solvable by counting no. of inversions
2. Set initial depth limit (d) as 0.
3. Perform Depth-Limited Search (DLS) with current depth limit
4. If not found, increment d by 1
5. Repeat steps 3 and 4 until either goal found or max depth limit reached.

2	8	3
1	6	4
7		5

Initial State

1	2	3
8		4
7	6	5

Final State

Code:

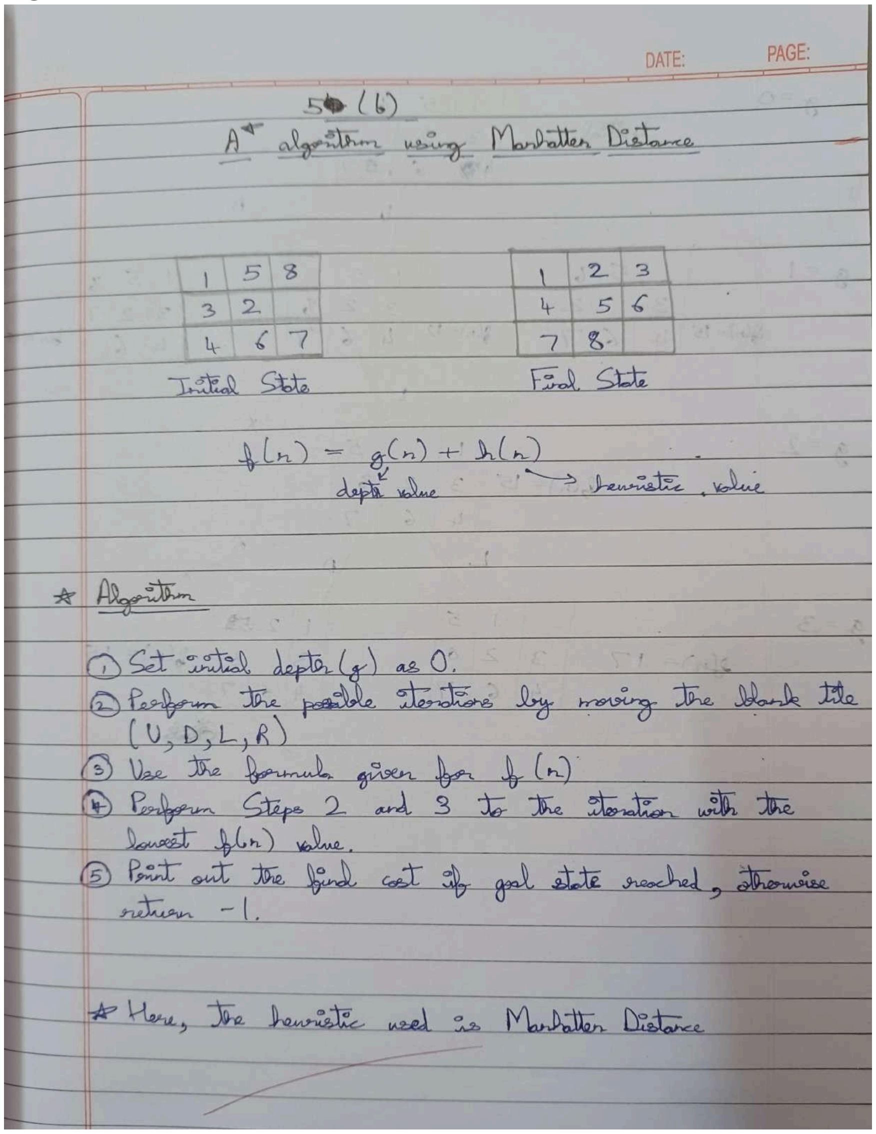
```
# 8-puzzle problem using DFS



from collections import deque



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



valid_moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]

def is_valid_move(position, move, size=3):
    row, col = position
    new_row, new_col = row + move[0], col + move[1]
    return 0 <= new_row < size and 0 <= new_col < size

def get_new_state(state, position, move):
    row, col = position
    new_row, new_col = row + move[0], col + move[1]
    new_state = list(state)
    new_pos = new_row * 3 + new_col
    blank_pos = row * 3 + col
    new_state[blank_pos], new_state[new_pos] = new_state[new_pos], new_state[blank_pos]
    return tuple(new_state)

def dfs(start_state):
    stack = [(start_state, start_state.index(0))]
    visited = set()
    visited.add(start_state)
    parent_map = {start_state: None}
    move_map = {start_state: None}
    total_cost = 1

    visited_states = []

    while stack:

        current_state, blank_pos = stack.pop()
        visited_states.append(current_state)
        if current_state == goal_state:
            path = []
            while current_state != start_state:
                path.append(move_map[current_state])
                current_state = parent_map[current_state]
            return path[::-1], visited_states, total_cost
        row, col = divmod(blank_pos, 3)

        for move in valid_moves:
            if is_valid_move((row, col), move):
                new_state = get_new_state(current_state, (row, col), move)
                if new_state not in visited:
                    visited.add(new_state)
                    stack.append((new_state, new_state.index(0)))
                    parent_map[new_state] = current_state
                    move_map[new_state] = move
                    total_cost += 1
    return None, visited_states, total_cost
def print_state(state):
    for i in range(0, 9, 3):
        print(state[i:i+3])



start_state = (2, 8, 3, 1, 6, 4, 7, 0, 5)
print("Start State:")
print_state(start_state)
path, visited_states, total_cost = dfs(start_state)


if path:


    print("\nSolution Path:")
    current_state = start_state
    for move in path:
        print(f"Move blank {move} from {current_state}")
        row, col = divmod(current_state.index(0), 3)
        current_state = get_new_state(current_state, (row, col), move)
        print_state(current_state)
else:
    print("\nNo solution found.")

print("\nVisited States:")
for state in visited_states:
    print_state(state)
    print("     ")
print(f"\nTotal Cost (Visited States): {total_cost}")
```

```
#8-puzzle using IDS

from collections import deque

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

valid_moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]

def is_valid_move(position, move, size=3):
    row, col = position
    new_row, new_col = row + move[0], col + move[1]
    return 0 <= new_row < size and 0 <= new_col < size

def get_new_state(state, position, move):
    row, col = position
    new_row, new_col = row + move[0], col + move[1]
    new_state = list(state)
    new_pos = new_row * 3 + new_col
    blank_pos = row * 3 + col
    new_state[blank_pos], new_state[new_pos] = new_state[new_pos], new_state[blank_pos]
    return tuple(new_state)

def depth_limited_dfs(start_state, depth_limit, visited_states):
    stack = [(start_state, start_state.index(0), 0)]
    visited = set()
    visited.add(start_state)

    while stack:
        current_state, blank_pos, current_depth = stack.pop()

        visited_states.append(current_state)

        if current_state == goal_state:
            return True

        if current_depth < depth_limit:
            row, col = divmod(blank_pos, 3)
            for move in valid_moves:
                if is_valid_move((row, col), move):
                    new_state = get_new_state(current_state, (row, col), move)
                    if new_state not in visited:
                        visited.add(new_state)
                        stack.append((new_state, new_state.index(0), current_depth + 1))

    return False

def iterative_deepening_search(start_state):
    depth = 0
    visited_states = []
    total_cost = 0

    while True:
        print(f"Searching with depth limit {depth}...")
        if depth_limited_dfs(start_state, depth, visited_states):
            print("Goal found!")
            break
        depth += 1

    total_cost = len(visited_states)

    return visited_states, total_cost

def print_state(state):
    for i in range(0, 9,
    3):
        print(state[i:i+3])


start_state = (2, 8, 3, 1, 6, 4, 7, 0, 5)
print("Start State:")
print_state(start_state)
visited_states, total_cost = iterative_deepening_search(start_state)

print(f"\nTotal Cost (Visited States): {total_cost}")
print("\nAll visited states:")
for state in visited_states:
    print_state(state)
    print("     ")
```

Program 3

Implement A* search algorithm

Algorithm:



5(b)

A* algorithm using Manhattan Distance

1	5	8
3	2	
4	6	7

Initial State

1	2	3
4	5	6
7	8	

Final State

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

depth value

heuristic value

★ Algorithm

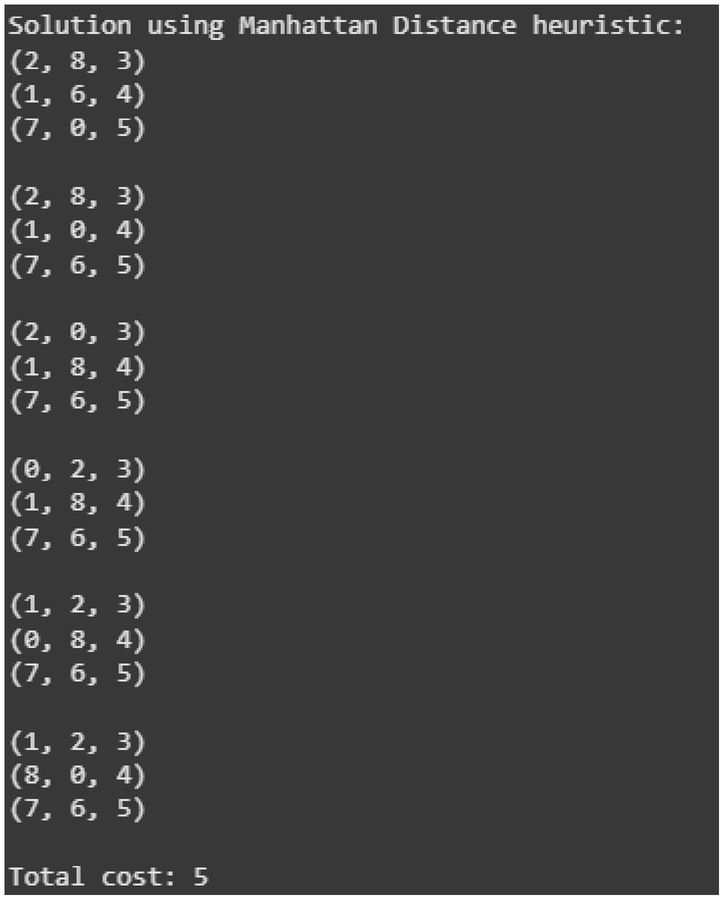
1. Set initial depth (g) as 0.
2. Perform the possible iterations by moving the blank tile (U, D, L, R)
3. Use the formula given for f(n)
4. Perform Steps 2 and 3 to the iteration with the lowest f(n) value.
5. Print out the final cost if goal state reached, otherwise return -1.

