

# VISVESVARAYA TECHNOLOGICAL UNIVERSITY

“JnanaSangama”, Belgaum -590014, Karnataka.



## LAB REPORT on

### Artificial Intelligence (23CS5PCAIN)

*Submitted by*

**Utkrisht Umang (1BM23CS355)**

*in partial fulfillment for the award of the degree of*  
**BACHELOR OF ENGINEERING**  
*in*  
**COMPUTER SCIENCE AND ENGINEERING**



**B.M.S. COLLEGE OF ENGINEERING**

(Autonomous Institution under VTU)

**BENGALURU-560019**

**Aug 2025 to Dec 2025**

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



**CERTIFICATE**

This is to certify that the Lab work entitled “Artificial Intelligence (23CS5PCAIN)” carried out by **Utkrisht Umang (1BM23CS355)**, who is bonafide student of **B.M.S. College of Engineering**. It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements in respect of an Artificial Intelligence (23CS5PCAIN) work prescribed for the said degree.

Prof. Anusha S Assistant Professor Department of CSE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE
---	--

# Index

<b>Sl. No.</b>	<b>Date</b>	<b>Experiment Title</b>	<b>Page No.</b>
1	18-8-2025	Implement Tic –Tac –Toe Game Implement vacuum cleaner agent	4-9
2	25-8-2025	Implement 8 puzzle problems using Depth First Search (DFS) Implement Iterative deepening search algorithm	10-19
3	8-9-2025	Implement A* search algorithm	20-23
4	15-9-2025	Implement Hill Climbing search algorithm to solve N-Queens problem	24-26
5	15-9-2025	Simulated Annealing to Solve 8-Queens problem	27-29
6	22-9-2025	Create a knowledge base using propositional logic and show that the given query entails the knowledge base or not.	30-33
7	13-10-2025	Implement unification in first order logic	34-40
8	13-10-2025	Create a knowledge base consisting of first order logic statements and prove the given query using forward reasoning.	41-49
9	27-10-2025	Create a knowledge base consisting of first order logic statements and prove the given query using Resolution	50-55
10	27-10-2025	Implement Alpha-Beta Pruning.	56-59

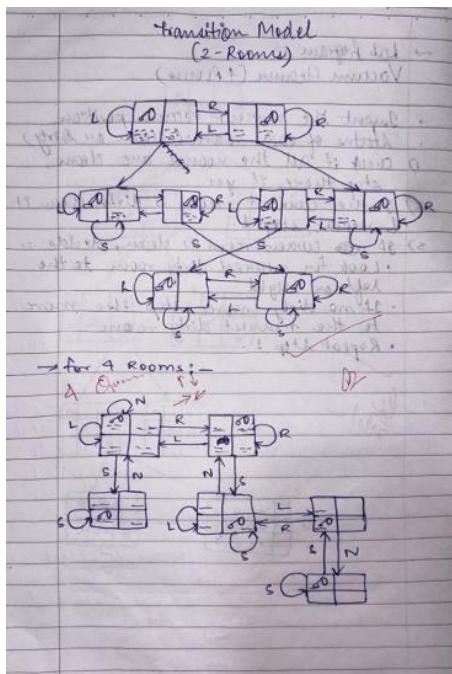
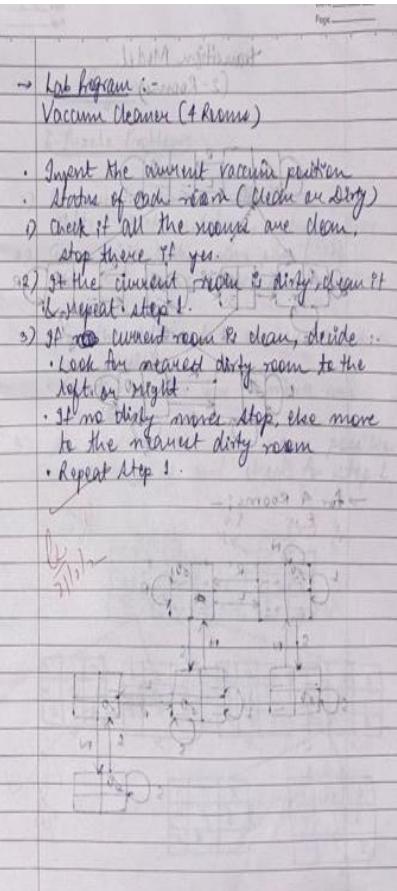
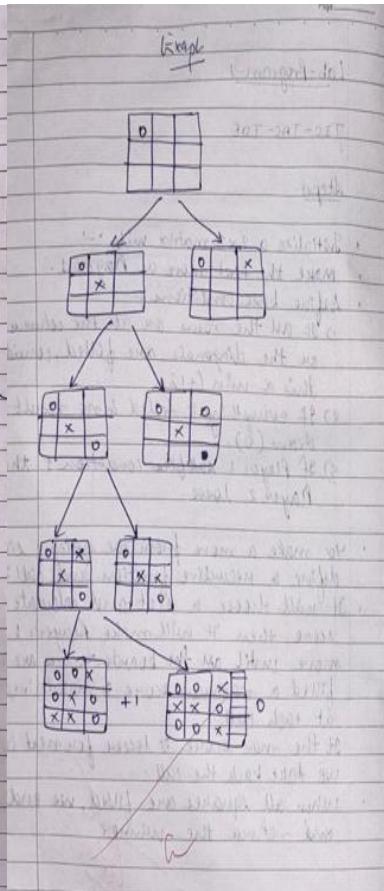
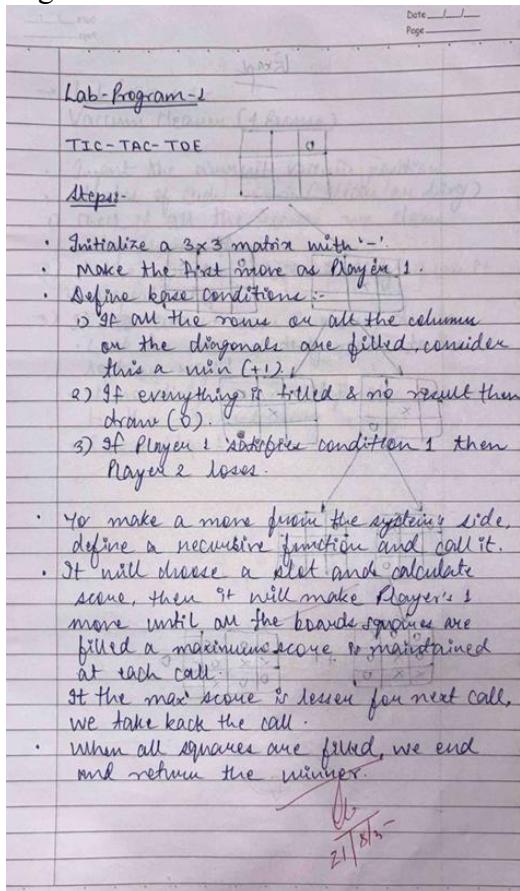
Github Link:

<https://github.com/utk1college/AI>

## Program 1

Implement Tic – Tac – Toe Game  
Implement vacuum cleaner agent

Algorithm:



Code:

## TIC TAC TOE Game

```
def print_board(board):
    print()
    print("-----")
    for i in range(3):
        print("|", board[i][0], "|", board[i][1], "|", board[i][2], "|")
        print("-----")
    print()

def is_win(board,symbol):
    #same row
    for i in range(3):
        if board[i][0] == symbol and board[i][1] == symbol and board[i][2] == symbol:
            return True

    #same Column
    for j in range(3):
        if board[0][j] == symbol and board[1][j] == symbol and board[2][j] == symbol:
            return True

    #same diagonal
    if board[0][0] == symbol and board[1][1] == symbol and board[2][2] == symbol:
        return True

    if board[0][2] == symbol and board[1][1] == symbol and board[2][0] == symbol:
        return True

    #if all case fails
    return False
```

```
def is_draw(board):
    for i in range(3):
        for j in range(3):
            if board[i][j] == " ":
                return False
    return True
```

```
def get_input(mark,id):
    while True:
        try:
            move = input(f'Player {id}, Enter the position to place {mark} -> ')
            ip = move.strip().split()

            if len(ip) != 2:
                print("Enter exactly 2 coordinates!")
                continue

            row,col = int(ip[0]),int(ip[1])

            if (row>=1 and row<= 3) and (col>=1 and col<=3):
                return [row-1,col-1]
            else:
                print("Enter values between 1 and 3 only")
```

```

except ValueError:
    print("Invalid inputs, enter numbers only")

board = []
for i in range(3):
    board.append([" "," "," "])

mark1 = "X"
mark2 = "O"
p1 = 1
p2 = 2
curr_p = 1
curr_m = "X"
while True:
    print_board(board)
    row,col = get_input(curr_m,curr_p)

    if board[row][col] != " ":
        print("Move already taken!, Try again")
        continue

    board[row][col] = curr_m

    if is_win(board,curr_m):
        print_board(board)
        print(f'Congrats {curr_p}, Player{curr_p} wins!!!')
        break

    if is_draw(board):
        print_board(board)
        print("Its a draw, 🤖!")
        break

    if curr_p == p1:
        curr_p = p2
        curr_m = "O"
    else:
        curr_p = p1
        curr_m = "X"

```

-----  
| | | |  
-----  
| | | |  
-----  
| | | |  
-----

Player1, Enter the position to place X-> 1 1

-----  
| X | | |  
-----  
| | | |  
-----  
| | | |

-----  
Player2, Enter the position to place O-> 3 1

-----  
| X | | |  
-----  
| | | |  
-----  
| O | | |  
-----

Player1, Enter the position to place X-> 2 2

-----  
| X | | |  
-----  
| | X | |  
-----  
| O | | |  
-----

Player2, Enter the position to place O-> 3 2

-----  
| X | | |  
-----  
| | X | |  
-----  
| O | O | |  
-----

Player1, Enter the position to place X-> 3 3

-----  
| X | | |  
-----  
| | X | |  
-----  
| O | O | X |  
-----

Congrats 🎉, Player1 wins!!!

