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LAB REPORT

on

Artificial Intelligence

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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CERTIFICATE

This is to certify that the Lab work entitled "**Artificial Intelligence**" carried out by **Nidhi A (1BM22CS177)**, 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 during the academic semester September-2024 to February-2024. 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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1. Implement TIC-TAC-TOE

Algorithm:

24/9/24
Tic - Tac - Toe
Algorithm

Step 1: Make a 3×3 matrix with "##" default value.
Step 2: while count < 9
Step 3: Take user input, as 0.
Step 4: call check function
Step 5: if all elements of a row has 1 or 0 return 1.
if all elements of column has 1 or 0 return 1.
if {0|1|0} & {1|0|1} has 1 or 0 return 1.
if {0|1|1} & {1|0|0} has 1 or 0 return 1.
else return 0.
if c=1
print("X win") break;
Step 6: generate random().
Step 7: i = generate random / 3
j = generate random * 3
if mat[i][j] = "##"
else return 1.
else generate random() *complete algorithm*
Step 8: check function called
Step 9: if (c-1) print("O wins") break;

Code:

```
board={1:' ',2:' ',3:' ',
       4:' ',5:' ',6:' ',
       7:' ',8:' ',9:' '}
}
```

```

def printBoard(board):
    print(board[1] + '|' + board[2] + '|' + board[3])
    print('---')
    print(board[4] + '|' + board[5] + '|' + board[6])
    print('---')
    print(board[7] + '|' + board[8] + '|' + board[9])
    print('\n')

def spaceFree(pos):
    if(board[pos]==' '):
        return True
    else:
        return False

def checkWin():
    if(board[1]==board[2] and board[1]==board[3] and board[1]!=' '):
        return True
    elif(board[4]==board[5] and board[4]==board[6] and board[4]!=' '):
        return True
    elif(board[7]==board[8] and board[7]==board[9] and board[7]!=' '):
        return True
    elif (board[1] == board[5] and board[1] == board[9] and board[1] != ' '):
        return True
    elif (board[3] == board[5] and board[3] == board[7] and board[3] != ' '):
        return True
    elif (board[1] == board[4] and board[1] == board[7] and board[1] != ' '):
        return True
    elif (board[2] == board[5] and board[2] == board[8] and board[2] != ' '):
        return True
    elif (board[3] == board[6] and board[3] == board[9] and board[3] != ' '):
        return True
    else:
        return False

def checkMoveForWin(move):
    if (board[1]==board[2] and board[1]==board[3] and board[1]==move):
        return True
    elif (board[4]==board[5] and board[4]==board[6] and board[4]==move):
        return True
    elif (board[7]==board[8] and board[7]==board[9] and board[7]==move):
        return True
    elif (board[1]==board[5] and board[1]==board[9] and board[1]==move):
        return True

```

```

        return True
    elif (board[3]==board[5] and board[3]==board[7] and board[3] ==move):
        return True
    elif (board[1]==board[4] and board[1]==board[7] and board[1] ==move):
        return True
    elif (board[2]==board[5] and board[2]==board[8] and board[2] ==move):
        return True
    elif (board[3]==board[6] and board[3]==board[9] and board[3] ==move):
        return True
    else:
        return False

def checkDraw():
    for key in board.keys():
        if (board[key]==' '):
            return False
    return True

def insertLetter(letter, position):
    if (spaceFree(position)):
        board[position] = letter
        printBoard(board)
        if (checkDraw()):
            print('Draw!')
        elif (checkWin()):
            if (letter == 'X'):
                print('Bot wins!')
            else:
                print('You win!')
        return
    else:
        print('Position taken, please pick a different position.')
        position = int(input('Enter new position: '))
        insertLetter(letter, position)
        return

player = 'O'
bot ='X'

def playerMove():
    position=int(input('Enter position for O:'))
    insertLetter(player, position)

```

```

return

def compMove():
    bestScore=-1000
    bestMove=0
    for key in board.keys():
        if (board[key]==' '):
            board[key]=bot
            score = minimax(board, False)
            board[key] = ''
            if (score > bestScore):
                bestScore = score
                bestMove = key
    insertLetter(bot, bestMove)
    return

def minimax(board, isMaximizing):
    if (checkMoveForWin(bot)):
        return 1
    elif (checkMoveForWin(player)):
        return -1
    elif (checkDraw()):
        return 0
    if isMaximizing:
        bestScore = -1000
        for key in board.keys():
            if board[key] == '':
                board[key] = bot
                score = minimax(board, False)
                board[key] = ''
                if (score > bestScore):
                    bestScore = score
        return bestScore
    else:
        bestScore = 1000
        for key in board.keys():
            if board[key] == '':
                board[key] = player
                score = minimax(board, True)
                board[key] = ''

```

```
if (score < bestScore):  
    bestScore = score  
return bestScore
```

```
while not checkWin():  
    compMove()  
    playerMove()
```

Output:

```
X| |  
---+  
| |  
---+  
| |
```

```
Enter position for 0:2
```

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

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

```
Enter position for 0:7
```

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

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

```
Enter position for 0:6
```

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

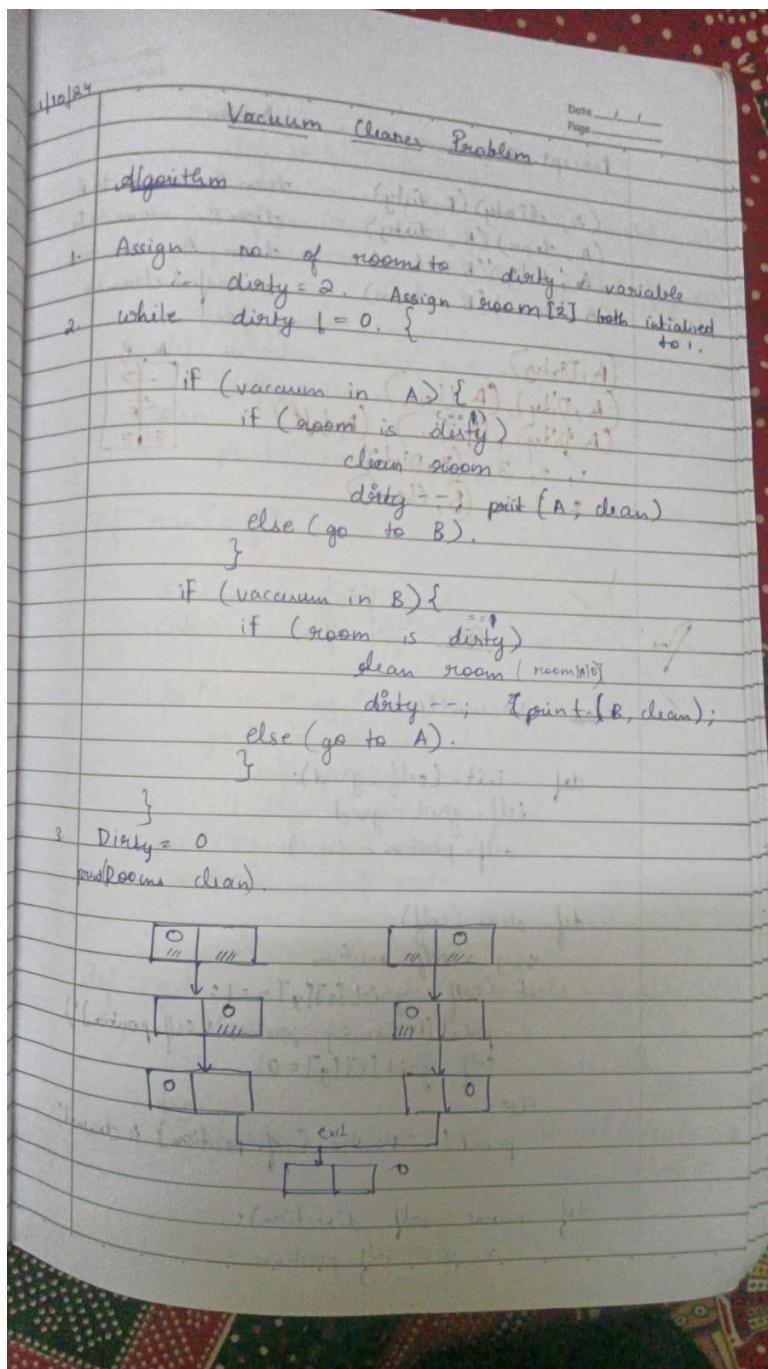
```
X|O|  
---+  
X|X|O  
---+  
O| |X
```

```
Bot wins!
```

```
Enter position for 0:$
```

2. Implement a vacuum cleaner agent.

Algorithm:



Code:

```
def vacuum_world():
    goal_state = {'A': '0', 'B': '0'}
```

```

cost = 0

location_input = input("Enter Location of Vacuum (A or B): ").strip().upper()
status_input = input(f"Enter status of {location_input} (0 for Clean, 1 for Dirty): ").strip()

other_location = 'B' if location_input == 'A' else 'A'
status_input_complement = input(f"Enter status of {other_location} (0 for Clean, 1 for Dirty): ").strip()

print("Initial Location Condition:", goal_state)

if location_input == 'A':
    print("Vacuum is placed in Location A")
    if status_input == '1':
        print("Location A is Dirty.")
        goal_state['A'] = '0'
        cost += 2
        print("Cost for CLEANING A:", cost)
        print("Location A has been Cleaned.")

    if status_input_complement == '1':
        print("Location B is Dirty.")
        print("Moving right to Location B.")
        cost += 1
        print("COST for moving RIGHT:", cost)
        goal_state['B'] = '0'
        cost += 2
        print("COST for SUCK:", cost)
        print("Location B has been Cleaned.")

    else:
        print("Location B is already clean.")

elif location_input == 'B':
    print("Vacuum is placed in Location B")
    if status_input == '1':
        print("Location B is Dirty.")
        goal_state['B'] = '0'
        cost += 2
        print("COST for CLEANING B:", cost)
        print("Location B has been Cleaned.")