★ Here, the heuristic used is Manhattan Distance

Code:

```
# A* algorithm using Manhattan

distance import heapq

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

NEIGHBORS = {
    0: [1, 3], 1: [0, 2, 4], 2: [1, 5],
    3: [0, 4, 6], 4: [1, 3, 5, 7], 5: [2, 4, 8],
    6: [3, 7], 7: [4, 6, 8], 8: [5, 7]
}

def manhattan_distance(state):
    distance = 0
    for i, tile in enumerate(state):
        if tile == 0:
            continue
        goal_pos = GOAL_STATE.index(tile)
        x1, y1 = divmod(i, 3)
        x2, y2 = divmod(goal_pos, 3)
        distance += abs(x1 - x2) + abs(y1 - y2)
    return distance

def get_neighbors(state):
    zero_index = state.index(0)
    neighbors = []
    for swap_index in NEIGHBORS[zero_index]:
        new_state = list(state)
        new_state[zero_index], new_state[swap_index] = new_state[swap_index],
new_state[zero_index]
        neighbors.append(tuple(new_state))
    return neighbors

def reconstruct_path(came_from, current):
    path = [current]
    while current in came_from:
        current = came_from[current]
        path.append(current)
    path.reverse()
    return path

def a_star_manhattan(start_state):
    open_set = []
    heapq.heappush(open_set, (manhattan_distance(start_state), 0, start_state))
    came_from = {}
    g_score = {start_state: 0}
    closed_set = set()
    while open_set:
        f, g, current = heapq.heappop(open_set)

        if current == GOAL_STATE:
            return reconstruct_path(came_from, current)

        closed_set.add(current)

        for neighbor in get_neighbors(current):
            if neighbor in closed_set:
                continue

            tentative_g = g + 1

            if tentative_g < g_score.get(neighbor, float('inf')):
                came_from[neighbor] = current
                g_score[neighbor] = tentative_g
                f_score = tentative_g + manhattan_distance(neighbor)
                heapq.heappush(open_set, (f_score, tentative_g, neighbor))
    return None


if _name____== "_main_": start
    = (2, 8, 3, 1, 6, 4, 7, 0, 5)
    path = a_star_manhattan(start)

    if path:
        print("Solution using Manhattan Distance heuristic:")
        for state in path:
            print(state[:3], state[3:6], state[6:], sep="\n", end="\n\n")
        print(f"Total cost: {len(path) - 1}")
    else:
        print("No solution found.")
```

Output:

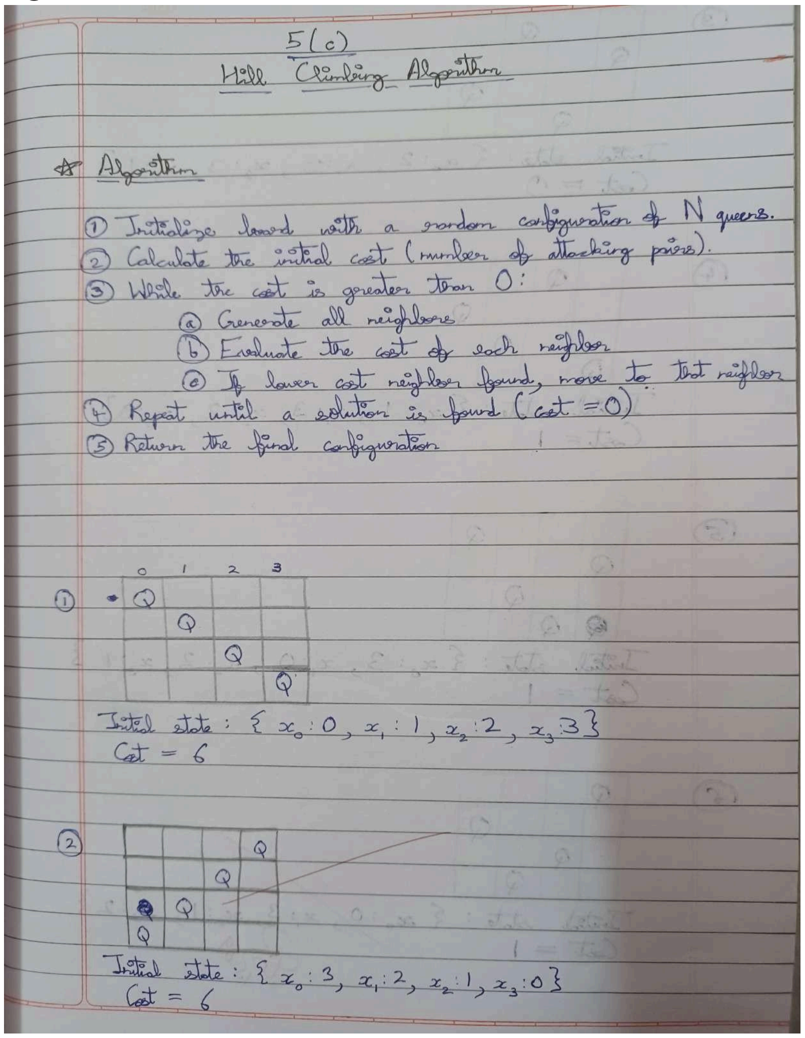


```
Solution using Manhattan Distance heuristic:
(2, 8, 3)
(1, 6, 4)
(7, 0, 5)

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

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

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

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

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

Total cost: 5
```

Program 4

Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm:



5(c)

Hill Climbing Algorithm

☆ Algorithm

```
① Initialize board with a random configuration of N queens.
② Calculate the initial cost (number of attacking pairs).
③ While the cost is greater than 0:
        ⓐ Generate all neighbors
        ⓑ Evaluate the cost of each neighbor
        ⓒ If lower cost neighbor found, move to that neighbor
④ Repeat until a solution is found (cost = 0)
⑤ Return the final configuration
```

①

	0	1	2	3
	Q			
		Q		
			Q	
				Q

Initial state : { x_0 : 0 , x_1 : 1 , x_2 : 2 , x_3 3 }
Cost = 6

②

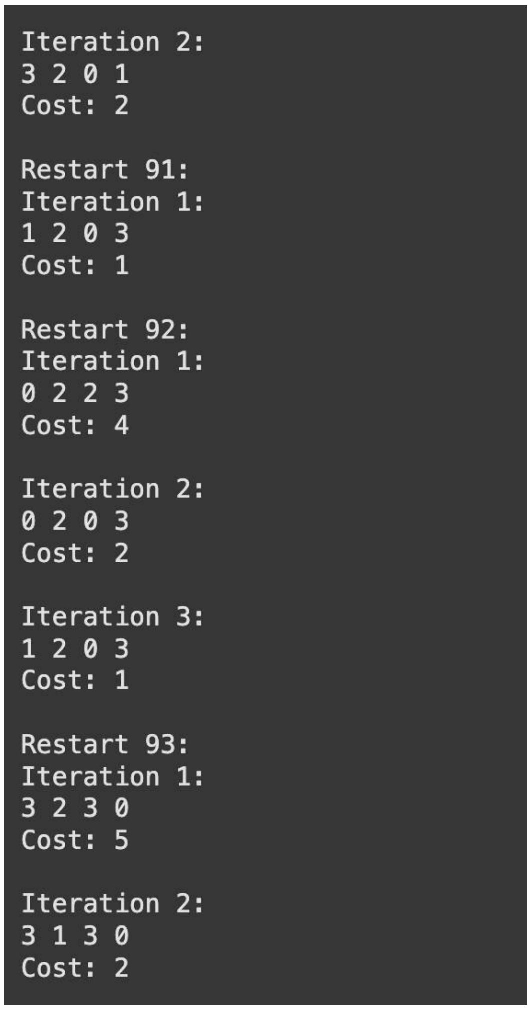
			Q
		Q	
	Q		
Q			

Initial state : { x_0 : 3, x_1 : 2, x_2 : 1, x_3 : 0 }
Cost = 6

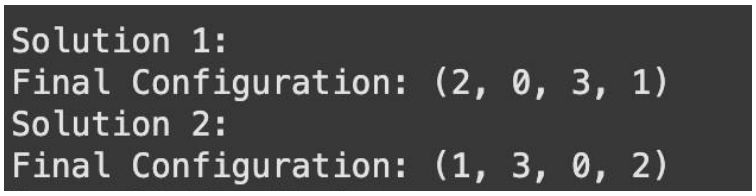
Code:

```
# All steps for Hill Climbing Algorithm

import random

def calculate_cost(board):

    cost = 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]) == j - i:
                cost += 1
    return cost

def get_neighbors(board):
    neighbors = []
    n = len(board)
    for row in range(n):
        for new_col in range(n):
            if new_col != board[row]:
                new_board = board[:]
                new_board[row] = new_col
                neighbors.append(new_board)
    return neighbors

def hill_climbing(n, max_restarts=100):
    solutions = set()
    all_iterations = []

    for restart in range(max_restarts):
        current_board = [random.randint(0, n-1) for _ in range(n)]
        current_cost = calculate_cost(current_board)
        iterations = []
        iterations.append((list(current_board),
        current_cost)) while current_cost > 0:
            neighbors = get_neighbors(current_board)
            next_board = None
            next_cost = current_cost

            for neighbor in neighbors:
                cost = calculate_cost(neighbor)
                if cost < next_cost:
                    next_board = neighbor
                    next_cost = cost

            if next_board is None:
                break
            else:
                current_board = next_board
                current_cost = next_cost
            iterations.append((list(current_board),


        current_cost)) if current_cost == 0:


            solutions.add(tuple(current_board))

        all_iterations.append(iterations)

    return list(solutions), all_iterations

def print_solution(board): print("
    ".join(map(str, board)))

n = 4
solutions, all_iterations = hill_climbing(n)

for restart_idx, iterations in enumerate(all_iterations):
    print(f"Restart {restart_idx + 1}:")
    for step_idx, (board_state, cost) in enumerate(iterations):
        print(f"Iteration {step_idx + 1}:")
        print_solution(board_state)
        print(f"Cost: {cost}")
        print()


for i, solution in enumerate(solutions):
    print(f"Solution {i + 1}:")
    print_solution(solution)
    print()
```