## Vacuum Cleaner Agent

```
def is_clean(status):
```

```

return status[room_a] and status[room_b]

def simulate(state, choice, status, cost, do_clean=True):
    if is_clean(status):
        print("All rooms are clean")
        return cost

    if choice != 1 and choice != -1:
        print("Invalid choice")
        return cost

    # Vacuum in room A
    if state[0][0]:
        if choice == -1:
            if do_clean and not state[0][1]:
                state[0][1] = True
                status[room_a] = True
                print("Cleaned room A")
                cost += 1 # Cost of cleaning
        else:
            print("No cleaning in room A")
    elif choice == 1:
        state[0][0] = False
        state[1][0] = True
        print("Moved vacuum from A to B")
    else:
        print("Cannot move from A to B")

    # Vacuum in room B
    elif state[1][0]:
        if choice == 1:
            if do_clean and not state[1][1]:
                state[1][1] = True
                status[room_b] = True
                print("Cleaned room B")
                cost += 1 # Cost of cleaning
        else:
            print("No cleaning in room B")
    elif choice == -1:
        state[1][0] = False
        state[0][0] = True
        print("Moved vacuum from B to A")
    else:
        print("Cannot move from B to A")
    else:
        print("Vacuum is not in any room!")

    return cost

if __name__ == "__main__":
    room_a = 'A'
    room_b = 'B'
    state = [[True, False], [False, False]]
    status = {room_a:False, room_b:False}
    total_cost = 0 # Initialize total cost

```

```

while True:
    if is_clean(status):
        print("All rooms are clean. Exiting.")
        print(f"Total cost: {total_cost}") # Display total cost
        break

choice = int(input("Enter -1 to act in Room A, 1 to act in Room B: "))
action = input("Enter 'c' to clean, 'm' to move without cleaning: ").lower()

if action == 'c':
    total_cost = simulate(state, choice, status, total_cost)
elif action == 'm':
    total_cost = simulate(state, choice, status, total_cost, False)
else:
    print("Invalid action choice")

```

Enter -1 to act in Room A, 1 to act in Room B: -1

Enter 'c' to clean, 'm' to move without cleaning: c

Cleaned room A

Enter -1 to act in Room A, 1 to act in Room B: 1

Enter 'c' to clean, 'm' to move without cleaning: m

Moved vacuum from A to B

Enter -1 to act in Room A, 1 to act in Room B: 1

Enter 'c' to clean, 'm' to move without cleaning: c

Cleaned room B

All rooms are clean. Exiting.

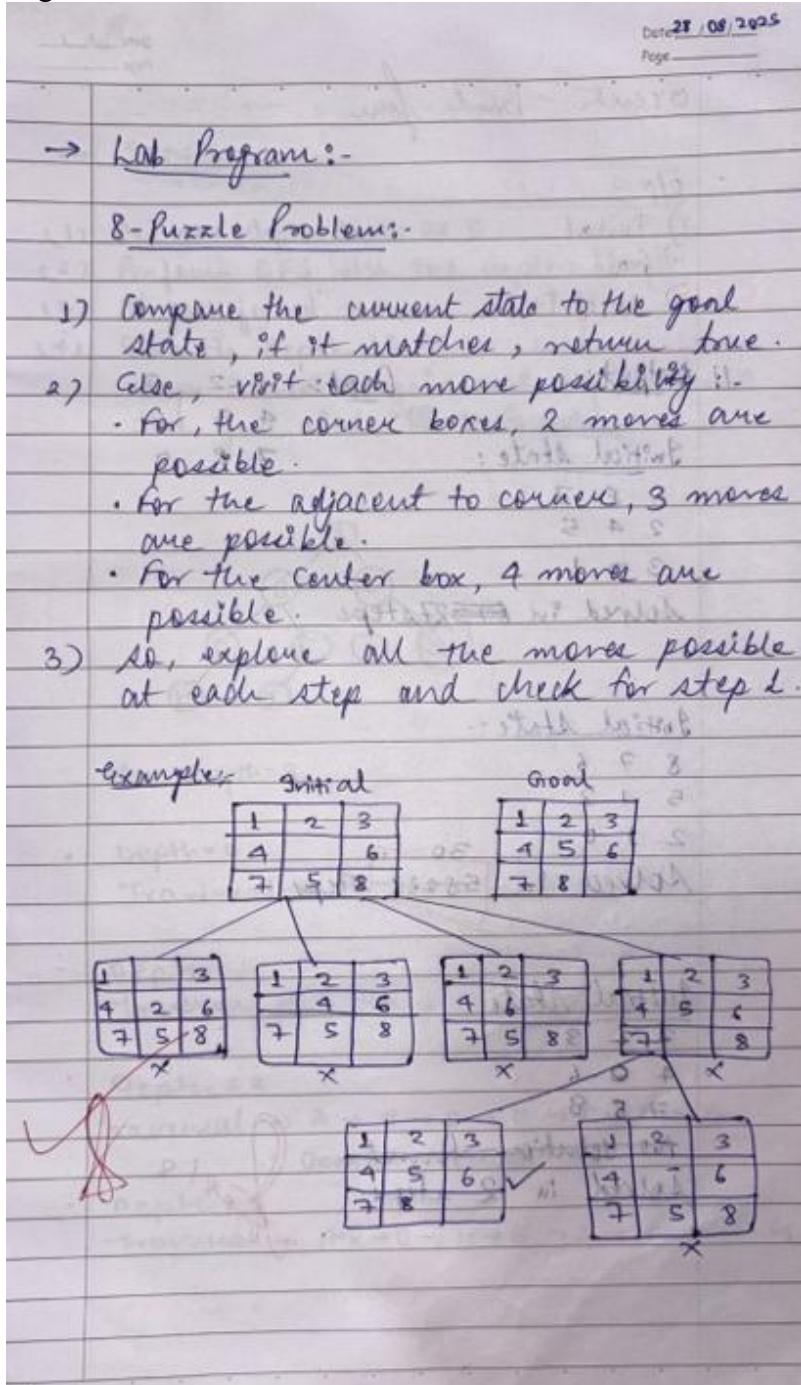
Total cost: 2

## Program 2

Implement 8 puzzle problems using Depth First Search (DFS)