```

```

if status_input_complement == '1':
    print("Location A is Dirty.")
    print("Moving LEFT to Location A.")
    cost += 1
    print("COST for moving LEFT:", cost)
    goal_state['A'] = '0'
    cost += 2
    print("COST for SUCK:", cost)
    print("Location A has been Cleaned.")
else:
    print("Location A is already clean.")

print("GOAL STATE:", goal_state)
print("Performance Measurement (Total Cost):", cost)
vacuum_world()

```

Output:

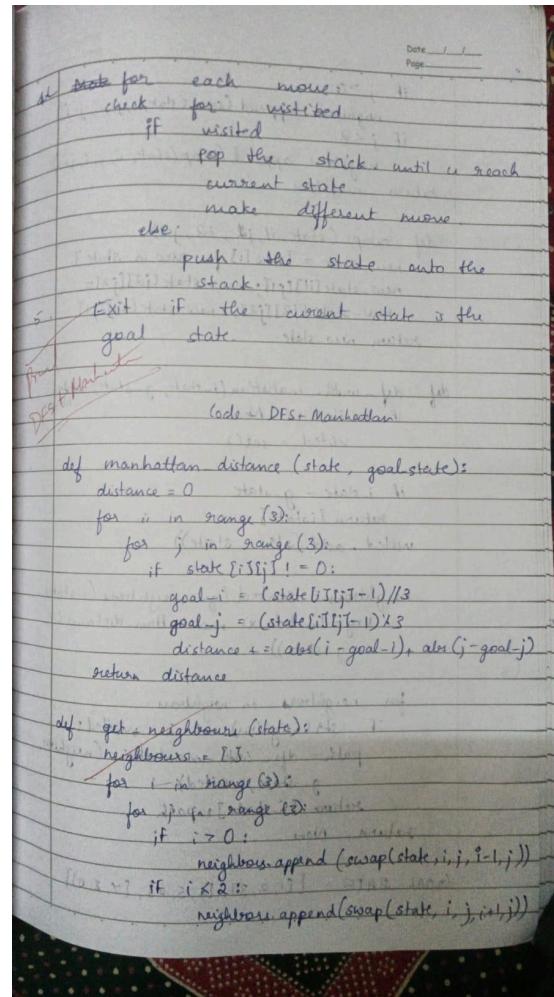
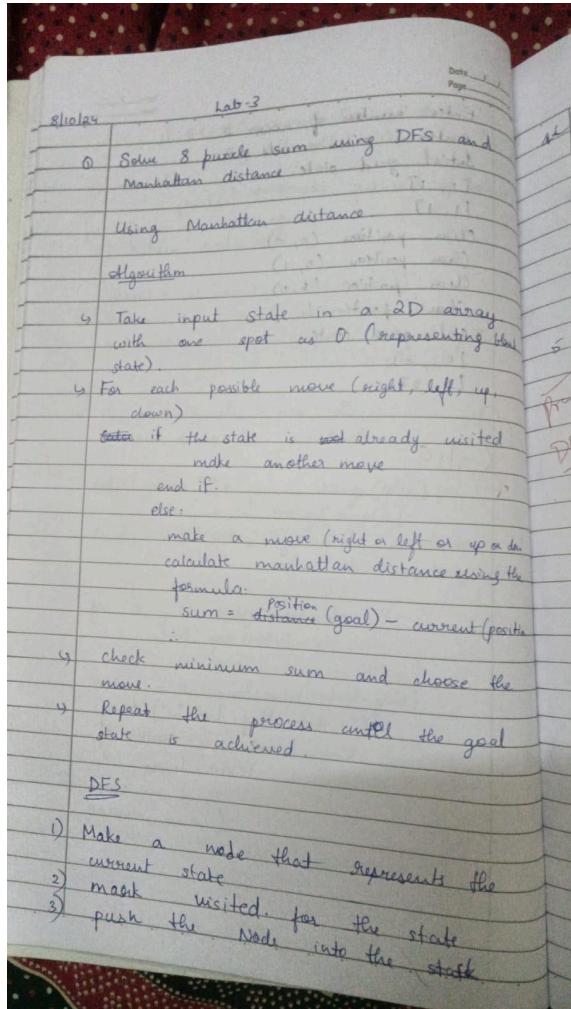
```

Enter Location of Vacuum (A or B): A
Enter status of A (0 for Clean, 1 for Dirty): 1
Enter status of B (0 for Clean, 1 for Dirty): 1
Initial Location Condition: {'A': '0', 'B': '0'}
Vacuum is placed in Location A
Location A is Dirty.
Cost for CLEANING A: 2
Location A has been Cleaned.
Location B is Dirty.
Moving right to Location B.
COST for moving RIGHT: 3
COST for SUCK: 5
Location B has been Cleaned.
GOAL STATE: {'A': '0', 'B': '0'}
Performance Measurement (Total Cost): 5

```

1. Solve 8-puzzle problem using DFS

Algorithm:



Code:

```
from collections import deque
```

```
def is_goal(state, goal_state):
    return state == goal_state
```

```
def get_neighbors(state):
    neighbors = []
```

```

index = state.index(0)
row, col = divmod(index, 3)
moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]
for move in moves:
    new_row, new_col = row + move[0], col + move[1]
    if 0 <= new_row < 3 and 0 <= new_col < 3:
        new_index = new_row * 3 + new_col
        new_state = list(state)
        new_state[index], new_state[new_index] = new_state[new_index], new_state[index]
        neighbors.append(tuple(new_state))
return neighbors

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

def dfs(start, goal):
    visited = set()
    stack = [(start, [])]
    while stack:
        current_state, path = stack.pop()
        if current_state in visited:
            continue
        visited.add(current_state)
        if is_goal(current_state, goal):
            return path + [current_state]
        for neighbor in get_neighbors(current_state):
            if neighbor not in visited:
                stack.append((neighbor, path + [current_state]))
    return None

def input_puzzle(prompt):
    print(prompt)
    puzzle = []
    for i in range(3):
        row = input(f'Enter row {i + 1} (3 numbers separated by spaces): ').split()
        puzzle.extend([int(x) for x in row])
    return tuple(puzzle)

```

```

def select_goal_state():
    print("Select a goal state:")
    print("1. Goal State:")
    print("  0 1 2")
    print("  3 4 5")
    print("  6 7 8")
    print("2. Goal State:")
    print("  1 2 3")
    print("  4 5 6")
    print("  7 8 0")
    choice = input("Enter 1 or 2: ")
    if choice == '1':
        return (0, 1, 2, 3, 4, 5, 6, 7, 8)
    else:
        return (1, 2, 3, 4, 5, 6, 7, 8, 0)

start_state = input_puzzle("Enter the start state (use 0 for the blank space):")
goal_state = select_goal_state()
print("\nSolving using DFS...")
dfs_solution = dfs(start_state, goal_state)
if dfs_solution:
    print("DFS Solution found! Steps:")
    for i, step in enumerate(dfs_solution):
        print(f"Step {i + 1}:")
        print_state(step)
else:
    print("No solution found using DFS.")

```

Output:

```

Enter the start state (use 0 for the blank space):
Enter row 1 (3 numbers separated by spaces): 1 2 3
Enter row 2 (3 numbers separated by spaces): 4 5 6
Enter row 3 (3 numbers separated by spaces): 0 7 8
Select a goal state:
1. Goal State:
  0 1 2
  3 4 5
  6 7 8
2. Goal State:
  1 2 3
  4 5 6
  7 8 0
Enter 1 or 2: 2

Solving using DFS...
DFS Solution found! Steps:
Step 1:
(1, 2, 3)
(4, 5, 6)
(0, 7, 8)

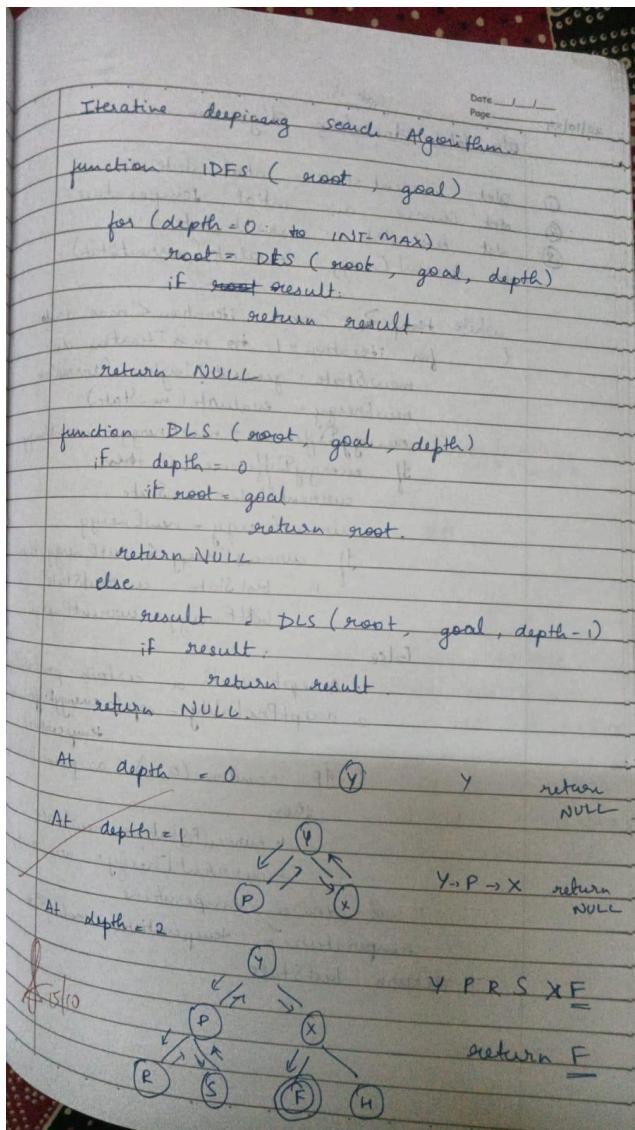
Step 2:
(1, 2, 3)
(4, 5, 6)
(7, 0, 8)

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

```

Implement iddfs:

Algorithm:



CODE:

```
def depth_limited_search(node, goal, depth, graph):
    """
    Perform Depth Limited Search to find the goal node.
    """
    if node == goal:
        return True
    if depth <= 0:
        return False
    for child in graph.get(node, []):
        if depth_limited_search(child, goal, depth - 1, graph):
```

```

        return True
    return False

def iterative_deepening_dfs(start, goal, max_depth, graph):
    """
    Perform Iterative Deepening Depth-First Search (IDDFS).
    """

    for depth in range(max_depth + 1):
        print(f'Depth: {depth}')
        if depth_limited_search(start, goal, depth, graph):
            return True
    return False

# Input graph from the user
graph = {}
num_edges = int(input("Enter the number of edges in the graph: "))
print("Enter the edges in the format 'node1 node2':")
for _ in range(num_edges):
    node1, node2 = input().split()
    if node1 not in graph:
        graph[node1] = []
    graph[node1].append(node2)

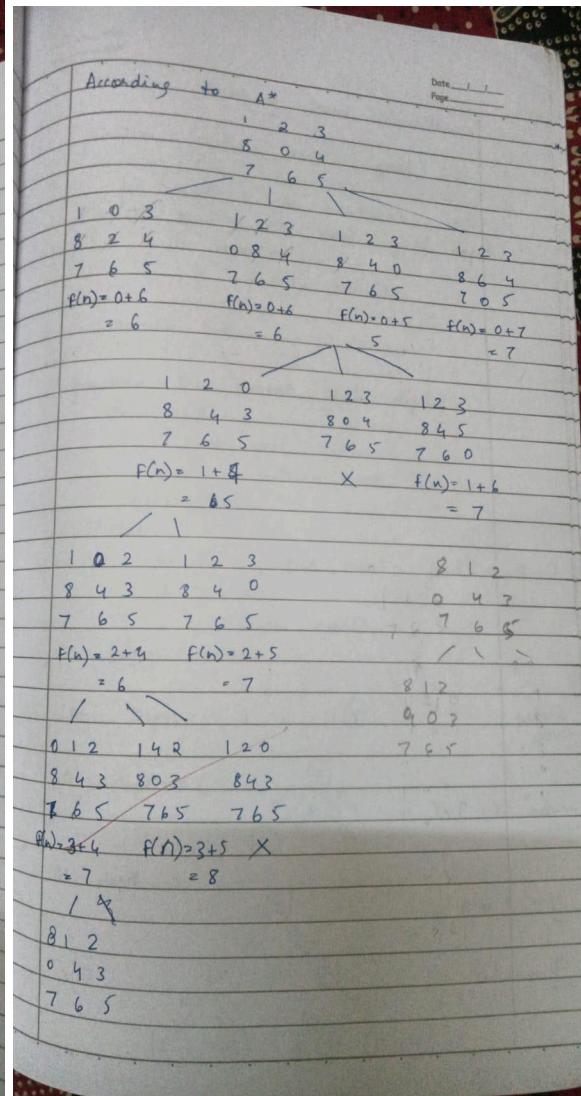
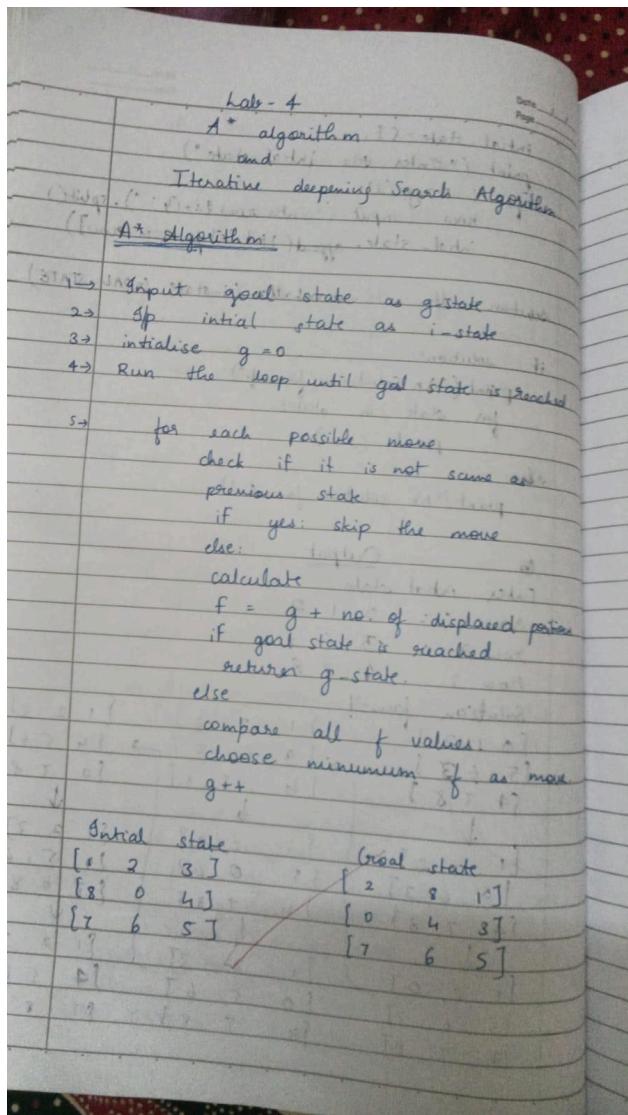
# Input start node, goal node, and maximum depth
start_node = input("Enter the start node: ")
goal_node = input("Enter the goal node: ")
max_depth = int(input("Enter the maximum depth: "))

# Perform IDDFS
found = iterative_deepening_dfs(start_node, goal_node, max_depth, graph)
if found:
    print(f'Goal node '{goal_node}' found!')
else:
    print(f'Goal node '{goal_node}' not found within depth {max_depth}.')

```

For 8-puzzle A* implementation, to calculate, $f(n)$:

1. Algorithm:



Code:

```
import heapq
```

```
def is_goal(state, goal_state):  
    return state == goal_state
```

```
def get_neighbors(state):
```

```

neighbors = []
index = state.index(0)
row, col = divmod(index, 3)
moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]
for move in moves:
    new_row, new_col = row + move[0], col + move[1]
    if 0 <= new_row < 3 and 0 <= new_col < 3:
        new_index = new_row * 3 + new_col
        new_state = list(state)
        new_state[index], new_state[new_index] = new_state[new_index], new_state[index]
        neighbors.append(tuple(new_state))
return neighbors

def misplaced_tiles(state, goal):
    return sum(1 for i in range(9) if state[i] != 0 and state[i] != goal[i])

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

def a_star_level_wise(start, goal, heuristic):
    priority_queue = []
    heapq.heappush(priority_queue, (0, 0, start, []))
    visited = set()
    print("Level-wise output:")

    while priority_queue:
        f_n, g_n, current_state, path = heapq.heappop(priority_queue)
        if current_state in visited:
            continue
        visited.add(current_state)
        print(f"\nLevel {g_n} (g(n) = {g_n}):")
        print(f'f(n) = {f_n}, h(n) = {heuristic(current_state, goal)}')
        print_state(current_state)
        if is_goal(current_state, goal):
            return path + [current_state]
        neighbors = get_neighbors(current_state)
        for neighbor in neighbors:
            if neighbor not in visited:

```

```

g_new = g_n + 1
h_new = heuristic(neighbor, goal)
f_new = g_new + h_new
print(f" Adjacent Node (g(n) = {g_new}, h(n) = {h_new}, f(n) = {f_new}):")
print_state(neighbor)
heapq.heappush(priority_queue, (f_new, g_new, neighbor, path + [current_state]))
return None

def input_puzzle(prompt):
    print(prompt)
    puzzle = []
    for i in range(3):
        row = input(f"Enter row {i + 1} (3 numbers separated by spaces): ").split()
        puzzle.extend([int(x) for x in row])
    return tuple(puzzle)

start_state = input_puzzle("Enter the start state (use 0 for the blank space):")
goal_state = input_puzzle("Enter the goal state (use 0 for the blank space):")
heuristic = misplaced_tiles
print("\nSolving using A* Search with level-wise output...")
a_star_solution = a_star_level_wise(start_state, goal_state, heuristic)
if a_star_solution:
    print("A* Solution found! Steps:")
    for i, step in enumerate(a_star_solution):
        print(f"Step {i + 1}:")
        print_state(step)
else:
    print("No solution found using A*.")

```

Output:

```

Enter the start state (use 0 for the blank space):
Enter row 1 (3 numbers separated by spaces): 2 8 3
Enter row 2 (3 numbers separated by spaces): 1 6 4
Enter row 3 (3 numbers separated by spaces): 7 0 5
Enter the goal state (use 0 for the blank space):
Enter row 1 (3 numbers separated by spaces): 1 2 3
Enter row 2 (3 numbers separated by spaces): 8 0 4
Enter row 3 (3 numbers separated by spaces): 7 6 5

Solving using A* Search with level-wise output...
Level-wise output:

Level 0 (g(n) = 0):
f(n) = 0, h(n) = 4
(2, 8, 3)
(1, 6, 4)
(7, 0, 5)

    Adjacent Node (g(n) = 1, h(n) = 3, f(n) = 4):
(2, 8, 3)
(1, 0, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 1, h(n) = 5, f(n) = 6):
(2, 8, 3)
(1, 6, 4)
(0, 7, 5)

Level 1 (g(n) = 1):
f(n) = 4, h(n) = 3
(2, 8, 3)
(1, 0, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 2, h(n) = 3, f(n) = 5):
(2, 0, 3)
(1, 8, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 2, h(n) = 5, f(n) = 5):
(2, 8, 3)
(0, 1, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 2, h(n) = 6, f(n) = 6):
(2, 8, 3)
(1, 4, 0)
(7, 6, 5)

Level 2 (g(n) = 2):
f(n) = 5, h(n) = 3
(2, 0, 3)
(1, 8, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 3, h(n) = 2, f(n) = 5):
(0, 2, 3)
(1, 8, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 3, h(n) = 4, f(n) = 7):
(2, 3, 0)
(1, 8, 4)
(7, 6, 5)