Output:



```
Iteration 2:
3 2 0 1
Cost: 2

Restart 91:
Iteration 1:
1 2 0 3
Cost: 1

Restart 92:
Iteration 1:
0 2 2 3
Cost: 4

Iteration 2:
0 2 0 3
Cost: 2

Iteration 3:
1 2 0 3
Cost: 1

Restart 93:
Iteration 1:
3 2 3 0
Cost: 5

Iteration 2:
3 1 3 0
Cost: 2
```

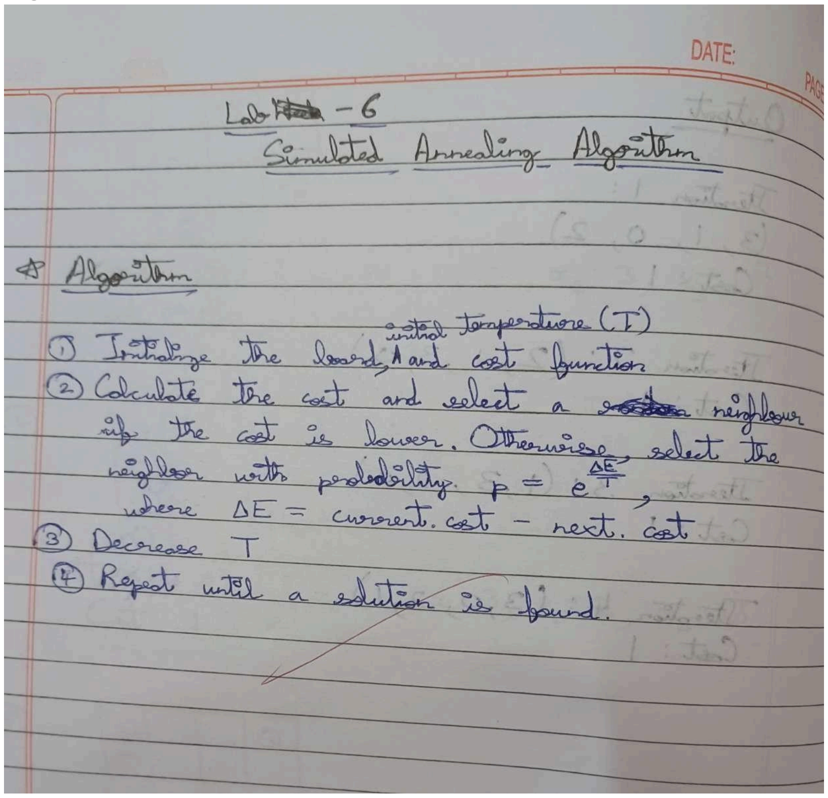


```
Solution 1:
Final Configuration: (2, 0, 3, 1)
Solution 2:
Final Configuration: (1, 3, 0, 2)
```

Program 5

Simulated Annealing to Solve 8-Queens problem

Algorithm:



DATE:

Lab - 6

Simulated Annealing Algorithm

Algorithm

1. Initialize the board, initial temperature (T) and cost function
2. Calculate the cost and select a [illegible] neighbour if the cost is lower. Otherwise, select the neighbour with probability $p = e^{\frac{\Delta E}{T}}$, where ΔE = current. cost - next. cost
3. Decrease T
4. Repeat until a solution is found.

Code:

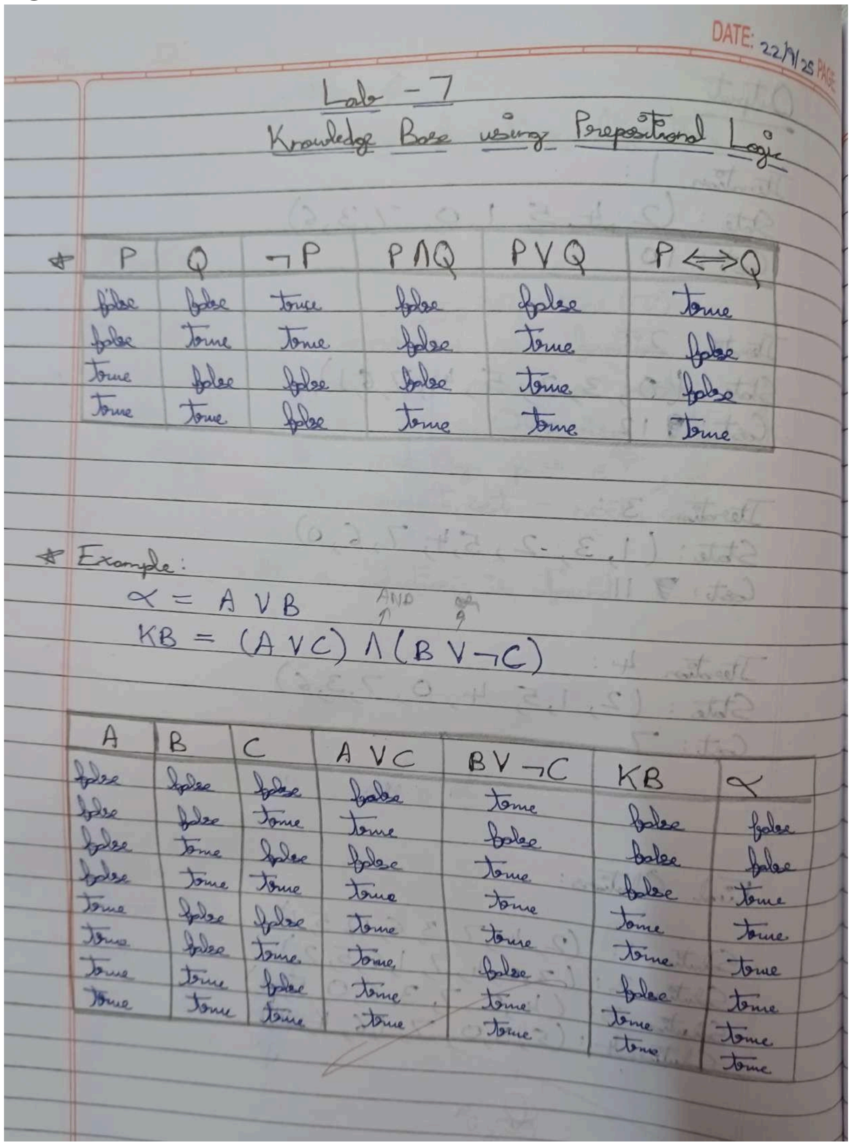
```
# Simualted Annealing
# All steps

import numpy as np
from scipy.optimize import dual_annealing

def calculate_cost(board):
    cost = 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]) == j - i:
                cost += 1
    return cost
```

```
def cost_function(board):
    board = np.round(board).astype(int)
    return calculate_cost(board)

def log_intermediate_results(x, f, context):
    iteration_data.append((np.round(x).astype(int), f))

def solve_8_queens(n=8, max_restarts=100):
    bounds = [(0, n-1)] * n
    unique_solutions = set()

    all_iterations = []
    for _ in range(max_restarts):
        global iteration_data
        iteration_data = []
        result = dual_annealing(cost_function, bounds, callback=log_intermediate_results)


        solution = np.round(result.x).astype(int)


        cost = result.fun
        all_iterations.append(iteration_data)
        if cost == 0:
            unique_solutions.add(tuple(solution))

    return list(unique_solutions), all_iterations

def print_solution(board): print("
    ".join(map(str, board)))
solutions, all_iterations = solve_8_queens()


print("All Iterations for Each Restart:")


for restart_idx, iterations in enumerate(all_iterations):
    print(f"Restart {restart_idx + 1}:")
    for step_idx, (board_state, cost) in enumerate(iterations):
        print(f"Iteration {step_idx + 1}:")
        print("State (Queen positions):", board_state)
        print("Cost:", cost)
        print()

print("Unique Solutions Found:")
for idx, solution in enumerate(solutions):
    print(f"Solution {idx + 1}:")
    print_solution(solution)
    print()
```

Program 6

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

Algorithm:



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Lab - 7

Knowledge Base using Prepositional Logic

P	Q	$\neg P$	$P \wedge Q$	$P \vee Q$	$P \Leftrightarrow Q$
false	false	true	false	false	true
false	true	true	false	true	false
true	false	false	false	true	false
true	true	false	true	true	true

Example:

$\alpha = A \vee B$

$KB = (A \vee C) \overset{AND}{\wedge} (B \overset{OR}{\vee} \neg C)$

A	B	C	$A \vee C$	$B \vee \neg C$	KB	α
false	false	false	false	true	false	false
false	false	true	true	false	false	false
false	true	false	false	true	false	true
false	true	true	true	true	true	true
true	false	false	true	true	true	true
true	false	true	true	false	false	true
true	true	false	true	true	true	true
true	true	true	true	true	true	true