Implement Iterative deepening search algorithm

Algorithm:



Excuti - Banti form

- O/P -  
 1) Initial  
 2) Goal  
 3) No. of states

II Output:- Graph: 1 2 3  
 4 5 6  
 7 8 0

Initial State:-  
 6 8 7  
 2 4 5  
 3 0 1  
 Solved in 5 steps

Initial State:-  
 8 7 6  
 5 4 3  
 2 1 0  
 Solved in 5 steps

Initial State:-  
 1 2 3  
 4 0 6  
 7 5 8  
 No solution found.  
 Solved in 2 steps.

Solving 8-Puzzle using IDDFS:-

Start State:      Goal State:  
 1 2 3                  1 2 3  
 4 5 6                  4 5 6  
 0 7 8                  7 0 8  
 Depth = 0

Goal + Start.

Depth = 1

1 2 3  
 4 5 6  
 0 7 8

State + Goal      State + Start

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

State + Goal      State + Start

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

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

Goal = State      X

... solution found

O/P

Depth = 2

1 2 3  
 4 5 6  
 0 7 8

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

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

Goal = State      X

... solution found

Code:

## 8 Puzzle using DFS

```
from collections import deque

# Helper to print board in 3x3 format
def print_board(state):
    for i in range(0, 9, 3):
        print(state[i:i+3])
    print()

# Generate possible moves
def get_neighbors(state):
    neighbors = []
    idx = state.index(0) # blank space
    row, col = divmod(idx, 3)
    moves = []
    if row > 0: moves.append((-1, 0, 'Up'))
    if row < 2: moves.append((1, 0, 'Down'))
    if col > 0: moves.append((0, -1, 'Left'))
    if col < 2: moves.append((0, 1, 'Right'))

    for dr, dc, action in moves:
        new_row, new_col = row + dr, col + dc
        new_idx = new_row * 3 + new_col
        new_state = list(state)
        new_state[idx], new_state[new_idx] = new_state[new_idx], new_state[idx]
        neighbors.append((tuple(new_state), action))

    return neighbors

# DFS Search
def solve_puzzle(start, goal, max_depth=50):
    stack = [(start, [])]
    explored = set()

    while stack:
        state, path = stack.pop()

        if state in explored:
            continue
        explored.add(state)

        if state == goal:
            return path

        if len(path) < max_depth:
            for neighbor, action in get_neighbors(state):
                if neighbor not in explored:
                    stack.append((neighbor, path + [(action, neighbor)]))

    return None

if __name__ == "__main__":
    print("Enter the initial state (0 for blank, space-separated, 9 numbers):")
    start = tuple(map(int, input().split()))

    print("Enter the goal state (0 for blank, space-separated, 9 numbers):")
    goal = tuple(map(int, input().split()))
```

```

print("\nSolving puzzle with DFS...\n")
solution = solve_puzzle(start, goal)

if solution:
    print("Solution found using DFS! (may not be optimal)\n")
    print("Total steps:", len(solution))
    current = start
    print("Initial State:")
    print_board(current)
    for step, state in solution:
        print("Move:", step)
        print_board(state)
else:
    print("No solution found within depth limit.")

```

Enter the initial state (0 for blank, space-separated, 9 numbers):

2 8 3 1 6 4 7 0 5

Enter the goal state (0 for blank, space-separated, 9 numbers):

1 2 3 8 0 4 7 6 5

Solving puzzle with DFS...

Solution found using DFS! (may not be optimal)

Total steps: 49

Initial State:

(2, 8, 3)

(1, 6, 4)

(7, 0, 5)

Move: Right

(2, 8, 3)

(1, 6, 4)

(7, 5, 0)

Move: Up

(2, 8, 3)

(1, 6, 0)

(7, 5, 4)

Move: Left

(2, 8, 3)

(1, 0, 6)

(7, 5, 4)

Move: Left

(2, 8, 3)

(0, 1, 6)

(7, 5, 4)

Move: Down

(2, 8, 3)

(7, 1, 6)

(0, 5, 4)

Move: Right

(2, 8, 3)

(7, 1, 6)

(5, 0, 4)

Move: Right

(2, 8, 3)

(7, 1, 6)

(5, 4, 0)

Move: Up

(2, 8, 3)

(7, 1, 0)

(5, 4, 6)

Move: Left

(2, 8, 3)

(7, 0, 1)

(5, 4, 6)

Move: Left

(2, 8, 3)

(0, 7, 1)

(5, 4, 6)

Move: Down

(2, 8, 3)

(5, 7, 1)

(0, 4, 6)

Move: Right

(2, 8, 3)

(5, 7, 1)

(4, 0, 6)

Move: Right

(2, 8, 3)

(5, 7, 1)

(4, 6, 0)

Move: Up

(2, 8, 3)

(5, 7, 0)

(4, 6, 1)

Move: Left

(2, 8, 3)

(5, 0, 7)

(4, 6, 1)

Move: Left

(2, 8, 3)

(0, 5, 7)

(4, 6, 1)

Move: Down

(2, 8, 3)

(4, 5, 7)

(0, 6, 1)

Move: Right

(2, 8, 3)

(4, 5, 7)

(6, 0, 1)

Move: Right

(2, 8, 3)