```

```

Level 3 (g(n) = 3):
f(n) = 5, h(n) = 2
(0, 2, 3)
(1, 8, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 4, h(n) = 1, f(n) = 5):
(1, 2, 3)
(0, 8, 4)
(7, 6, 5)

Level 4 (g(n) = 4):
f(n) = 5, h(n) = 1
(1, 2, 3)
(0, 8, 4)
(7, 6, 5)

    Adjacent Node (g(n) = 5, h(n) = 2, f(n) = 7):
(1, 2, 3)
(7, 8, 4)
(0, 6, 5)

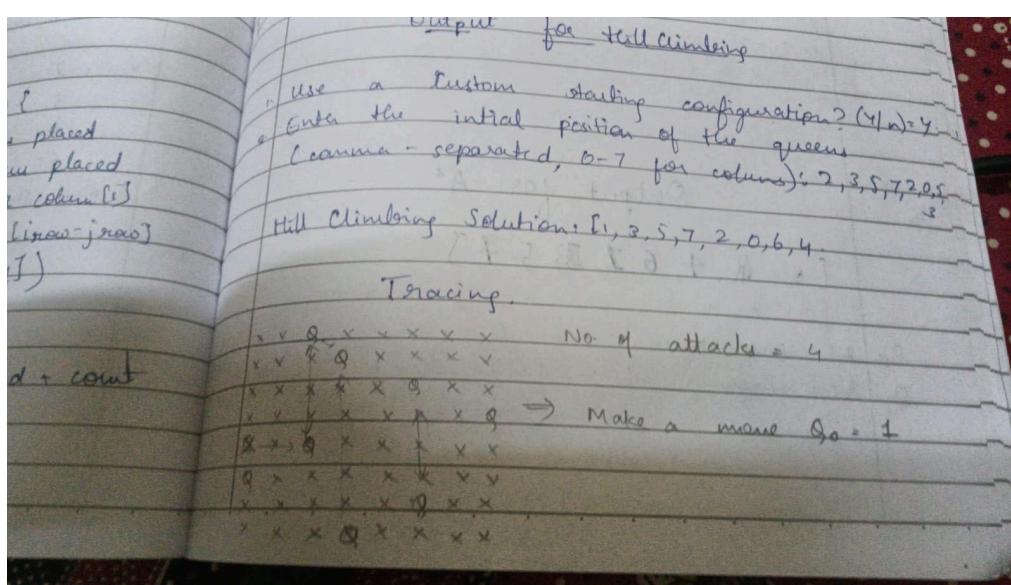
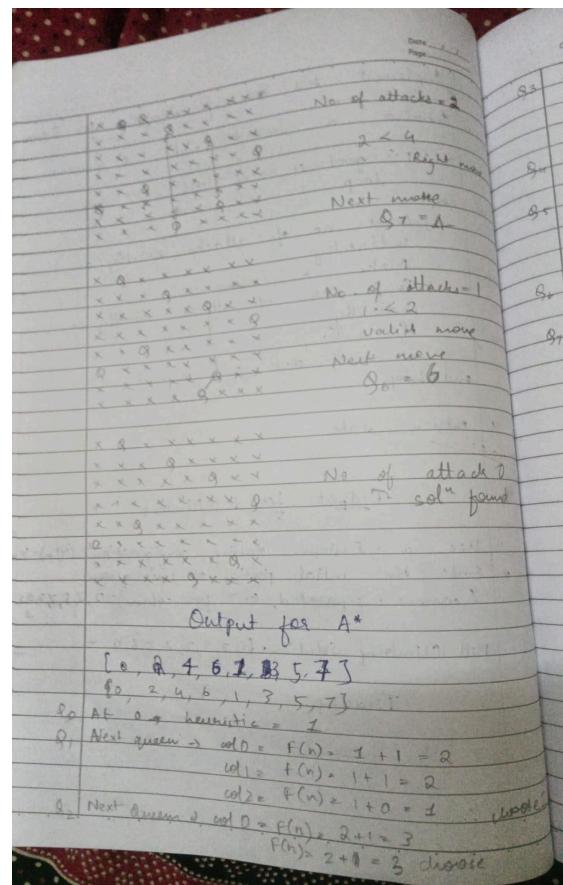
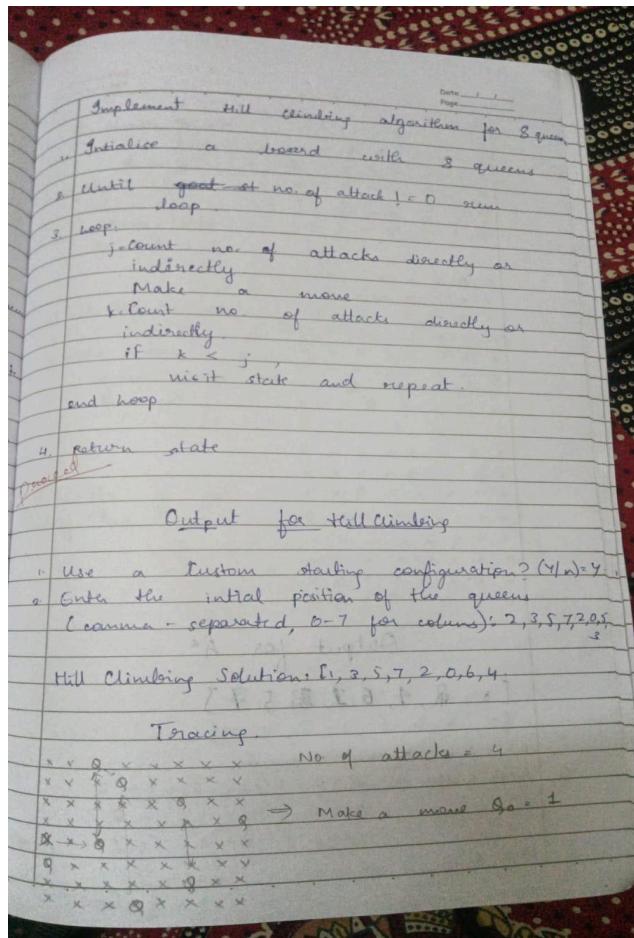
    Adjacent Node (g(n) = 5, h(n) = 0, f(n) = 5):
(1, 2, 3)
(8, 0, 4)
(7, 6, 5)

Level 5 (g(n) = 5):
f(n) = 5, h(n) = 0
(1, 2, 3)
(8, 0, 4)
(7, 6, 5)

```

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

Algorithm:



Code:

```
def print_board(state):
    n = len(state)
    board = [ '.' for _ in range(n) ] for _ in range(n)]
    for col, row in enumerate(state):
        board[row][col] = 'Q'
    for row in board:
        print(' '.join(row))
    print()

def calculate_cost(state):
    cost = 0
    n = len(state)

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

def generate_neighbors(state):
    neighbors = []
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            new_state = state.copy()
            new_state[i], new_state[j] = new_state[j], new_state[i] # Swap row positions of two
queens
            neighbors.append(new_state)
    return neighbors

def hill_climbing_4_queens(initial_state):
    n = 4

    current_state = initial_state
    current_cost = calculate_cost(current_state)

    print(f"Initial state: {current_state}, Cost: {current_cost}")
    print_board(current_state)

    steps = 0
    while current_cost != 0:
        steps += 1
```

```

neighbors = generate_neighbors(current_state)
neighbor_costs = [calculate_cost(neighbor) for neighbor in neighbors]

min_cost = min(neighbor_costs)
best_neighbor = neighbors[neighbor_costs.index(min_cost)]

print(f"Step {steps}: Best neighbor: {best_neighbor}, Cost: {min_cost}")
print_board(best_neighbor)

if min_cost < current_cost:
    current_state = best_neighbor
    current_cost = min_cost
else:
    print("Stuck at local maximum.")
    break

if current_cost == 0:
    print("Solution found:")
    print_board(current_state)
else:
    print("No solution found. Stuck at a local maximum.")

def get_user_input():
    print("Enter the initial positions of the queens on the board (0-based index for each column):")
    initial_state = []
    for col in range(4):
        row = int(input(f"Enter row position for column {col+1}: "))
        initial_state.append(row)
    return initial_state

def main():
    confirm = input("Run Hill Climbing for the 4-Queens problem? (yes/no): ").strip().lower()
    if confirm == 'yes':
        initial_state = get_user_input()
        hill_climbing_4_queens(initial_state)
    else:
        print("Operation cancelled.")

if __name__ == "__main__":
    main()

```

Output:

```
Enter the initial positions of the queens on the board (0-based index for each column):
Enter row position for column 1: 0
Enter row position for column 2: 0
Enter row position for column 3: 0
Enter row position for column 4: 0
Initial state: [0, 0, 0, 0], Cost: 6
Q Q Q Q
. . .
. . .
. . .

Step 1: Best neighbor: [0, 3, 0, 0], Cost: 3
Q . Q Q
. . .
. . .
. Q . .

Step 2: Best neighbor: [1, 3, 0, 0], Cost: 1
. . Q Q
Q . .
. . .
. Q . .

Step 3: Best neighbor: [1, 3, 0, 2], Cost: 0
. . Q .
Q . .
. . .
. Q . .

Solution found:
. . Q .
Q . .
. . .
. Q . .
```

Simulated Annealing to Solve 8-Queens problem

Algorithm:

Lab - 5

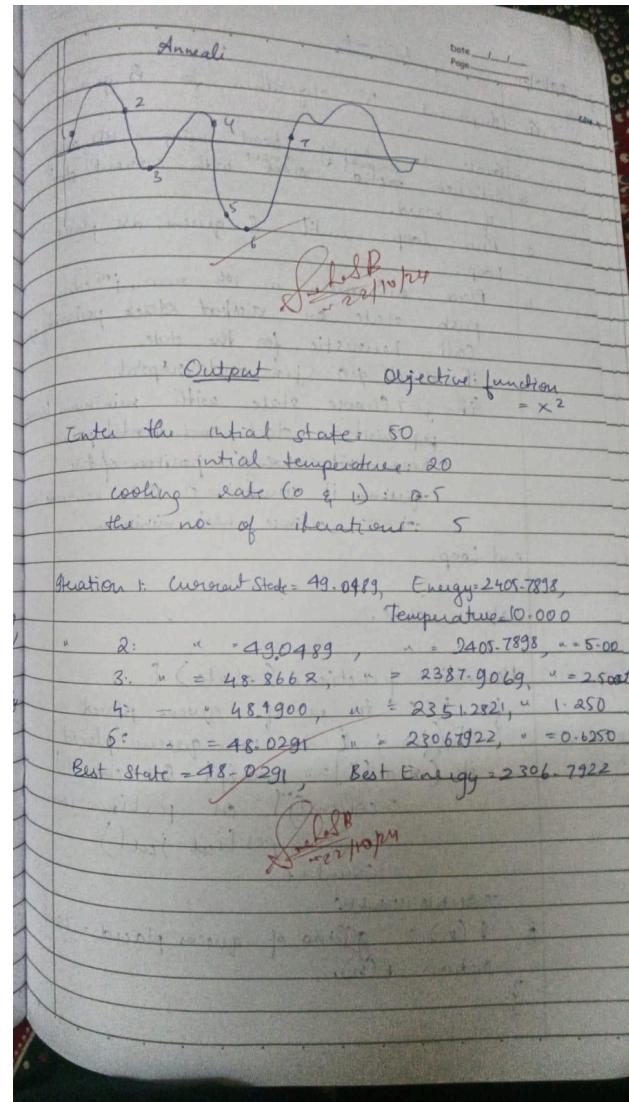
Simulated Annealing Algorithm

```

① set current state = initial state
② set choose an initial temperature
③ set best state = current state
set currentEnergy = evaluate (currentState)

while temp >= 0 and iteration < max_iterate
{
    for iteration = 1 to maxIteration do
        newState = generateNeighbor (currentState)
        newEnergy = evaluate (newState)
        energyDifference = newEnergy - currentEnergy
        If energyDifference < 0 then
            currentState = newState
            currentEnergy = newEnergy
        If currentEnergy < bestEnergy then
            bestState = currentState
            bestEnergy = currentEnergy
    Else
        1. Accept with a certain probability
        2. acceptProbability = exp (-energyDifference / temperature)
        3. If random (0, 1) < acceptanceProbability
            then
                1. currentState = newState
                2. currentEnergy = newEnergy
                // cool down temperature
                temperature = temperature * coolingRate
    7. Return bestState
}