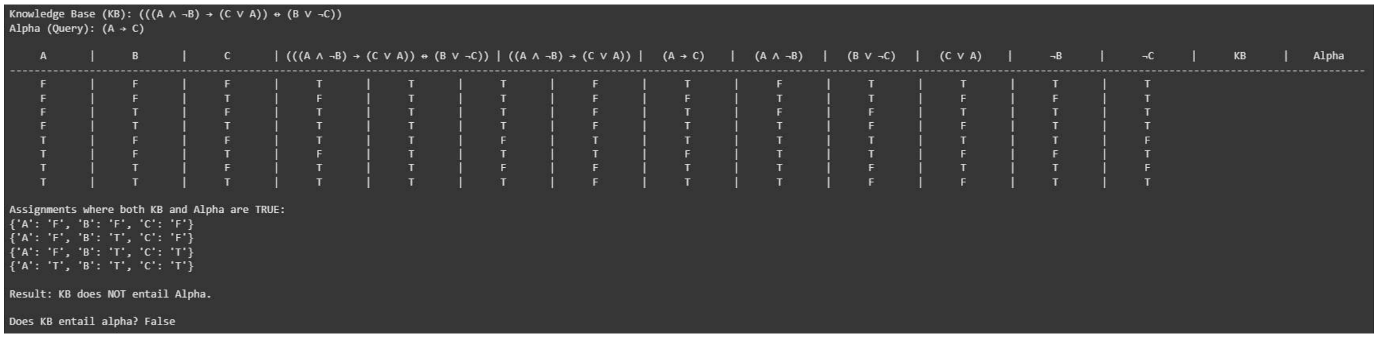
Code:

```
# Knowledge Base using Prepositional Logic

# Symbols: AND, OR, Negation/NOT, Implies/Implication, If and only If

from itertools import product
```

```
def AND(p, q):
    return p and q

def OR(p, q):
    return p or q

def NOT(p):
    return not p

def IMPLIES(p, q):
    return (not p) or q

def IFF(p, q):
    return p == q

class Formula:
    def _init_(self, op, *args):
        self.op = op
        self.args = args

    def evaluate(self, assignment):
        if isinstance(self.op, str) and len(self.args) == 0:
            return assignment[self.op]

        if self.op == 'AND':
            return AND(self.args[0].evaluate(assignment), self.args[1].evaluate(assignment))
        elif self.op == 'OR':
            return OR(self.args[0].evaluate(assignment), self.args[1].evaluate(assignment))
        elif self.op == 'NOT':
            return NOT(self.args[0].evaluate(assignment))
        elif self.op == 'IMPLIES':
            return IMPLIES(self.args[0].evaluate(assignment), self.args[1].evaluate(assignment))
        elif self.op == 'IFF':
            return IFF(self.args[0].evaluate(assignment), self.args[1].evaluate(assignment))
        else:
            raise ValueError(f"Unknown operator: {self.op}")

    def _str_(self):
        if isinstance(self.op, str) and len(self.args) == 0:
            return self.op
        elif self.op == 'NOT':
            return f"¬{self.args[0]}"
        elif self.op == 'AND':
            return f"({self.args[0]} ∧ {self.args[1]})"
        elif self.op == 'OR':
            return f"({self.args[0]} ∨ {self.args[1]})"
        elif self.op == 'IMPLIES':
            return f"({self.args[0]} → {self.args[1]})"
        elif self.op == 'IFF':
            return f"({self.args[0]} ↔ {self.args[1]})"
        else:
            return f"UnknownOp({self.op})"

def
    extract_symbols(formula):
    symbols = set()
    if isinstance(formula.op, str) and len(formula.args) == 0:
        symbols.add(formula.op)
    else:
        for arg in formula.args:
            symbols |= extract_symbols(arg)
    return symbols

def extract_main_subformulas(formula):
    subs = set()
    subs.add(formula)
    for arg in formula.args:
        subs.add(arg)
    return subs

def entails(KB, alpha):
    base_symbols = {'A', 'B', 'C'}
    symbols_in_formulas = extract_symbols(KB) | extract_symbols(alpha)
    all_symbols = sorted(list(base_symbols | symbols_in_formulas))

    subformulas_KB = extract_subformulas(KB)
    subformulas_alpha = extract_subformulas(alpha)
    all_subformulas = list(subformulas_KB | subformulas_alpha)

    all_subformulas = [f for f in all_subformulas if not (isinstance(f.op, str) and len(f.args) == 0)]
```

```
all_subformulas.sort(key=lambda f: str(f))

print("Knowledge Base (KB):", KB)
print("Alpha (Query):", alpha)
print()
headers = all_symbols + [str(f) for f in all_subformulas] + ["KB", "Alpha"]

truth_table = []


true_assignments = []

for values in product([False, True], repeat=len(all_symbols)):
    assignment = dict(zip(all_symbols, values))

    subformula_values = []
    for f in all_subformulas:
        val = f.evaluate(assignment)
        subformula_values.append(val)

    kb_val = KB.evaluate(assignment)
    alpha_val = alpha.evaluate(assignment)

    truth_table.append((assignment, subformula_values, kb_val, alpha_val))
    if kb_val and alpha_val:
        true_assignments.append(assignment)

header_str = " | ".join(f"{h:^12}" for h in headers)
print(header_str)
print("-" * len(header_str))

for assignment, sub_vals, kb_val, alpha_val in truth_table:
    vals = ['T' if assignment[s] else 'F' for s in all_symbols]
    vals += ['T' if v else 'F' for v in sub_vals]
    vals += ['T' if kb_val else 'F', 'T' if alpha_val else 'F']

    row_str = " | ".join(f"{v:^12}" for v in vals)
    print(row_str)

print("\nAssignments where both KB and Alpha are TRUE:")
if true_assignments:
        for a in true_assignments:
            print({k: ('T' if v else 'F') for k, v in a.items()})
    else:
        print("None")

    for assignment, sub_vals, kb_val, alpha_val in truth_table:
        if kb_val and not alpha_val:
            print("\nResult: KB does NOT entail Alpha.")
            return False

    print("\nResult: KB entails Alpha.")
    return True



A = Formula('A')
B = Formula('B')
C = Formula('C')

KB = Formula('IFF',
            Formula('IMPLIES',
                    Formula('AND', A, Formula('NOT', B)),
                    Formula('OR', C, A)),
            Formula('OR', B, Formula('NOT', C))
           )
alpha = Formula('IMPLIES', A, C)
result = entails(KB, alpha)
print(f"\nDoes KB entail alpha? {result}")
```

<u>Output:</u>

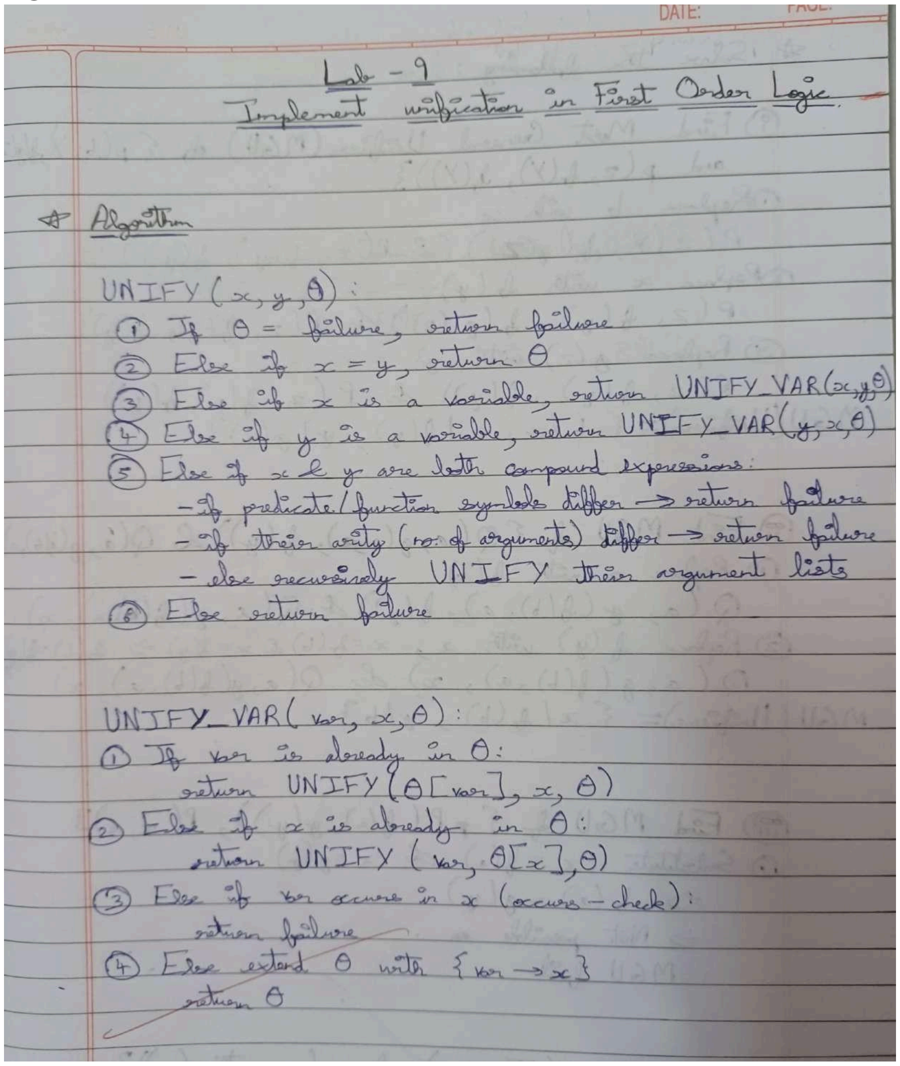


```
Knowledge Base (KB): (((A ∧ ¬B) → (C ∨ A)) ↔ (B ∨ ¬C))
Alpha (Query): (A → C)

    A      |     B      |     C      | (((A ∧ ¬B) → (C ∨ A)) ↔ (B ∨ ¬C)) | ((A ∧ ¬B) → (C ∨ A)) |   (A → C)    |  (A ∧ ¬B)   |  (B ∨ ¬C)   |  (C ∨ A)    |     ¬B      |     ¬C      |     KB      |    Alpha
-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
    F      |     F      |     F      |     T      |     T      |     T      |     F      |     T      |     F      |     T      |     T      |     T      |     T
    F      |     F      |     T      |     F      |     T      |     T      |     F      |     F      |     T      |     T      |     F      |     F      |     T
    F      |     T      |     F      |     T      |     T      |     T      |     F      |     T      |     F      |     F      |     T      |     T      |     T
    F      |     T      |     T      |     T      |     T      |     T      |     F      |     T      |     T      |     F      |     F      |     T      |     T
    T      |     F      |     F      |     T      |     T      |     F      |     T      |     T      |     T      |     T      |     T      |     T      |     F
    T      |     F      |     T      |     F      |     T      |     T      |     T      |     F      |     T      |     T      |     F      |     F      |     T
    T      |     T      |     F      |     T      |     T      |     F      |     F      |     T      |     T      |     F      |     T      |     T      |     F
    T      |     T      |     T      |     T      |     T      |     T      |     F      |     T      |     T      |     F      |     F      |     T      |     T

Assignments where both KB and Alpha are TRUE:
{'A': 'F', 'B': 'F', 'C': 'F'}
{'A': 'F', 'B': 'T', 'C': 'F'}
{'A': 'F', 'B': 'T', 'C': 'T'}
{'A': 'T', 'B': 'T', 'C': 'T'}

Result: KB does NOT entail Alpha.

Does KB entail alpha? False
```