(4, 5, 7)

(6, 1, 0)

Move: Up

(2, 8, 3)

(4, 5, 0)

(6, 1, 7)

Move: Left

(2, 8, 3)

(4, 0, 5)

(6, 1, 7)

Move: Left

(2, 8, 3)

(0, 4, 5)

(6, 1, 7)

Move: Down

(2, 8, 3)

(6, 4, 5)

(0, 1, 7)

Move: Right

(2, 8, 3)

(6, 4, 5)

(1, 0, 7)

Move: Right

(2, 8, 3)

(6, 4, 5)

(1, 7, 0)

Move: Up

(2, 8, 3)

(6, 4, 0)

(1, 7, 5)

Move: Left

(2, 8, 3)

(6, 0, 4)

(1, 7, 5)

Move: Down

(2, 8, 3)

(6, 7, 4)

(1, 0, 5)

Move: Left

(2, 8, 3)

(6, 7, 4)

(0, 1, 5)

Move: Up

(2, 8, 3)

(0, 7, 4)

(6, 1, 5)

Move: Right

(2, 8, 3)

(7, 0, 4)

(6, 1, 5)

Move: Right

(2, 8, 3)

(7, 4, 0)

(6, 1, 5)

Move: Down

(2, 8, 3)

(7, 4, 5)

(6, 1, 0)

Move: Left

(2, 8, 3)

(7, 4, 5)

(6, 0, 1)

Move: Up

(2, 8, 3)

(7, 0, 5)

(6, 4, 1)

Move: Right

(2, 8, 3)

(7, 5, 0)

(6, 4, 1)

Move: Down

(2, 8, 3)

(7, 5, 1)

(6, 4, 0)

Move: Left

(2, 8, 3)

(7, 5, 1)

(6, 0, 4)

Move: Up

(2, 8, 3)

(7, 0, 1)

(6, 5, 4)

Move: Right

(2, 8, 3)

(7, 1, 0)

(6, 5, 4)

Move: Down

(2, 8, 3)

(7, 1, 4)

(6, 5, 0)

Move: Left

(2, 8, 3)

(7, 1, 4)

(6, 0, 5)

Move: Left

(2, 8, 3)

(7, 1, 4)

(0, 6, 5)

Move: Up

(2, 8, 3)

(0, 1, 4)

(7, 6, 5)

Move: Right

(2, 8, 3)

(1, 0, 4)

(7, 6, 5)

Move: Up

(2, 0, 3)

(1, 8, 4)

(7, 6, 5)

Move: Left

(0, 2, 3)

(1, 8, 4)

(7, 6, 5)

Move: Down

(1, 2, 3)

(0, 8, 4)

(7, 6, 5)

Move: Right

(1, 2, 3)

(8, 0, 4)

(7, 6, 5)

## 8 Puzzle using Iterative Deepening DFS

```
from collections import deque

# Helper to print board in 3x3 format
def print_board(state):
    for i in range(0, 9, 3):
        print(state[i:i+3])
    print()

# Generate possible moves
def get_neighbors(state):
    neighbors = []
    idx = state.index(0) # blank space
    row, col = divmod(idx, 3)
    moves = []
    if row > 0: moves.append((-1, 0, 'Up'))
    if row < 2: moves.append((1, 0, 'Down'))
    if col > 0: moves.append((0, -1, 'Left'))
    if col < 2: moves.append((0, 1, 'Right'))

    for dr, dc, action in moves:
        new_row, new_col = row + dr, col + dc
        new_idx = new_row * 3 + new_col
        new_state = list(state)
        new_state[idx], new_state[new_idx] = new_state[new_idx], new_state[idx]
        neighbors.append((tuple(new_state), action))
    return neighbors

# Depth-Limited Search (helper for IDDFS)
def dls(state, goal, depth, path, explored):
    if state == goal:
        return path
    if depth == 0:
        return None
    explored.add(state)
    for neighbor, action in get_neighbors(state):
        if neighbor not in explored:
            result = dls(neighbor, goal, depth-1, path + [(action, neighbor)], explored)
            if result is not None:
                return result
    return None

# Iterative Deepening DFS
def iddfs(start, goal, max_depth=50):
    for depth in range(max_depth):
        explored = set()
        result = dls(start, goal, depth, [], explored)
        if result is not None:
            return result
    return None

if __name__ == "__main__":
    print("Enter the initial state (0 for blank, space-separated, 9 numbers):")
    start = tuple(map(int, input().split()))

    print("Enter the goal state (0 for blank, space-separated, 9 numbers):")
    goal = tuple(map(int, input().split()))
```

```

print("\nSolving puzzle with Iterative Deepening DFS...\n")
solution = iddfs(start, goal)

if solution:
    print("Optimal solution found using IDDFS!\n")
    print("Total steps:", len(solution))
    current = start
    print("Initial State:")
    print_board(current)
    for step, state in solution:
        print("Move:", step)
        print_board(state)
else:
    print("No solution found within depth limit.")

```

Enter the initial state (0 for blank, space-separated, 9 numbers):

2 8 3 1 6 4 7 0 5

Enter the goal state (0 for blank, space-separated, 9 numbers):

1 2 3 8 0 4 7 6 5

Solving puzzle with Iterative Deepening DFS...

Optimal solution found using IDDFS!