```



Code:

```
import random
import math
```

```
def calculate_conflicts(board):
```

```

n = len(board)
conflicts = 0

for i in range(n):
    for j in range(i + 1, n):
        if board[i] == board[j] or abs(board[i] - board[j]) == abs(i - j):
            conflicts += 1
return conflicts

def simulated_annealing(board, max_steps=1000, initial_temp=100, cooling_rate=0.99):
    current_conflicts = calculate_conflicts(board)
    temperature = initial_temp
    n = len(board)

    for step in range(max_steps):
        if current_conflicts == 0:
            return board

        col = random.randint(0, n - 1)
        new_row = random.randint(0, n - 1)

        new_board = board[:]
        new_board[col] = new_row
        new_conflicts = calculate_conflicts(new_board)

        delta = new_conflicts - current_conflicts
        if delta < 0 or random.uniform(0, 1) < math.exp(-delta / temperature):
            board = new_board
            current_conflicts = new_conflicts

        temperature *= cooling_rate

    return None

def main():
    n = int(input("Enter the number of queens (default is 8): ") or 8)
    print(f"Enter the positions of the queens as an array of size {n}:")
    print(f"(Example: 0,4,7,5,2,6,1,3 or space-separated values)")
    input_str = input().strip()

```

```

if ',' in input_str:
    board = list(map(int, input_str.split(',')))
else:
    board = list(map(int, input_str.split()))

if len(board) != n:
    print("Error: The number of positions must match the number of queens.")
    return

solution = simulated_annealing(board)

if solution:
    print("\nSolution found:")
    for row in range(n):
        line = ['.'] * n
        line[solution[row]] = 'Q'
        print(" ".join(line))
else:
    print("No solution found.")

if __name__ == "__main__":
    main()

```

Output:

```

Enter the number of queens (default is 8): 8
Enter the positions of the queens as an array of size 8:
(Example: 0,4,7,5,2,6,1,3 or space-separated values)
0 4 7 5 2 6 1 3

```

Solution found:

```

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

```

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

Algorithm:

Algo/Plan

Knowledge Base

1. Alice is the mother of Bob
2. Bob is the father of Charlie
3. A parent is a parent
4. A mother is a parent
5. All parents have children
6. If someone is a parent, their children are siblings
7. Alice is married to David

Hypothesis

- Charlie is the sibling of Bob.

Premises

A : Alice is mother of Bob
B : Bob is the father of Charlie
C : If someone is parent, their children are siblings.

Entailment Process:

From the premise, Alice is the mother of Bob, so Alice is a parent.
Bob is the father of Charlie, so Charlie's father is Bob.
From the premise C, their children are siblings.

$A \rightarrow P$ Alice is Bob's mother
 $B \rightarrow P$ Bob is Charlie's father
 $F \rightarrow P$ Father is a parent
 $M \rightarrow P$ Mother is a parent

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Page _____

$P \rightarrow S$ If someone is parent, their children are siblings

$A \wedge B \rightarrow Q$ (If Alice is mother of Bob & Bob is father of Charlie, then Charlie is a sibling of Bob)

Check for entailment

If A is true (Alice, Bob's mom) then B must be true (Bob is a father of Charlie). $A \rightarrow B$

If B is true then C must be true (Bob is a parent). $F \rightarrow P$. $F \cdot M$ must be true. $(M \rightarrow P)$ (Alice is a parent)

If both Alice & Charlie are parents (ie M & F are true) then S (their children are siblings) must be true. $(P \rightarrow S)$

Since S is true, the hypothesis (Charlie is sibling of Bob) is true.

Conclusion:
Using propositional logic, we can conclude the hypothesis ("Charlie is a sibling of Bob") is entailed by K.B.

Code:

```
combinations = [
    (True, True, True), (True, True, False),
    (True, False, True), (True, False, False),
    (False, True, True), (False, True, False),
    (False, False, True), (False, False, False)
]
variable = {'p': 0, 'q': 1, 'r': 2}
kb = ""
q = ""
priority = {'~': 3, 'v': 1, '^': 2}
def input_rules():
    global kb, q
    kb = input("Enter rule: ")
    q = input("Enter the Query: ")
def entailment():
    global kb, q
    print('*' * 10 + "Truth Table Reference" + '*' * 10)
    print('p', 'q', 'r', 'kb', 'query')
    print('*' * 10)
    entails = True # Assumption: The Knowledge Base entails the query
    for comb in combinations:
        s = evaluatePostfix(toPostfix(kb), comb)
        f = evaluatePostfix(toPostfix(q), comb)
        print(comb[0], comb[1], comb[2], s, f)
        print('-' * 10)
        if s and not f:
            entails = False # Counterexample found
    return entails
def isOperand(c):
    return c.isalpha() and c != 'v'
def isLeftParanthesis(c):
    return c == '('
def isRightParanthesis(c):
    return c == ')'
def isEmpty(stack):
    return len(stack) == 0
def peek(stack):
    return stack[-1]
```

```

def hasLessOrEqualPriority(c1, c2):
    try:
        return priority[c1] <= priority[c2]
    except KeyError:
        return False
def toPostfix(infix):
    stack = []
    postfix = ""
    for c in infix:
        if isOperand(c):
            postfix += c
        else:
            if isLeftParanthesis(c):
                stack.append(c)
            elif isRightParanthesis(c):
                operator = stack.pop()
                while not isLeftParanthesis(operator):
                    postfix += operator
                    operator = stack.pop()
            else:
                while (not isEmpty(stack)) and hasLessOrEqualPriority(c, peek(stack)):
                    postfix += stack.pop()
                stack.append(c)
    while (not isEmpty(stack)):
        postfix += stack.pop()
    return postfix
def evaluatePostfix(exp, comb):
    stack = []
    for i in exp:
        if isOperand(i):
            stack.append(comb[variable[i]])
        elif i == '¬':
            val1 = stack.pop()
            stack.append(not val1)
        else:
            val1 = stack.pop()
            val2 = stack.pop()
            stack.append(_eval(i, val2, val1))
    return stack.pop()
def _eval(i, val1, val2):

```

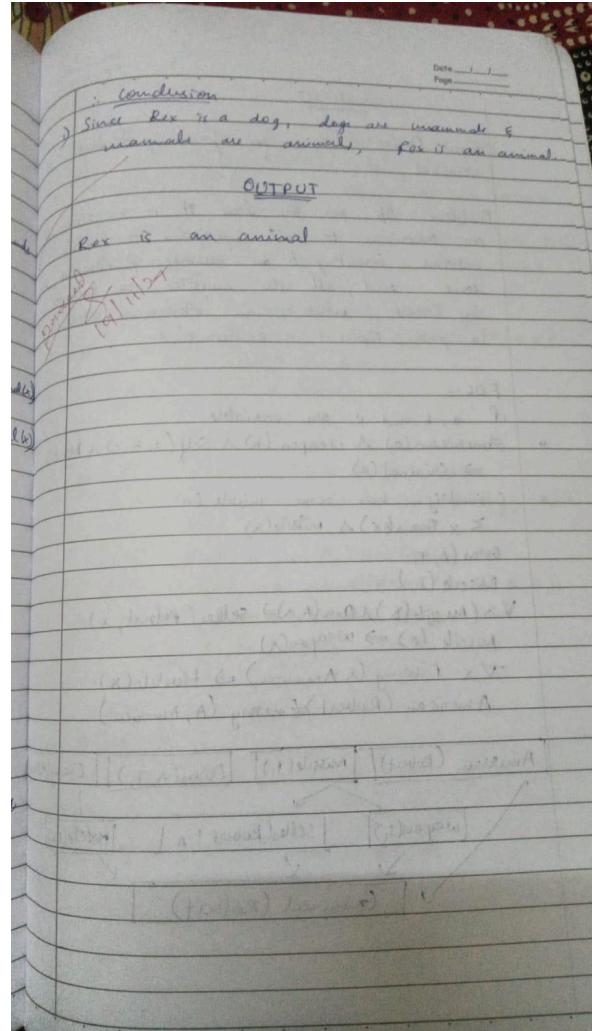
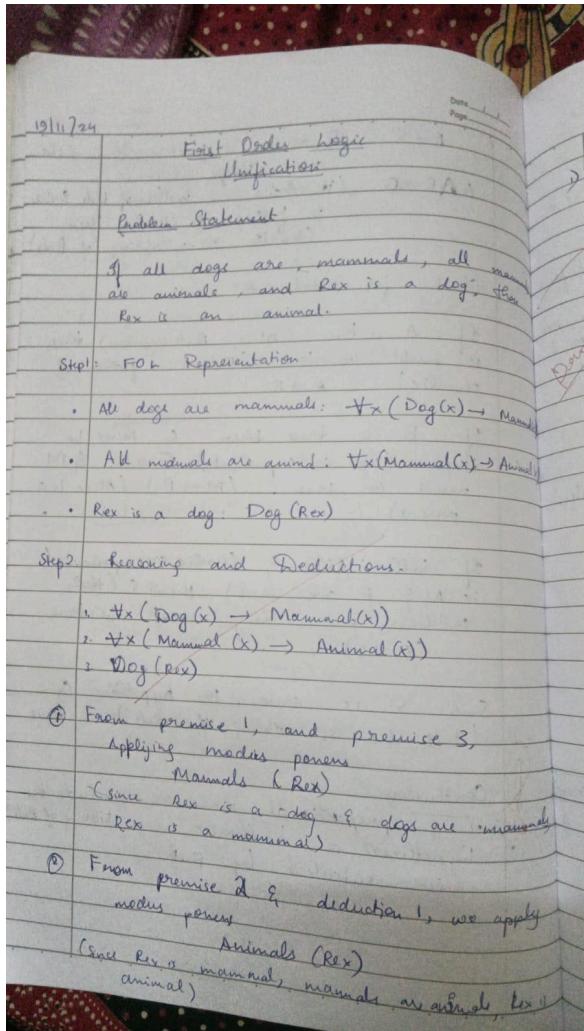
```
if i == '^':  
    return val2 and val1  
return val2 or val1  
input_rules()  
ans = entailment()  
if ans:  
    print("The Knowledge Base entails the query.")  
else:  
    print("The Knowledge Base does not entail the query.")
```

Output:

```
Enter rule: p^q  
Enter the Query: r  
*****Truth Table Reference*****  
kb alpha  
*****  
True True  
-----  
True False  
-----  
The Knowledge Base does not entail query
```

Implement unification in first order logic.