Program 7

Implement unification in first order logic

Algorithm:



Lab - 9

Implement unification in First Order Logic

Algorithm

```
UNIFY(x, y, θ):
① If θ = failure, return failure
② Else if x = y, return θ
③ Else if x is a variable, return UNIFY_VAR(x,y,θ)
④ Else if y is a variable, return UNIFY_VAR(y,x,θ)
⑤ Else if x & y are both compound expressions:
     - if predicate/function symbols differ → return failure
     - if their arity (no. of arguments) differ → return failure
     - else recursively UNIFY their argument lists
⑥ Else return failure

UNIFY_VAR(var, x, θ):
① If var is already in θ:
     return UNIFY(θ[var], x, θ)
② Else if x is already in θ:
     return UNIFY(var, θ[x], θ)
③ Else if var occurs in x (occurs-check):
     return failure
④ Else extend θ with {var → x}
     return θ
```

Code:

```
# Implement unification in first order logic

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

def is_compound(x):
    return isinstance(x, tuple) and len(x) > 0

def get_functor(x):
    return x[0] if is_compound(x) else None
```

```
def get_args(x):
    return list(x[1:]) if is_compound(x) else []

def occur_check(var, x, theta):
    if var == x:
        return True
    elif is_variable(x) and x in theta:
        return occur_check(var, theta[x], theta)
    elif is_compound(x):
        return any(occur_check(var, arg, theta) for arg in get_args(x))
    else:
        return False

def unify(x, y, theta=None):
    if theta is None:
        theta = {}

    if theta == "failure":
        return "failure"
    elif x == y:
        return theta
    elif is_variable(x):
        return unify_var(x, y, theta)
    elif is_variable(y):
        return unify_var(y, x, theta)
    elif is_compound(x) and is_compound(y):
        if get_functor(x) != get_functor(y):
            return "failure"
        if len(get_args(x)) != len(get_args(y)):
            return "failure"
        return unify(get_args(x), get_args(y), theta)
    elif isinstance(x, list) and isinstance(y, list):
        if len(x) != len(y):
            return "failure"
        if not x:
            return theta
        first_unify = unify(x[0], y[0], theta)
        return unify(x[1:], y[1:], first_unify)
    else:
        return "failure"

def unify_var(var, x, theta):
    if var in theta:
        return unify(theta[var], x, theta)
    elif is_variable(x) and x in theta:
        return unify(var, theta[x], theta)
    elif occur_check(var, x, theta):
        return
    "failure" else:
        theta[var] = x
        return theta



expr1 = ("P", "x", ("h", "y"))
expr2 = ("P", "a", ("h", "b"))
print(unify(expr1, expr2))

expr3 = ("P", "x", ("h", "y"))
expr4 = ("P", "a", ("f", "z"))
print(unify(expr3, expr4))

expr5 = ("Knows", "John", "x")
expr6 = ("Knows", "x", "Elisabeth")
print(unify(expr5, expr6))
```

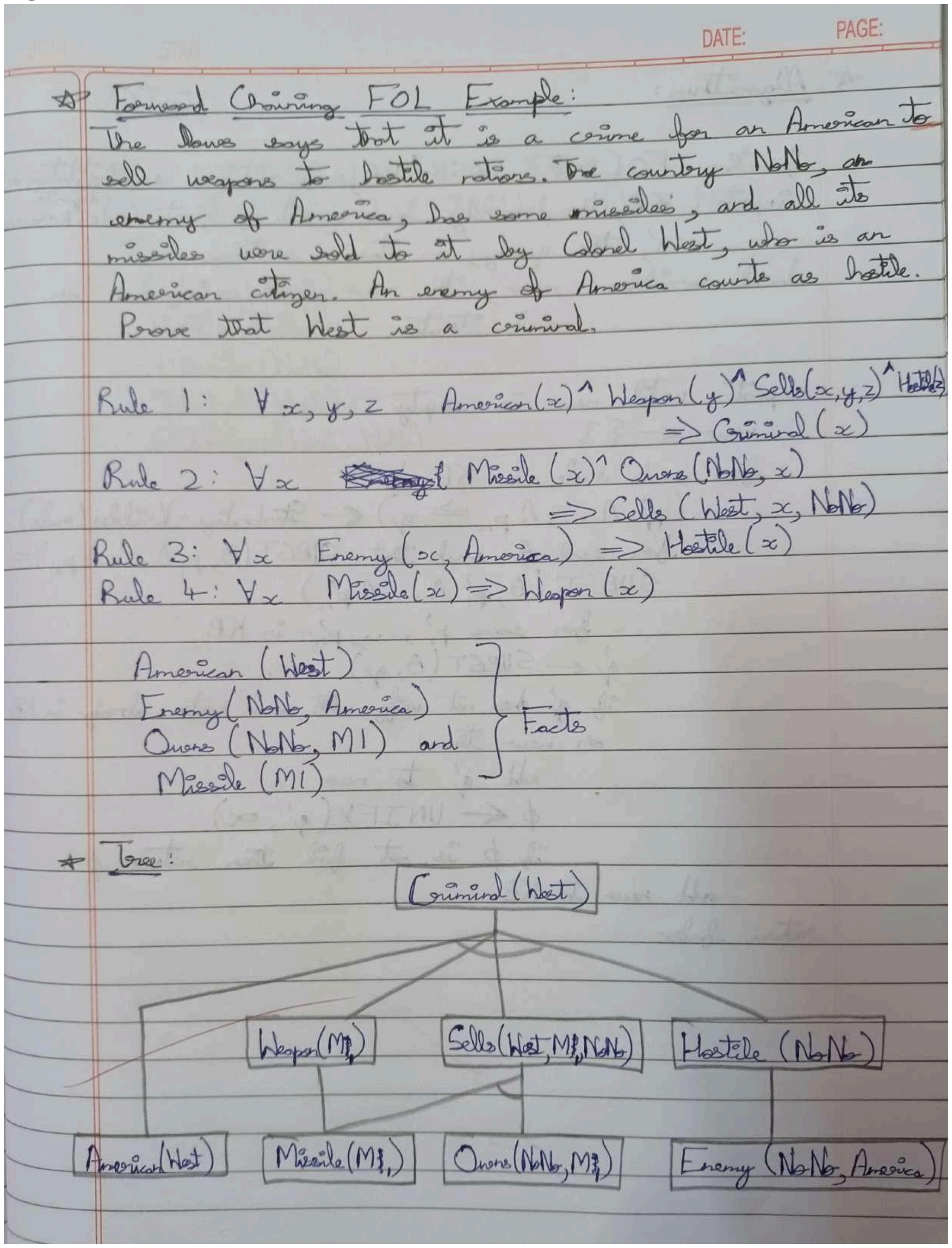
Output:

```
{'x': 'a', 'y': 'b'}
failure
failure
```

Program 8

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

Algorithm:



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☆ Forward Chaining FOL Example:

The laws says that it is a crime for an American to sell weapons to hostile nations. The country NoNo, an enemy of America, has some missiles, and all its missiles were sold to it by Colonel West, who is an American citizen. An enemy of America counts as hostile. Prove that West is a criminal.

Rule 1: $\forall x, y, z$ American$(x) \wedge$ Weapon$(y) \wedge$ Sells$(x,y,z) \wedge$ Hostile(z) $\Rightarrow$ Criminal(x)

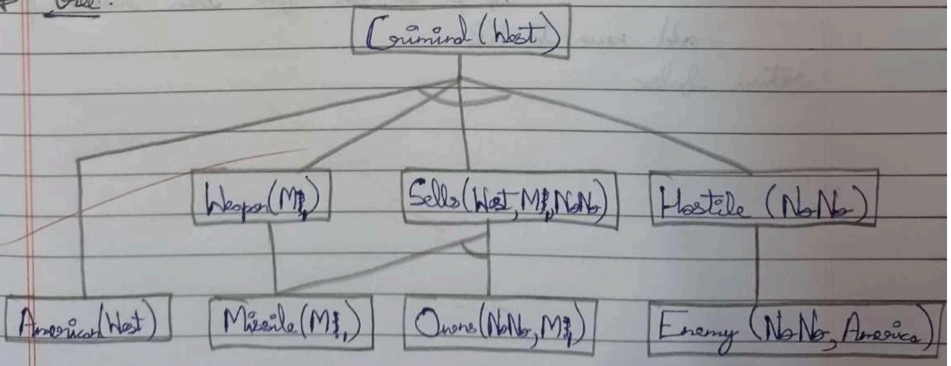
Rule 2: $\forall x$ ~~[illegible]~~ Missile$(x) \wedge$ Owns(NoNo, x) $\Rightarrow$ Sells(West, x, NoNo)

Rule 3: $\forall x$ Enemy(x, America) $\Rightarrow$ Hostile(x)

Rule 4: $\forall x$ Missile$(x) \Rightarrow$ Weapon(x)

American (West)
Enemy(NoNo, America)
Owns (NoNo, M1) and
Missile (M1)
} Facts

* Tree:



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

```
# Forward reasoning in First Order Logic

from itertools import product


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

def substitute(theta, x):
    if isinstance(x, tuple):
        return (x[0], [substitute(theta, arg) for arg in x[1]])
    elif isinstance(x, list):
        return [substitute(theta, xi) for xi in x]
    else:
        return theta.get(x, x)


def unify(x, y, theta=None):
    if theta is None:
        theta = {}
    if theta == "fail":
        return "fail"
    elif x == y:
        return theta
    elif is_variable(x):
        return unify_var(x, y, theta)
    elif is_variable(y):
        return unify_var(y, x, theta)
    elif isinstance(x, tuple) and isinstance(y, tuple):
        if x[0] != y[0] or len(x[1]) != len(y[1]):
            return "fail"
        return unify(x[1], y[1], theta)
    elif isinstance(x, list) and isinstance(y, list):
        if not x and not y:
            return theta
        return unify(x[1:], y[1:], unify(x[0], y[0], theta))
    else:
        return "fail"

def unify_var(var, x, theta):
    if var in theta:
        return unify(theta[var], x, theta)
    elif x in theta:
        return unify(var, theta[x], theta)
    elif occurs_check(var, x, theta):
        return "fail"
    else:
        new_theta = theta.copy()
        new_theta[var] = x
        return new_theta

def occurs_check(var, x, theta):
    if var == x:
        return True
    elif isinstance(x, list):
        return any(occurs_check(var, xi, theta) for xi in x)
    elif isinstance(x, tuple):
        return occurs_check(var, x[1], theta)
    elif x in theta:
        return occurs_check(var, theta[x], theta)
    return False


def pred(name, *args):
    return (name, list(args))


def fol_fc_ask(KB, query, trace=True):
    inferred = set(map(str, KB["facts"]))
    new_inferred = True
    iteration = 0

    while new_inferred:
        iteration += 1
        new_inferred = False
        if trace:
```

```
        print(f"\n--- Iteration {iteration} ---")

      for rule in KB["rules"]:
        premises, conclusion = rule
        possible_bindings = [list(inferred) for _ in premises]

        for facts_combo in product(*possible_bindings):
          theta = {}
          ok = True
          for premise, fact in zip(premises, facts_combo):
            fact = eval(fact)
            theta = unify(premise, fact, theta)
            if theta == "fail":
              ok = False
              break

          if not ok:
            continu
            e

          inferred_fact = substitute(theta, conclusion)
          inferred_str = str(inferred_fact)

          if inferred_str not in inferred:
            inferred.add(inferred_str)
            new_inferred = True
            if trace:
              print(f"Derived new fact: {inferred_fact} from {premises}")

            if unify(inferred_fact, query) != "fail":
              if trace:
                print(f"\nDerived goal: {query}")
              return True

    return False




if _name___== "_main_":
    KB = {
      "facts": [
        pred("American", "West"),
        pred("Missile", "M1"),
        pred("Owns", "Nono", "M1"),
        pred("Enemy", "Nono", "America")
      ],
      "rules": [
        ([pred("American", "x"), pred("Weapon", "y"), pred("Sells", "x", "y", "z"),
pred("Hostile", "z")],
             pred("Criminal", "x")),
        ([pred("Missile", "x")], pred("Weapon", "x")),
        ([pred("Missile", "x"), pred("Owns", "Nono", "x")], pred("Sells", "West", "x", "Nono")),
        ([pred("Enemy", "x", "America")], pred("Hostile", "x"))
      ]
    }
    query = pred("Criminal", "West")
    print("Inference process:")
    result = fol_fc_ask(KB, query)

    if result:
      print("\nConclusion: West is a Criminal.")
    else:
      print("\nCould not prove the query.")
```

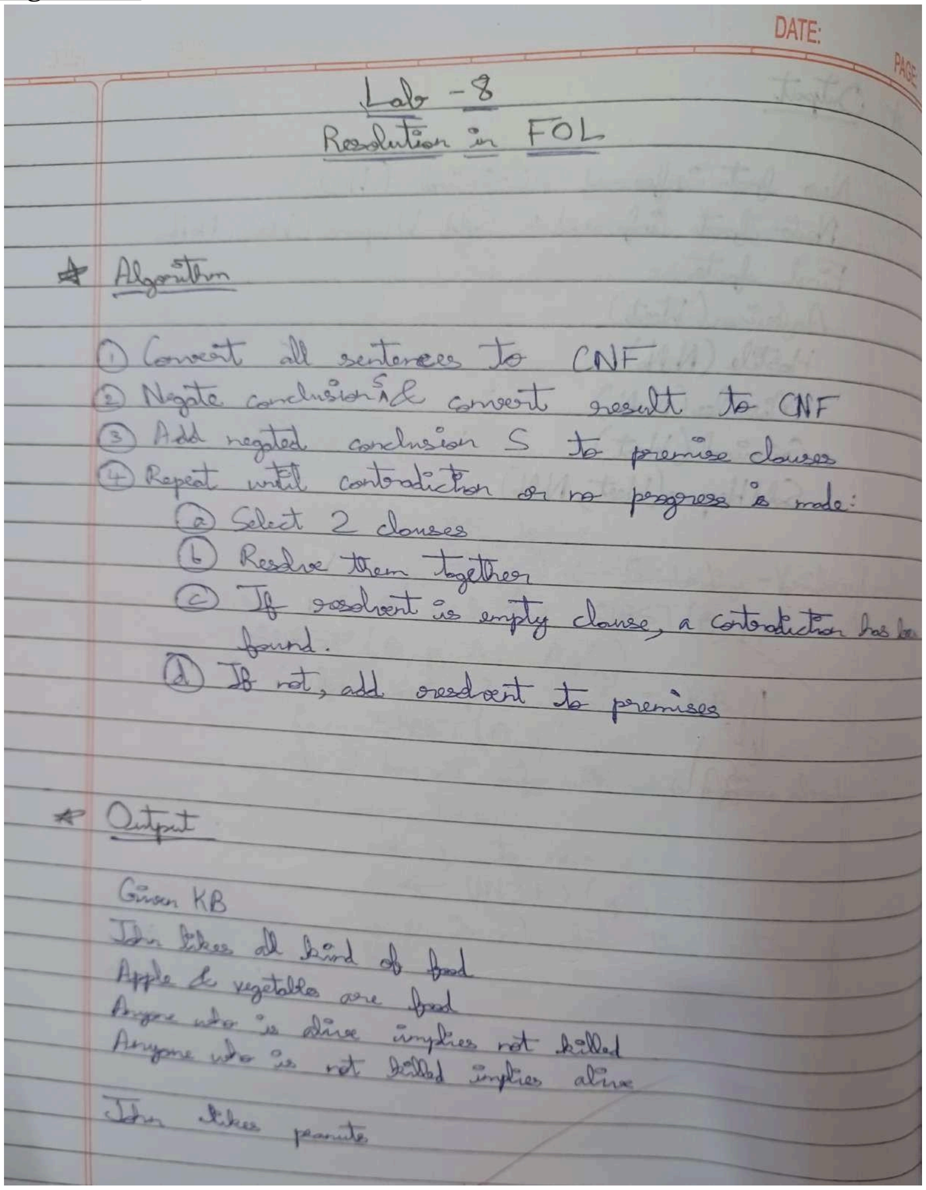
Output:

```
Inference process:

--- Iteration 1 ---
Derived new fact: ('Weapon', ['M1']) from [('Missile', ['x'])]
Derived new fact: ('Sells', ['West', 'M1', 'Nono']) from [('Missile', ['x']), ('Owns', ['Nono', 'x'])]
Derived new fact: ('Hostile', ['Nono']) from [('Enemy', ['x', 'America'])]

--- Iteration 2 ---
Derived new fact: ('Criminal', ['West']) from [('American', ['x']), ('Weapon', ['y']), ('Sells', ['x', 'y', 'z']), ('Hostile', ['z'])]

Derived goal: ('Criminal', ['West'])

Conclusion: West is a Criminal.
```

Program 9

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

Algorithm:



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Lab - 8

Resolution in FOL

★ Algorithm

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

★ Output

Given KB
John likes all kind of food
Apple & vegetables are food
Anyone who is alive implies not killed
Anyone who is not killed implies alive

John likes peanuts

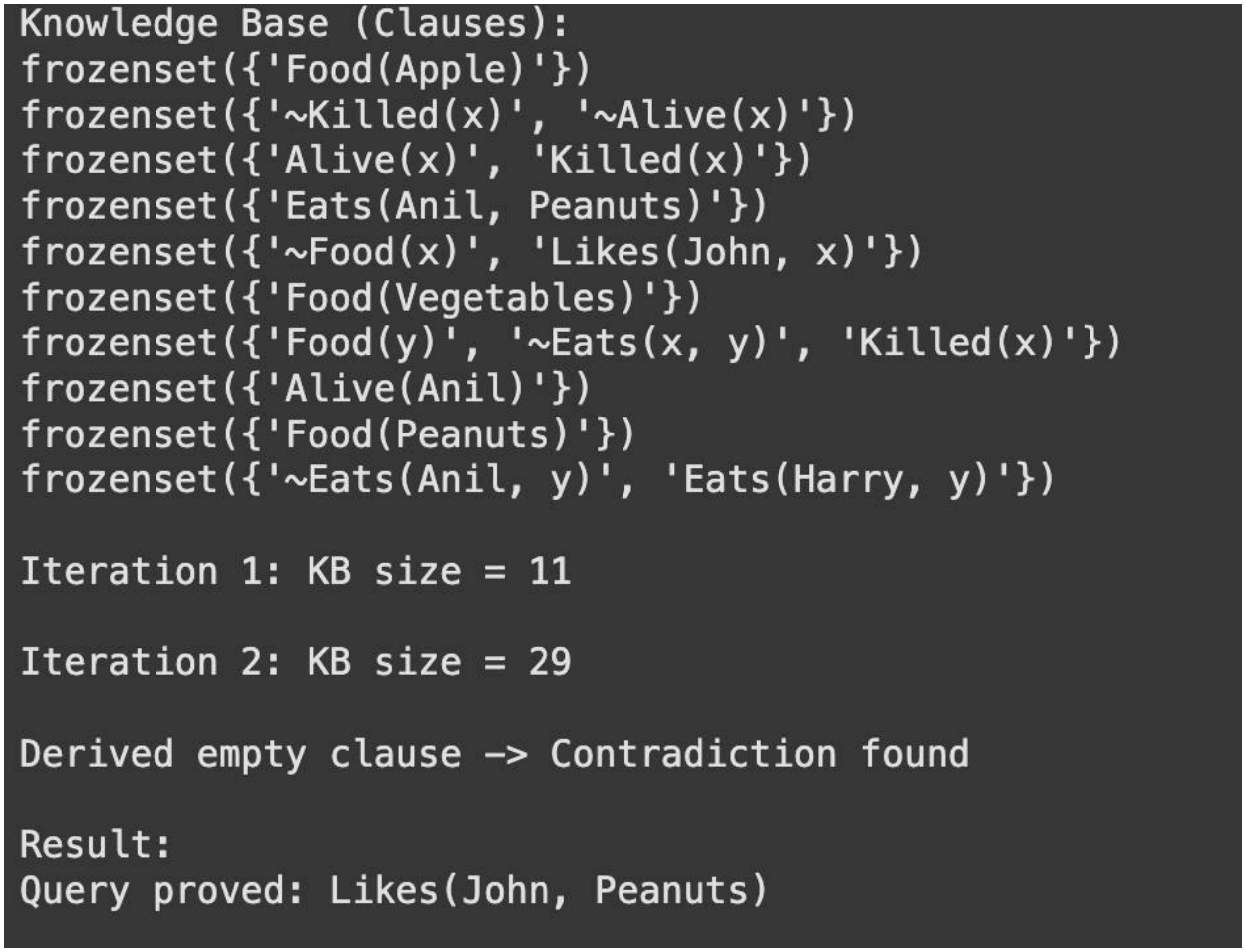
Code:

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


from itertools import combinations
```

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

def is_variable(x):
    return isinstance(x, str) and len(x) == 1 and x.islower()

def get_predicate(literal):
    if literal.startswith("~"):
        return literal[1:literal.find("(")]
    else:
        return literal[:literal.find("(")]

def get_args_from_literal(literal):
    return [arg.strip() for arg in literal[literal.find("(")+1:-1].split(",")]

def literal_to_tuple(literal):
    pred = get_predicate(literal)
    args = get_args_from_literal(literal)
    return (pred, *args)

def tuple_to_literal(tuple_form, negated=False):
    pred = tuple_form[0]
    args = ", ".join(tuple_form[1:])
    literal = f"{pred}({args})"
    if negated:
        return "~" + literal
    else:
        return literal

def substitute_literal(literal, subs):
    lit_tuple = literal_to_tuple(literal)
    new_args = []
    for arg in lit_tuple[1:]:
        if is_variable(arg) and arg in subs:
            new_args.append(subs[arg])
        else:
            new_args.append(arg)
    new_literal_tuple = (lit_tuple[0], *new_args)
    return tuple_to_literal(new_literal_tuple, literal.startswith("~"))


def resolve(ci, cj):
    resolvents = set()
    for lit_i in ci:
        for lit_j in cj:
            if negate(lit_i) == lit_j or lit_i == negate(lit_j):
                new_clause = (ci - {lit_i}) | (cj - {lit_j})
                resolvents.add(frozenset(new_clause))

    for lit_i in ci:
        for lit_j in cj:
            neg_lit_i = negate(lit_i)
            if get_predicate(neg_lit_i) == get_predicate(lit_j) and
len(get_args_from_literal(neg_lit_i)) == len(get_args_from_literal(lit_j)):
                term_i = literal_to_tuple(neg_lit_i)
                term_j = literal_to_tuple(lit_j)
                unifier = unify(term_i, term_j)

                if unifier != "failure":

                    new_clause_i = {substitute_literal(l, unifier) for l in ci - {lit_i}}
                    new_clause_j = {substitute_literal(l, unifier) for l in cj - {lit_j}}
                    new_clause = frozenset(new_clause_i | new_clause_j)
                    resolvents.add(new_clause)

    return resolvents

def resolution(kb, query):
    kb_clauses = set(kb)
    kb_clauses.add(frozenset([negate(query)]))

    new_clauses = set()
    iterations = 0

    while True:
        iterations += 1
        print(f"\nIteration {iterations}: KB size = {len(kb_clauses)}")
        pairs = list(combinations(kb_clauses, 2))
        for (ci, cj) in pairs:
            resolvents = resolve(ci, cj)
            for res in resolvents:
                if frozenset() in resolvents:
                    print("\nDerived empty clause -> Contradiction found")
                    return True
                if res not in kb_clauses and res not in new_clauses:
                    new_clauses.add(res)

        if new_clauses.issubset(kb_clauses):
            return False
        kb_clauses = kb_clauses.union(new_clauses)
        new_clauses = set()


def is_variable(x):
    return isinstance(x, str) and len(x) == 1 and x.islower()

def is_compound(x):
    return isinstance(x, tuple) and len(x) > 0

def get_functor(x):
    return x[0] if is_compound(x) else None

def get_args(x):
    return list(x[1:]) if is_compound(x) else []

def occur_check(var, x, theta):
    if var == x:
        return True
    elif is_variable(x) and x in theta:
        return occur_check(var, theta[x], theta)
    elif is_compound(x):
        return any(occur_check(var, arg, theta) for arg in get_args(x))
    else:
        return False

def unify(x, y, theta=None):
    if theta is None:
        theta = {}

    if theta == "failure":
        return "failure"
    elif x == y:
        return theta
    elif is_variable(x):
        return unify_var(x, y, theta)
    elif is_variable(y):
        return unify_var(y, x, theta)
    elif is_compound(x) and is_compound(y):
        if get_functor(x) != get_functor(y):
            return "failure"
        if len(get_args(x)) != len(get_args(y)):
            return "failure"
        return unify(get_args(x), get_args(y), theta)
    elif isinstance(x, list) and isinstance(y, list):
        if len(x) != len(y):
            return "failure"
        if not x:
            return theta
        first_unify = unify(x[0], y[0], theta)
        if first_unify == "failure":
            return "failure"
        return unify(x[1:], y[1:], first_unify)
    else:
        return "failure"

def unify_var(var, x, theta):
    if var in theta:
        return unify(theta[var], x, theta)
    elif is_variable(x) and x in theta:
        return unify(var, theta[x], theta)
    elif occur_check(var, x, theta):
        return
    "failure" else:
        theta[var] = x
        return theta
```

```
kb = set()

kb.add(frozenset(["~Food(x)", "Likes(John, x)"]))
kb.add(frozenset(["Food(Peanuts)"]))
kb.add(frozenset(["Food(Apple)"]))
kb.add(frozenset(["Food(Vegetables)"]))
kb.add(frozenset(["~Eats(x, y)", "Killed(x)", "Food(y)"]))
kb.add(frozenset(["Eats(Anil, Peanuts)"]))
kb.add(frozenset(["Alive(Anil)"]))
kb.add(frozenset(["~Eats(Anil, y)", "Eats(Harry, y)"]))
kb.add(frozenset(["~Alive(x)", "~Killed(x)"]))
kb.add(frozenset(["Killed(x)", "Alive(x)"]))


print("Knowledge Base (Clauses):")
for c in kb:
   print(c)
query = "Likes(John, Peanuts)"
proved = resolution(kb, query)
print("\nResult:")
if proved:
   print(f"Query proved: {query}")
else:
   print(f"Could not prove the query: {query}")
```

__Output:__

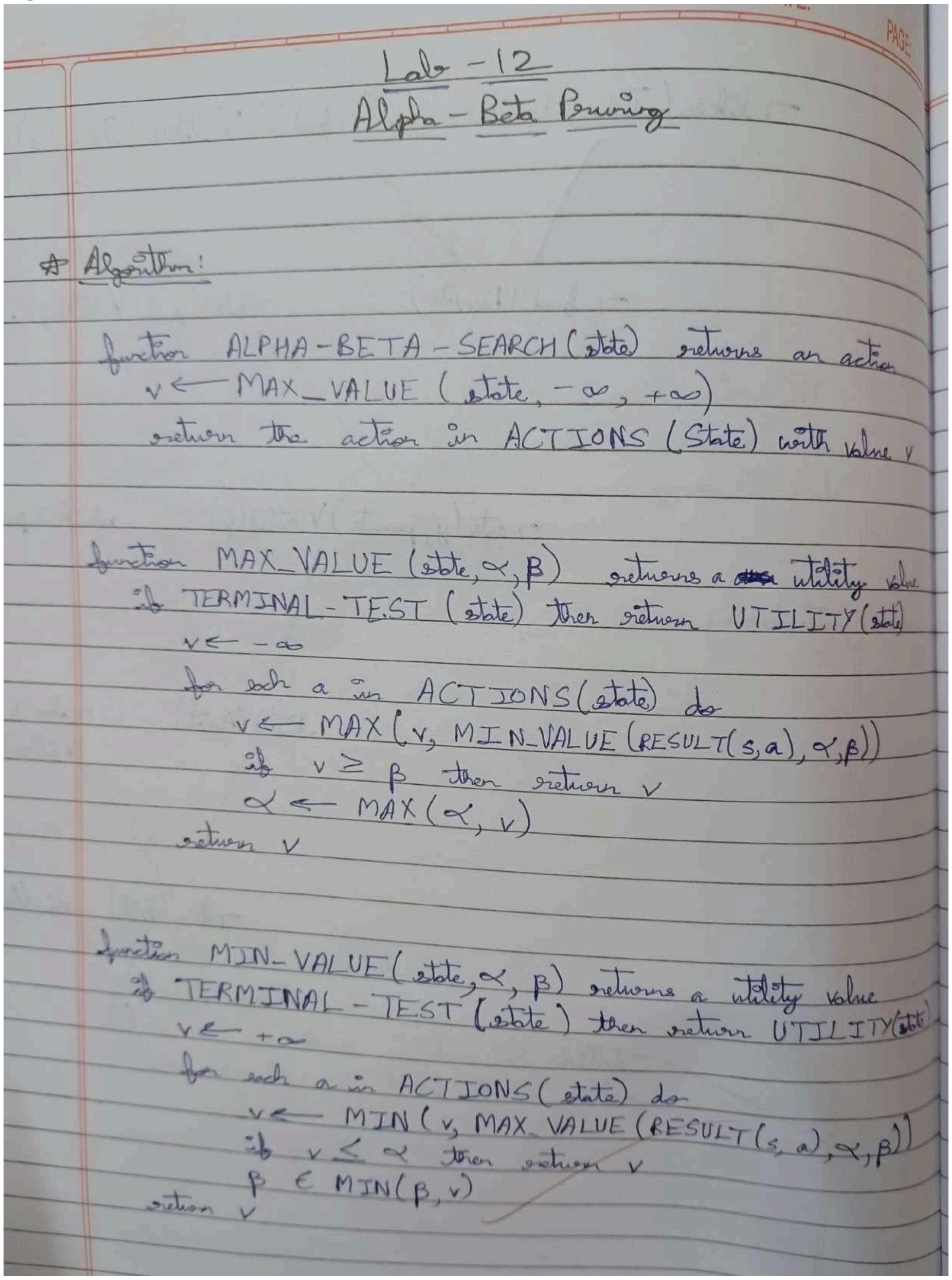


```
Knowledge Base (Clauses):
frozenset({'Food(Apple)'})
frozenset({'~Killed(x)', '~Alive(x)'})
frozenset({'Alive(x)', 'Killed(x)'})
frozenset({'Eats(Anil, Peanuts)'})
frozenset({'~Food(x)', 'Likes(John, x)'})
frozenset({'Food(Vegetables)'})
frozenset({'Food(y)', '~Eats(x, y)', 'Killed(x)'})
frozenset({'Alive(Anil)'})
frozenset({'Food(Peanuts)'})
frozenset({'~Eats(Anil, y)', 'Eats(Harry, y)'})

Iteration 1: KB size = 11

Iteration 2: KB size = 29

Derived empty clause -> Contradiction found

Result:
Query proved: Likes(John, Peanuts)
```