Total steps: 5

Initial State:

(2, 8, 3)

(1, 6, 4)

(7, 0, 5)

Move: Up

(2, 8, 3)

(1, 0, 4)

(7, 6, 5)

Move: Up

(2, 0, 3)

(1, 8, 4)

(7, 6, 5)

Move: Left

(0, 2, 3)

(1, 8, 4)

(7, 6, 5)

Move: Down

(1, 2, 3)

(0, 8, 4)

(7, 6, 5)

Move: Right

(1, 2, 3)

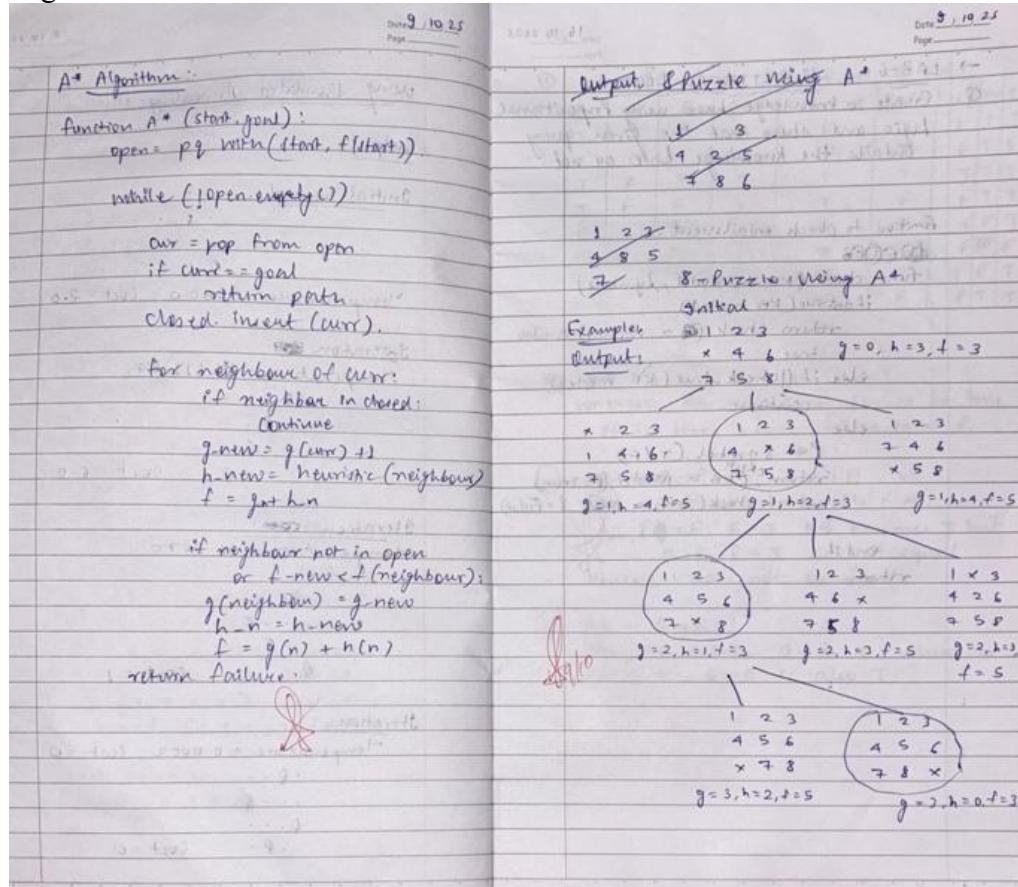
(8, 0, 4)

(7, 6, 5)

## Program 3

Implement A\* search algorithm

Algorithm:



Code:

### A\* using misplaced tiles for 8 puzzle

```
from heapq import heappush, heappop
```

```
MOVES = {
    'up': -3,
    'down': 3,
    'left': -1,
    'right': 1
}
```

```
def is_valid_move(zero_pos, move):
    if move == 'left' and zero_pos % 3 == 0:
        return False
    if move == 'right' and zero_pos % 3 == 2:
        return False
    if move == 'up' and zero_pos < 3:
        return False
    if move == 'down' and zero_pos > 5:
        return False
    return True
```

```

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

def print_state_formatted(state):
    for i in range(0, 9, 3):
        row = state[i:i+3]
        print(" ".join(str(x) if x != 0 else " " for x in row))
    print()

def a_star_misplaced(start, goal):
    open_set = []
    closed_set = set()
    g = 0
    h = misplaced_tiles(start, goal)
    f = g + h
    heappush(open_set, (f, g, start, [], None)) # last element: move that got here

    while open_set:
        f, g, current, path, move_made = heappop(open_set)

        # Print detailed info with matrix format and move made
        if move_made is None:
            print(f"Expanding node with f={f}, g={g} - Start state")
        else:
            print(f"Expanding node with f={f}, g={g} - Move: {move_made}")
            print_state_formatted(current)

        if current == goal:
            print("Goal reached!")
            print("Solution path (moves):", path)
            print(f"Final depth (number of moves): {g}")
            return path, g

        closed_set.add(current)

        zero_pos = current.index(0)

        for move, shift in MOVES.items():
            if is_valid_move(zero_pos, move):
                new_zero_pos = zero_pos + shift
                new_state = list(current)
                new_state[zero_pos], new_state[new_zero_pos] = new_state[new_zero_pos], new_state[zero_pos]
                new_state = tuple(new_state)

                if new_state in closed_set:
                    continue

                new_g = g + 1
                new_h = misplaced_tiles(new_state, goal)
                new_f = new_g + new_h
                heappush(open_set, (new_f, new_g, new_state, path + [move], move))

    print("No solution found.")
    return None, None

def get_state_matrix(prompt):
    print(prompt)