Algorithm:



Code:

```
def is_variable(x):
    """Check if x is a variable."""
    return isinstance(x, str) and x[0].islower()

def unify(x, y, subst):
    """Unify two terms x and y under a given substitution subst."""
    if is_variable(x):
        if x in subst:
            return unify(subst[x], y, subst)
        else:
            subst[x] = y
            return subst
    elif is_variable(y):
        if y in subst:
            return unify(x, subst[y], subst)
        else:
            subst[y] = x
            return subst
    elif x == y:
        return subst
    elif isinstance(x, list) and isinstance(y, list):
        if len(x) != len(y):
            return None
        else:
            return unify(x[1:], y[1:], unify(x[0], y[0], subst))
    else:
        return None
```

```

print(f"Comparing: {x} with {y}")
if subst is None:
    return None
elif x == y:
    print(f"Both are equal: {x} == {y}")
    return subst
elif is_variable(x):
    return unify_variable(x, y, subst)
elif is_variable(y):
    return unify_variable(y, x, subst)
elif isinstance(x, tuple) and isinstance(y, tuple) and len(x) == len(y):
    for xi, yi in zip(x, y):
        subst = unify(xi, yi, subst)
    if subst is None:
        return None
    return subst
else:
    print(f"Cannot unify {x} and {y}")
    return None

def unify_variable(var, x, subst):
    """Handle variable unification."""
    if var in subst:
        print(f"Variable {var} is already in substitution. Resolving with {subst[var]}")
        return unify(subst[var], x, subst)
    elif occurs_check(var, x, subst):
        print(f"Occurs check failed: {var} occurs in {x}.")
        return None # Avoid infinite loops in recursive substitutions
    else:
        print(f"Adding substitution: {var} -> {x}")
        new_subst = subst.copy()
        new_subst[var] = x
        return new_subst

def occurs_check(var, x, subst):
    """Check if var occurs in x to avoid infinite substitution."""
    if var == x:
        return True
    elif isinstance(x, tuple):
        return any(occurs_check(var, xi, subst) for xi in x)
    elif is_variable(x) and x in subst:

```

```

        return occurs_check(var, subst[x], subst)
    else:
        return False

def parse_sentence_to_expression(sentence):
    """Convert an English sentence to a logical expression."""
    sentence = sentence.strip().replace("(", " ( ").replace(")", " ) ").replace(",", ", ", ",")
    tokens = sentence.split()
    stack = []
    current = []
    for token in tokens:
        if token == "(":
            stack.append(current)
            current = []
        elif token == ")":
            if stack:
                last = stack.pop()
                last.append(tuple(current))
                current = last
        elif token == ",":
            continue
        else:
            current.append(token)
    return tuple(current) if len(current) == 1 else tuple(current)

def unification_with_explanation(expr1, expr2):
    """Perform unification on two expressions with step-by-step explanation."""
    print("\nStarting Unification Process...\n")
    subst = unify(expr1, expr2, {})
    if subst is not None:
        print("\nUnification Successful!")
        print("Substitution:", subst)
    else:
        print("\nUnification Failed!")

# Input from the user
print("Enter the logical expressions in English-like format.")
print("Example: Eats(x, Apple)")
sentence1 = input("Enter the first expression: ")
sentence2 = input("Enter the second expression: ")
# Parse sentences

```

```
expr1 = parse_sentence_to_expression(sentence1)
expr2 = parse_sentence_to_expression(sentence2)
# Perform unification with explanation
unification_with_explanation(expr1, expr2)
```

Output:

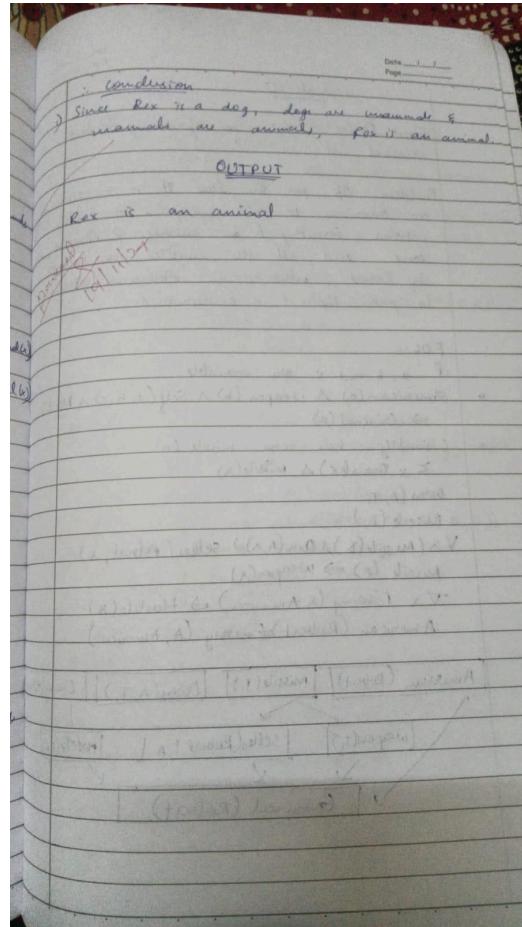
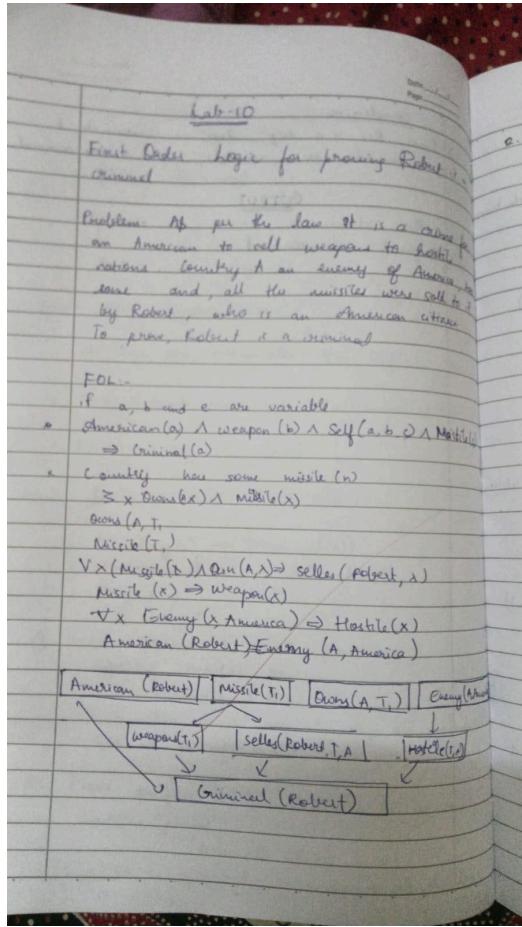
```
Enter the logical expressions in English-like format.
Example: Eats(x, Apple)
Enter the first expression: Works(x,y)
Enter the second expression: Works(Apple,Banana)

Starting Unification Process...

Comparing: ('Works', ('x', 'y')) with ('Works', ('Apple', 'Banana'))
Comparing: Works with Works
Both are equal: Works == Works
Comparing: ('x', 'y') with ('Apple', 'Banana')
Comparing: x with Apple
Adding substitution: x -> Apple
Comparing: y with Banana
Adding substitution: y -> Banana

Unification Successful!
Substitution: {'x': 'Apple', 'y': 'Banana'}
```

Create a KB consisting of first order logic statements and prove the following reasoning.



Algorithm:

Code:

```

class ForwardChainingFOL:
    def __init__(self):
        self.facts = set() # Set of known facts
        self.rules = [] # List of rules in the form (premises, conclusion)
    def add_fact(self, fact):
        self.facts.add(fact)
    def add_rule(self, premises, conclusion):
  
```

```

    self.rules.append((premises, conclusion))
def unify(self, fact1, fact2):
    """
    Unifies two facts if possible. Returns a substitution dictionary or None if unification fails.
    """
    if fact1 == fact2:
        return {} # No substitution needed
    if "(" in fact1 and "(" in fact2:
        # Split into predicate and arguments
        pred1, args1 = fact1.split("(", 1)
        pred2, args2 = fact2.split("(", 1)
        args1 = args1[:-1].split(",")
        args2 = args2[:-1].split ","
        if pred1 != pred2 or len(args1) != len(args2):
            return None
        # Unify arguments
        substitution = {}
        for a1, a2 in zip(args1, args2):
            if a1 != a2:
                if a1.islower(): # a1 is a variable
                    substitution[a1] = a2
                elif a2.islower(): # a2 is a variable
                    substitution[a2] = a1
                else: # Both are constants and different
                    return None
            return substitution
        return None
    def apply_substitution(self, fact, substitution):
        """
        Applies a substitution to a fact and returns the substituted fact.
        """
        if "(" in fact:
            pred, args = fact.split("(", 1)
            args = args[:-1].split ","
            substituted_args = [substitution.get(arg, arg) for arg in args]
            return f'{pred}({",".join(substituted_args)})'
        return fact
    def forward_chain(self, goal):
        iteration = 1
        while True:

```

```

new_facts = set()
print(f"\n==== Iteration {iteration} ====")
print("Known Facts:")
for fact in self.facts:
    print(f" - {fact}")
print("\nApplying rules...")
rule_triggered = False
for premises, conclusion in self.rules:
    substitutions = []
    for premise in premises:
        new_substitutions = []
        for fact in self.facts:
            for sub in substitutions:
                unified = self.unify(self.apply_substitution(premise, sub), fact)
                if unified is not None:
                    new_substitutions.append({**sub, **unified})
            substitutions = new_substitutions
        for sub in substitutions:
            inferred_fact = self.apply_substitution(conclusion, sub)
            if inferred_fact not in self.facts:
                rule_triggered = True
                print(f"Rule triggered: {premises} → {conclusion}")
                print(f" New fact inferred: {inferred_fact}")
                new_facts.add(inferred_fact)
    if not new_facts:
        if not rule_triggered:
            print("No rules triggered in this iteration.")
            print("No new facts inferred in this iteration.")
            break
    self.facts.update(new_facts)
    if goal in self.facts:
        print(f"\nGoal {goal} reached!")
        return True
    iteration += 1
    print("\nGoal not reached.")
return False
# Problem setup
fc = ForwardChainingFOL()
# Facts
fc.add_fact("American(Robert)")

```

```

fc.add_fact("Enemy(A,America)")
fc.add_fact("Owns(A,T1)")
fc.add_fact("Missile(T1)")
# Rules
fc.add_rule(["Missile(T1)", "Weapon(T1)"])
fc.add_rule(["Enemy(A,America)", "Hostile(A)"])
fc.add_rule(["Missile(p)", "Owns(A,p)"], "Sells(Robert,p,A)")
fc.add_rule(["American(p)", "Weapon(q)", "Sells(p,q,r)", "Hostile(r)"], "Criminal(p)")
# Goal
goal = "Criminal(Robert)"
# Perform forward chaining
if fc.forward_chain(goal):
    print(f"\nFinal result: Goal achieved: {goal}")
else:
    print("\nFinal result: Goal not achieved.")

```

Output:

```

==== Iteration 1 ====
Known Facts:
- American(Robert)
- Missile(T1)
- Owns(A,T1)
- Enemy(A,America)

Applying rules...
Rule triggered: ['Missile(T1)'] → Weapon(T1)
  New fact inferred: Weapon(T1)
Rule triggered: ['Enemy(A,America)'] → Hostile(A)
  New fact inferred: Hostile(A)
Rule triggered: ['Missile(p)', 'Owns(A,p)'] → Sells(Robert,p,A)
  New fact inferred: Sells(Robert,T1,A)

==== Iteration 2 ====
Known Facts:
- Hostile(A)
- Sells(Robert,T1,A)
- American(Robert)
- Missile(T1)
- Enemy(A,America)
- Weapon(T1)
- Owns(A,T1)

Applying rules...
Rule triggered: ['American(p)', 'Weapon(q)', 'Sells(p,q,r)', 'Hostile(r)'] → Criminal(p)
  New fact inferred: Criminal(Robert)

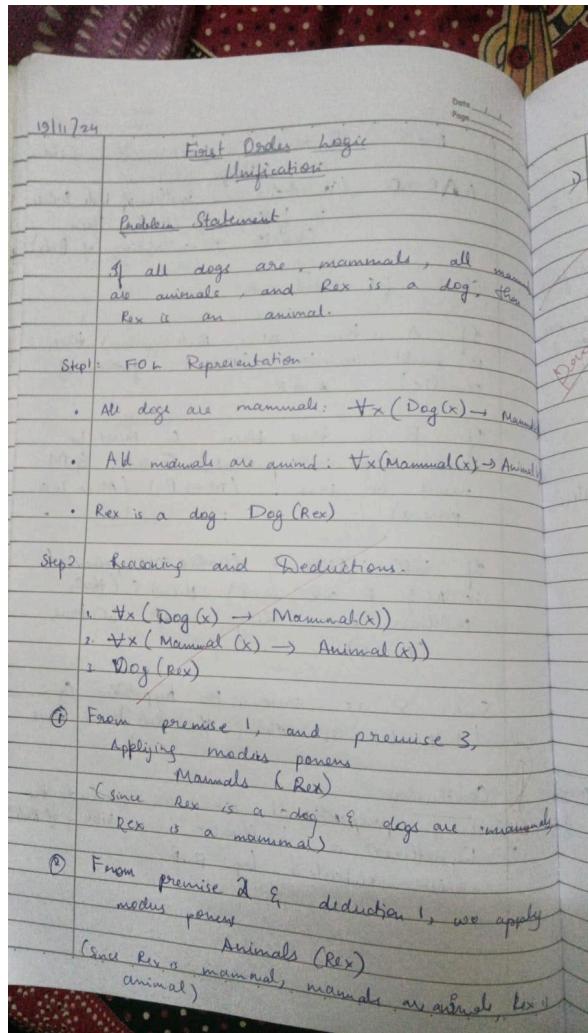
Goal Criminal(Robert) reached!

Final result: Goal achieved: Criminal(Robert)

```

Write a proof tree generated using CNF.

Algorithm:



Code:

```
def negate(literal):
    """Return the negation of a literal."""
    if isinstance(literal, tuple) and literal[0] == "not":
        return literal[1]
    else:
```

```

        return ("not", literal)
def resolve(clause1, clause2):
    """Return the resolvent of two clauses."""
    resolvents = set()
    for literal1 in clause1:
        for literal2 in clause2:
            if literal1 == negate(literal2):
                resolvent = (clause1 - {literal1}) | (clause2 - {literal2})
                print(f"  Resolving literal: {literal1} with {literal2}")
                print(f"  Resulting Resolvent: {resolvent}")
                resolvents.add(frozenset(resolvent))
    return resolvents

def resolution_algorithm(KB, query):
    """Perform the resolution algorithm to check if the query can be proven."""
    print("\n--- Step-by-Step Resolution Process ---")
    negated_query = negate(query)
    KB.append(frozenset([negated_query]))
    print(f"Negated Query Added to KB: {negated_query}")
    clauses = set(KB)
    step = 1
    while True:
        new_clauses = set()
        print(f"\nStep {step}: Resolving Clauses")
        for c1 in clauses:
            for c2 in clauses:
                if c1 != c2:
                    print(f"  Resolving clauses: {c1} and {c2}")
                    resolvent = resolve(c1, c2)
                    for res in resolvent:
                        if frozenset([]) in resolvent:
                            print("\nEmpty clause derived! The query is provable.")
                            return True
                        new_clauses.add(res)
        if new_clauses.issubset(clauses):
            print("\nNo new clauses can be derived. The query is not provable.")
            return False
        clauses.update(new_clauses)
        step += 1
KB = [
    frozenset([("not", "food(x)"), ("likes", "John", "x")]), # 1

```

```

frozenset([("food", "Apple")]),           # 2
frozenset([("food", "vegetables")]),       # 3
frozenset([("not", "eats(y, z)", ("killed", "y"), ("food", "z"))]), # 4
frozenset([("eats", "Anil", "Peanuts")]),   # 5
frozenset([("alive", "Anil")]),            # 6
frozenset([("not", "eats(Anil, w)", ("eats", "Harry", "w"))]), # 7
frozenset([("killed", "g"), ("alive", "g")]),      # 8
frozenset([("not", "alive(k)", ("not", "killed(k)"))]), # 9
frozenset([("likes", "John", "Peanuts")])          # 10
]

query = ("likes", "John", "Peanuts")
result = resolution_algorithm(KB, query)
if result:
    print("\nQuery is provable.")
else:
    print("\nQuery is not provable.")