Program 10

Implement Alpha-Beta Pruning

Algorithm:



Lab - 12

Alpha - Beta Pruning

Algorithm:

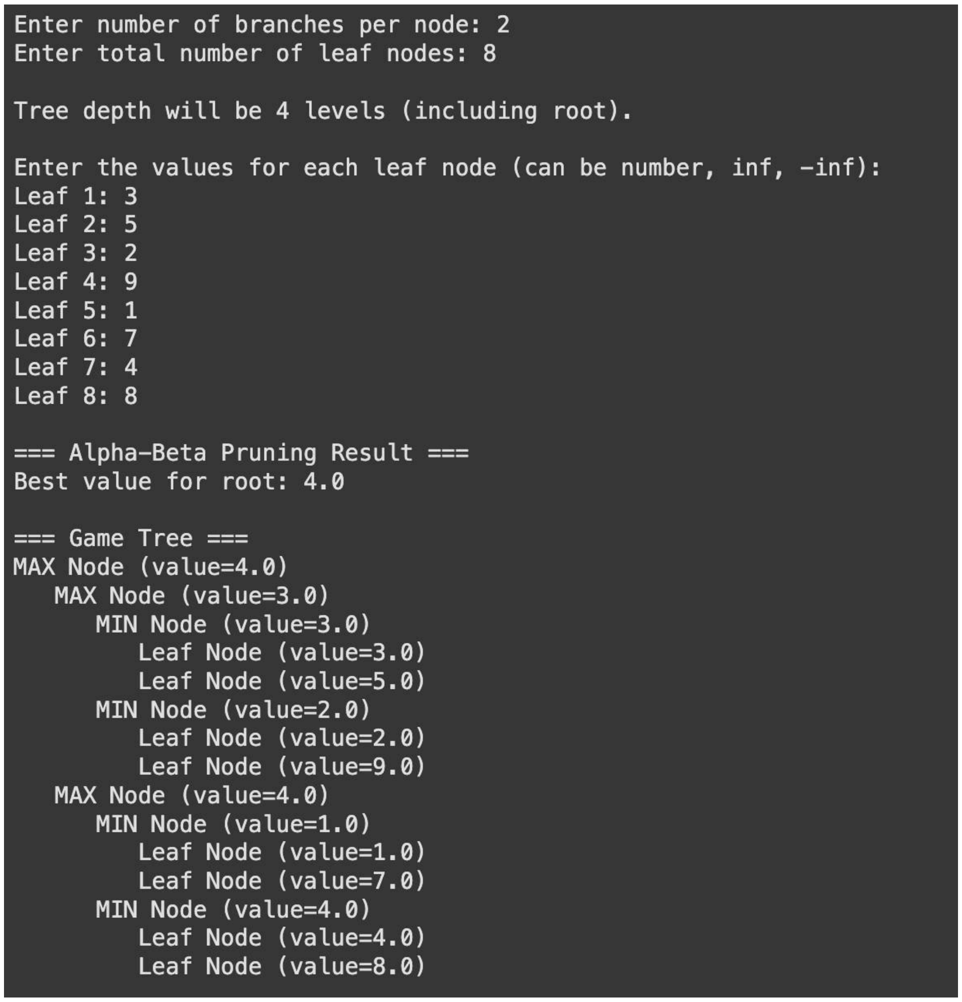
```
function ALPHA-BETA-SEARCH(state) returns an action
    v ← MAX_VALUE (state, $-\infty$, $+\infty$)
    return the action in ACTIONS (State) with value v

function MAX_VALUE (state, $\alpha$, $\beta$) returns a utility value
    if TERMINAL-TEST (state) then return UTILITY(state)
        v ← $-\infty$
        for each a in ACTIONS(state) do
            v ← MAX(v, MIN_VALUE (RESULT(s,a), $\alpha$, $\beta$))
            if v $\geq \beta$ then return v
            $\alpha$ ← MAX($\alpha$, v)
        return v

function MIN-VALUE(state, $\alpha$, $\beta$) returns a utility value
    if TERMINAL-TEST (state) then return UTILITY(state)
        v ← $+\infty$
        for each a in ACTIONS(state) do
            v ← MIN (v, MAX_VALUE (RESULT(s, a), $\alpha$, $\beta$))
            if v $\leq \alpha$ then return v
            $\beta$ ∈ MIN($\beta$, v)
    return v
```

Code:

# Implement Alpha-Beta Pruning.

```
import math

class Node:
    def _init_(self, value=None, children=None, is_max=True):
        self.value = value
        self.children = children or []
        self.is_max = is_max

def alpha_beta(node, alpha=-math.inf, beta=math.inf):
    if not node.children:
        return node.value

    if node.is_max:
        value = -math.inf
        for child in node.children:
            value = max(value, alpha_beta(child, alpha, beta))
            alpha = max(alpha, value)
            if alpha >= beta:
                break
        node.value = value
        return value
    else:
        value = math.inf
        for child in node.children:
            value = min(value, alpha_beta(child, alpha, beta))
            beta = min(beta, value)
            if beta <= alpha:
                break
        node.value = value
        return value

def print_tree(node, level=0):
    indent = "  " * level
    if not node.children:
        print(f"{indent}Leaf Node (value={node.value})")
    else:
        role = "MAX" if node.is_max else "MIN"
        print(f"{indent}{role} Node (value={node.value})")
        for child in node.children:
            print_tree(child, level + 1)

def build_tree_from_leaves(leaf_values, branching_factor, is_max=True):
    current_level_nodes = [Node(value=v, is_max=not is_max) for v in leaf_values]
    level = 1

    while len(current_level_nodes) > 1:
        next_level_nodes = []
        for i in range(0, len(current_level_nodes), branching_factor):
            children = current_level_nodes[i:i + branching_factor]
            node = Node(children=children, is_max=(level % 2 == 0))
            next_level_nodes.append(node)
        current_level_nodes = next_level_nodes
        level += 1

    root = current_level_nodes[0]
    root.is_max = True
    return root

if __name__ == "__main__":
    branching_factor = int(input("Enter number of branches per node: "))
    num_leaves = int(input("Enter total number of leaf nodes: "))

    depth = math.log(num_leaves, branching_factor) + 1
    if abs(round(depth) - depth) > 1e-9:
        print("\n Error: The number of leaves must form a full tree (b^(d-1)).")
        print(" Example: With 3 branches, leaf count = 3, 9, 27, ...")
        exit()

    depth = int(round(depth))
    print(f"\nTree depth will be {depth} levels (including root).")

    leaf_values = []
    print("\nEnter the values for each leaf node (can be number, inf, -inf):")
    for i in range(num_leaves):
        val = input(f"Leaf {i+1}: ").strip()
        if val.lower() == "inf":
            val = math.inf
        elif val.lower() == "-inf":
            val = -math.inf
        else:
            val = float(val)
        leaf_values.append(val)

    root = build_tree_from_leaves(leaf_values, branching_factor, is_max=True)
    best_value = alpha_beta(root)

    print("\n=== Alpha-Beta Pruning Result ===")
    print(f"Best value for root: {best_value}\n")

    print("=== Game Tree ===")
    print_tree(root)
```

Output:



```
Enter number of branches per node: 2
Enter total number of leaf nodes: 8

Tree depth will be 4 levels (including root).

Enter the values for each leaf node (can be number, inf, -inf):
Leaf 1: 3
Leaf 2: 5
Leaf 3: 2
Leaf 4: 9
Leaf 5: 1
Leaf 6: 7
Leaf 7: 4
Leaf 8: 8

=== Alpha-Beta Pruning Result ===
Best value for root: 4.0

=== Game Tree ===
MAX Node (value=4.0)
   MAX Node (value=3.0)
      MIN Node (value=3.0)
         Leaf Node (value=3.0)
         Leaf Node (value=5.0)
      MIN Node (value=2.0)
         Leaf Node (value=2.0)
         Leaf Node (value=9.0)
   MAX Node (value=4.0)
      MIN Node (value=1.0)
         Leaf Node (value=1.0)
         Leaf Node (value=7.0)
      MIN Node (value=4.0)
         Leaf Node (value=4.0)
         Leaf Node (value=8.0)
```