```

```

matrix = []
for i in range(3):
    while True:
        try:
            row = list(map(int, input().strip().split()))
            if len(row) != 3:
                raise ValueError("Each row must have exactly 3 numbers.")
            matrix.append(row)
            break
        except Exception as e:
            print("Invalid input:", e)
if set(matrix) != set(range(9)):
    print("Error: The numbers must be from 0 to 8 without repetition.")
    return get_state_matrix(prompt)
return tuple(matrix)

if __name__ == "__main__":
    start_state = get_state_matrix("Enter the initial state (3 rows, each with 3 numbers separated by spaces):")
    goal_state = get_state_matrix("Enter the goal state (3 rows, each with 3 numbers separated by spaces):")

    print("\nInitial State:")
    print_state_formatted(start_state)
    print("Goal State:")
    print_state_formatted(goal_state)

    a_star_misplaced(start_state, goal_state)

```

Enter the initial state (3 rows, each with 3 numbers separated by spaces):

2 8 3  
1 6 4  
7 0 5

Enter the goal state (3 rows, each with 3 numbers separated by spaces):

1 2 3  
8 0 4  
7 6 5

Initial State:

2 8 3  
1 6 4  
7 5

Goal State:

1 2 3  
8 4  
7 6 5

Expanding node with f=4, g=0 - Start state

2 8 3  
1 6 4  
7 5

Expanding node with f=4, g=1 - Move: up

2 8 3  
1 4  
7 6 5

Expanding node with f=5, g=2 - Move: up

2 3  
1 8 4  
7 6 5

Expanding node with f=5, g=2 - Move: left

2 8 3  
1 4  
7 6 5

Expanding node with f=5, g=3 - Move: left

2 3  
1 8 4  
7 6 5

Expanding node with f=5, g=4 - Move: down

1 2 3  
8 4  
7 6 5

Expanding node with f=5, g=5 - Move: right

1 2 3  
8 4  
7 6 5

Goal reached!

Solution path (moves): ['up', 'up', 'left', 'down', 'right']

Final depth (number of moves): 5

## Program 4

Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm:

<p>Date <u>9/10/25</u> Page _____</p> <pre> Hill Climbing func HillClimbing (currentVal, maxIter) {     for i=1 to maxIter:         newVal += randomVal         if newVal &gt; currentVal:             currentVal = newVal             continue         else if newVal &lt; currentVal:             reject the newVal             continue         state = bad     return currentVal }  Hill Climbing is a local search algorithm that iteratively moves from a current solution to a better solution until no improvement or maximum iteration </pre>	<p>Date <u>9/10/25</u> Page _____</p> <p><u>Example: (N-Queens)</u></p> <p>4-Queen using Hill Climbing.</p> <p>Initial board: [3, 1, 2, 0]</p> <p>Initial cost = 2</p> <p>Iteration 1</p> <table border="0"> <tr><td>Neighborhood:</td><td>[1, 3, 2, 0], Cost = 1</td></tr> <tr><td></td><td>[2, 1, 3, 0], Cost = 2</td></tr> <tr><td></td><td>[0, 1, 2, 3], Cost = 6</td></tr> <tr><td></td><td>[4, 3, 2, 1, 0], Cost = 6</td></tr> <tr><td></td><td>[5, 0, 2, 1, 0], Cost = 1</td></tr> </table> <p>Board: [3, 1, 0, 0], Cost = 1</p> <p>New Board: [1, 3, 2, 0], Cost = 1</p> <p>Iteration 2</p> <table border="0"> <tr><td>1: [3, 1, 2, 0], Cost = 2</td></tr> <tr><td>2: [2, 3, 1, 0], Cost = 2</td></tr> <tr><td>3: [0, 3, 2, 1], Cost = 4</td></tr> <tr><td>4: [1, 2, 3, 0], Cost = 4</td></tr> <tr><td>5: [1, 0, 2, 3], Cost = 2</td></tr> <tr><td>6: [1, 3, 0, 2], Cost = 0</td></tr> </table> <p>Newboard: [1, 3, 0, 2], Cost = 0</p> <p>Final Solution:</p> <p>Board: [1, 3, 0, 2] Cost: 0</p>	Neighborhood:	[1, 3, 2, 0], Cost = 1		[2, 1, 3, 0], Cost = 2		[0, 1, 2, 3], Cost = 6		[4, 3, 2, 1, 0], Cost = 6		[5, 0, 2, 1, 0], Cost = 1	1: [3, 1, 2, 0], Cost = 2	2: [2, 3, 1, 0], Cost = 2	3: [0, 3, 2, 1], Cost = 4	4: [1, 2, 3, 0], Cost = 4	5: [1, 0, 2, 3], Cost = 2	6: [1, 3, 0, 2], Cost = 0
Neighborhood:	[1, 3, 2, 0], Cost = 1																
	[2, 1, 3, 0], Cost = 2																
	[0, 1, 2, 3], Cost = 6																
	[4, 3, 2, 1, 0], Cost = 6																
	[5, 0, 2, 1, 0], Cost = 1																
1: [3, 1, 2, 0], Cost = 2																	
2: [2, 3, 1, 0], Cost = 2																	
3: [0, 3, 2, 1], Cost = 4																	
4: [1, 2, 3, 0], Cost = 4																	
5: [1, 0, 2, 3], Cost = 2																	
6: [1, 3, 0, 2], Cost = 0																	