```

Output:

```

---- Step-by-Step Resolution Process ---
Negated Query Added to KB: ('not', ('likes', 'John', 'Peanuts'))

Step 1: Resolving Clauses
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('alive', 'g'), ('killed', 'g')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('eats', 'Anil', 'Peanuts')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('food', 'z'), ('killed', 'y'), ('not', 'eats(y, z)')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('alive', 'Anil')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('food', 'vegetables')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('food', 'Apple')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('not', 'killed(k)'), ('not', 'alive(k)')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('not', ('likes', 'John', 'Peanuts'))})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('not', 'eats(Anil, w)'), ('eats', 'Harry', 'w')})
Resolving clauses: frozenset({('likes', 'John', 'x'), ('not', 'food(x)')}) and frozenset({('likes', 'John', 'Peanuts')})
Resolving clauses: frozenset({('alive', 'g'), ('killed', 'g')}) and frozenset({('likes', 'John', 'x'), ('not', 'food(x)')})
Resolving clauses: frozenset({('alive', 'g'), ('killed', 'g')}) and frozenset({('eats', 'Anil', 'Peanuts')})
Resolving clauses: frozenset({('alive', 'g'), ('killed', 'g')}) and frozenset({('alive', 'Anil')})
Resolving clauses: frozenset({('alive', 'g'), ('killed', 'g')}) and frozenset({('food', 'vegetables')})
Resolving clauses: frozenset({('alive', 'g'), ('killed', 'g')}) and frozenset({('food', 'Apple')})
Resolving clauses: frozenset({('alive', 'g'), ('killed', 'g')}) and frozenset({('not', 'killed(k)'), ('not', 'alive(k)')})
Resolving clauses: frozenset({('alive', 'g'), ('killed', 'g')}) and frozenset({('not', ('likes', 'John', 'Peanuts'))})

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'Peanuts'))})
  Resolving clauses: frozenset({{'alive', 'g'}, {'killed', 'g'}}) and frozenset({{'not', 'eats(Anil, w)'}, {'eats', 'Harry', 'w'}})
  Resolving clauses: frozenset({{'alive', 'g'}, {'killed', 'g'}}) and frozenset({{'not', 'likes', 'John', 'Peanuts'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'likes', 'John', 'x'}, {'not', 'food(x)'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'alive', 'g'}, {'killed', 'g'}}))
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'food', 'z'}, {'killed', 'y'}, {'not', 'eats(y, z)'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'alive', 'Anil'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'food', 'vegetables'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'food', 'Apple'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'not', 'likes', 'John', 'Peanuts'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'not', 'eats(Anil, w)'}, {'eats', 'Harry', 'w'}})
  Resolving clauses: frozenset({{'eats', 'Anil', 'Peanuts'}}) and frozenset({{'not', 'likes', 'John', 'Peanuts'}})
  Resolving clauses: frozenset({{'food', 'z'}, {'killed', 'y'}, {'not', 'eats(y, z)'}) and frozenset({{'likes', 'John', 'x'}, {'not', 'food(x)'}})
  Resolving clauses: frozenset({{'food', 'z'}, {'killed', 'y'}, {'not', 'eats(y, z)'}) and frozenset({{'alive', 'g'}, {'killed', 'g'}})
  Resolving clauses: frozenset({{'food', 'z'}, {'killed', 'y'}, {'not', 'eats(y, z)'}) and frozenset({{'eats', 'Anil', 'Peanuts'}})
  Resolving clauses: frozenset({{'food', 'z'}, {'killed', 'y'}, {'not', 'eats(y, z)'}) and frozenset({{'not', 'alive(k)'}, {'not', 'killed(k)'}, {'not', 'alive(k)'}})
  Resolving clauses: frozenset({{'food', 'z'}, {'killed', 'y'}, {'not', 'eats(y, z)'}) and frozenset({{'not', 'likes', 'John', 'Peanuts'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'alive', 'Anil'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'food', 'vegetables'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'food', 'Apple'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}, {'not', 'alive(k)'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'not', 'likes', 'John', 'Peanuts'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'not', 'eats(Anil, w)'}, {'eats', 'Harry', 'w'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'not', 'eats(Anil, w)'}, {'eats', 'Harry', 'w'}})
  Resolving clauses: frozenset({{'not', 'killed(k)'}, {'not', 'alive(k)'}) and frozenset({{'not', 'likes', 'John', 'Peanuts'}})
  Resolving clauses: frozenset({{'not', 'likes', 'John', 'Peanuts'}}) with ('likes', 'John', 'Peanuts')
  Resulting Resolvent: frozenset()

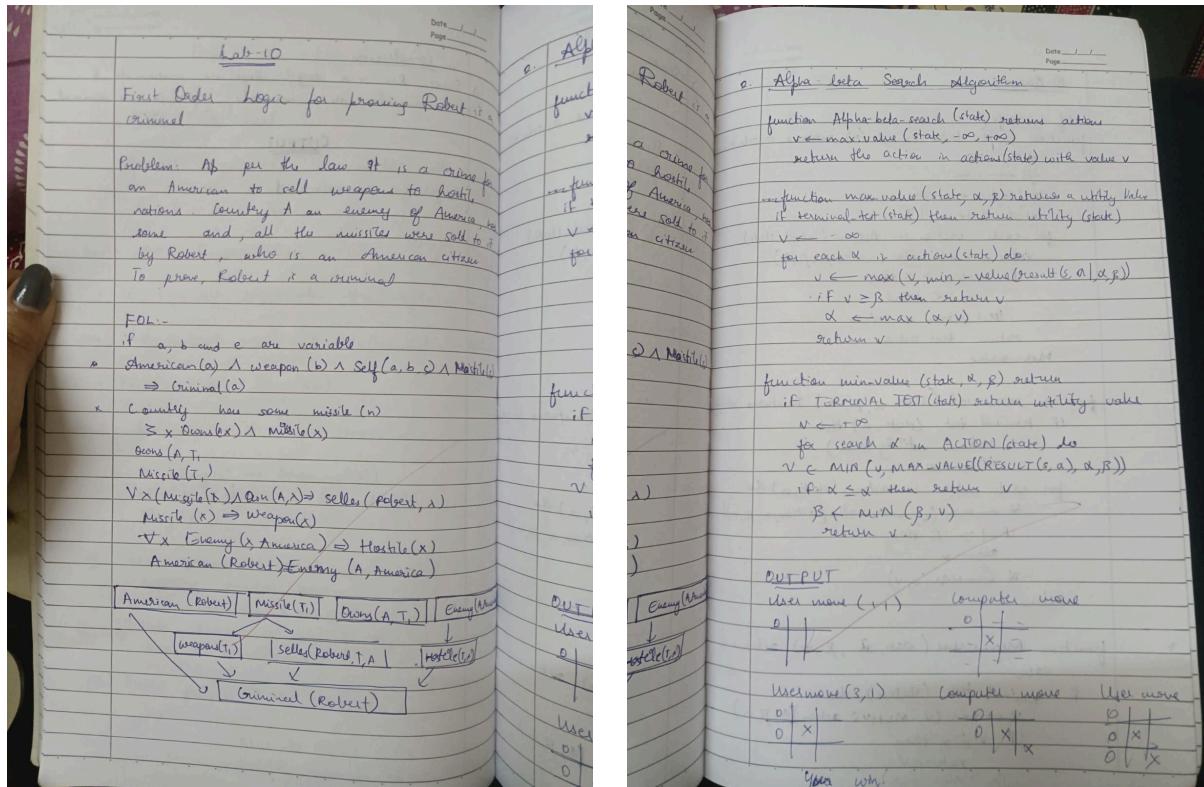
Empty clause derived! The query is provable.

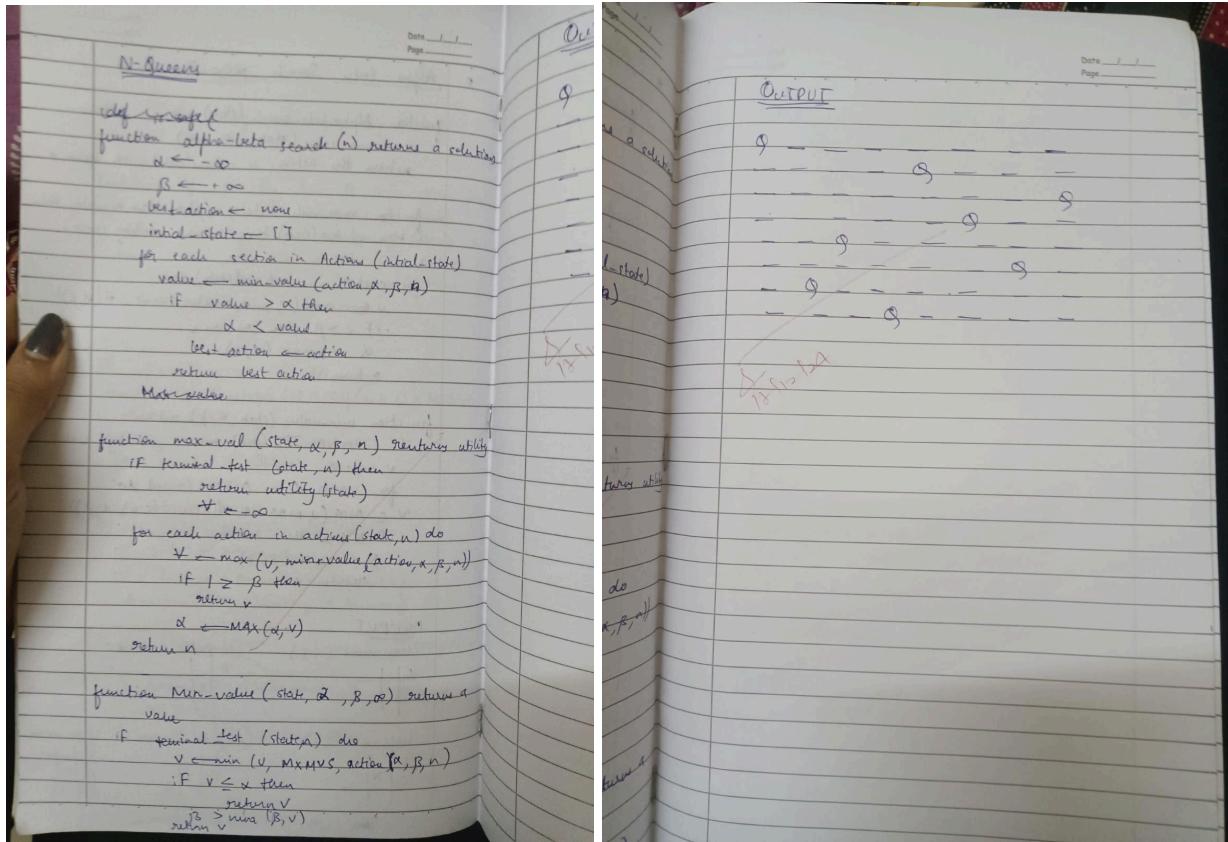
Query is provable.

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Implement Alpha Beta pruning.

Algorithm:





Code:

```

class AlphaBetaPruning:
    def __init__(self):
        self.pruned_branches = []
    def alpha_beta(self, node, depth, alpha, beta, maximizing_player):
        if isinstance(node, int):
            return node
        if maximizing_player:
            max_eval = float('-inf')
            for child in node:
                eval = self.alpha_beta(child, depth - 1, alpha, beta, False)
                max_eval = max(max_eval, eval)
                alpha = max(alpha, eval)
                if beta <= alpha:
                    self.pruned_branches.append(child)
                    break
            return max_eval
        else:
            min_eval = float('inf')

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for child in node:
    eval = self.alpha_beta(child, depth - 1, alpha, beta, True)
    min_eval = min(min_eval, eval)
    beta = min(beta, eval)
    if beta <= alpha:
        self.pruned_branches.append(child)
        break
return min_eval

def run(self, game_tree):
    alpha = float('-inf')
    beta = float('inf')
    max_value = self.alpha_beta(game_tree, float('inf'), alpha, beta, True)
    return max_value, self.pruned_branches

def construct_tree_from_leaves(leaves):
    current_level = leaves
    while len(current_level) > 1:
        next_level = []
        for i in range(0, len(current_level), 2):
            if i + 1 < len(current_level):
                next_level.append([current_level[i], current_level[i + 1]])
            else:
                next_level.append(current_level[i])
        current_level = next_level
    return current_level[0]

def input_leaf_nodes():
    print("Enter the leaf nodes of the game tree separated by spaces (e.g., 3 5 6 9 1 4 7 10 11):")
    while True:
        try:
            leaves = list(map(int, input("Leaf nodes: ").split()))
            if len(leaves) >= 2:
                return leaves
            else:
                print("Please enter at least two leaf nodes.")
        except ValueError:
            print("Invalid input. Please enter integers only.")

if __name__ == "__main__":
    leaves = input_leaf_nodes()
    game_tree = construct_tree_from_leaves(leaves)

```

```
abp = AlphaBetaPruning()
final_max_value, pruned_branches = abp.run(game_tree)
print(f"Final value of MAX node: {final_max_value}")
print(f"Subtrees pruned: {pruned_branches}")
```

Output:

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Enter the leaf nodes of the game tree separated by spaces (e.g., 3 5 6 9 1 4 7 10 11):
Leaf nodes: 10 9 14 18 5 4 50 3
Final value of MAX node: 10
Subtrees pruned: [14, [5, 4]]
```