Code:

```

def get_user_input(n):
    board = []
    print(f"Enter the row positions (0 to {n-1}) of the queens for each column:")
    for col in range(n):
        while True:
            try:
                row = int(input(f"Column {col}: "))
                if 0 <= row < n:
                    board.append(row)
                    break
                else:
                    print(f"Invalid input. Please enter a number between 0 and {n-1}.")
            except ValueError:
                print("Invalid input. Please enter an integer.")
    return board

```

```
def print_board(board):
```

```

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

def heuristic(board):
    n = len(board)
    attacks = 0
    for i in range(n):
        for j in range(i+1, n):
            # Check same row
            if board[i] == board[j]:
                attacks += 1
            # Check same diagonal
            if abs(board[i] - board[j]) == abs(i - j):
                attacks += 1
    return attacks

def get_best_neighbor(board):
    n = len(board)
    current_heuristic = heuristic(board)
    best_board = list(board)
    best_heuristic = current_heuristic

    for col in range(n):
        for row in range(n):
            if board[col] != row:
                new_board = list(board)
                new_board[col] = row
                new_heuristic = heuristic(new_board)
                if new_heuristic < best_heuristic:
                    best_heuristic = new_heuristic
                    best_board = new_board
    return best_board, best_heuristic

def hill_climbing_with_user_input(n):
    board = get_user_input(n)
    current_heuristic = heuristic(board)

    steps = 0
    while True:
        print(f"Step {steps}: Heuristic = {current_heuristic}")
        print_board(board)

        if current_heuristic == 0:
            print("Solution found!")
            return board

        neighbor, neighbor_heuristic = get_best_neighbor(board)

        # If no improvement, stuck at local minimum
        if neighbor_heuristic >= current_heuristic:

```

```

print("Reached local minimum (no better neighbors).")
return board

board = neighbor
current_heuristic = neighbor_heuristic
steps += 1

# Run the algorithm
if __name__ == "__main__":
    n = 4
    solution = hill_climbing_with_user_input(n)
    print("Final solution:")
    print_board(solution)

```

Enter the row positions (0 to 3) of the queens for each column:

Column 0: 3  
 Column 1: 1  
 Column 2: 2  
 Column 3: 0

Step 0: Heuristic = 2

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

Reached local minimum (no better neighbors).

Final solution:

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

## Program 5

Simulated Annealing to Solve 8-Queens problem

Algorithm:

<p><u>Simulated Annealing</u></p> <pre> func SimulatedAnn(current_val, T, max)     Set T as some high value     for i = 1 to max_iter:         neighbour = neighbour + random_val         if neighbour &gt; current_val             current_val ← neighbour         else if neighbour &lt; current_val:             // Accept neighbour with             // some probability             change = current_val - neighbour             prob = e^-change/T             if prob &gt;= random()                 current_val ← neighbour     Reduce T by some factor     Loop over     Return current_val </pre> <p>Simulated Annealing is a search algorithm like Hill Climbing, but it also accepts the bad solution with some probability to avoid getting stuck at local maxima</p>	<p>Date 9/10/25 Page _____</p> <p><u>using Simulated Annealing</u></p> <p><u>Initial Random</u></p> <table border="0"> <tr><td>Q</td><td>.</td><td>.</td></tr> <tr><td>.</td><td>Q</td><td>.</td></tr> <tr><td>.</td><td>.</td><td>Q</td></tr> </table> <p>Temperature = 9950.0, Cost = 2.0</p> <p><u>Iteration 1</u></p> <table border="0"> <tr><td>Q</td><td>.</td><td>.</td></tr> <tr><td>.</td><td>Q</td><td>.</td></tr> <tr><td>.</td><td>.</td><td>Q</td></tr> </table> <p>Temperature = 811.64</p> <p><u>Iteration 2</u></p> <table border="0"> <tr><td>Q</td><td>.</td><td>.</td></tr> <tr><td>.</td><td>Q</td><td>.</td></tr> <tr><td>.</td><td>.</td><td>Q</td></tr> </table> <p>Cost = 6.0</p> <p><u>Iteration 3</u></p> <table border="0"> <tr><td>Q</td><td>.</td><td>.</td></tr> <tr><td>.</td><td>Q</td><td>.</td></tr> <tr><td>.</td><td>.</td><td>Q</td></tr> </table> <p>Temperature = 66.2070</p> <p><u>Iteration 4</u></p> <table border="0"> <tr><td>Q</td><td>.</td><td>.</td></tr> <tr><td>.</td><td>Q</td><td>.</td></tr> <tr><td>.</td><td>.</td><td>Q</td></tr> </table> <p>Cost = 1</p> <p><u>Iteration 5</u></p> <table border="0"> <tr><td>Q</td><td>.</td><td>.</td></tr> <tr><td>.</td><td>Q</td><td>.</td></tr> <tr><td>.</td><td>.</td><td>Q</td></tr> </table> <p>Temperature = 0.0002, Cost = 0</p>	Q	.	.	.	Q	.	.	.	Q	Q	.	.	.	Q	.	.	.	Q	Q	.	.	.	Q	.	.	.	Q	Q	.	.	.	Q	.	.	.	Q	Q	.	.	.	Q	.	.	.	Q	Q	.	.	.	Q	.	.	.	Q
Q	.	.																																																					
.	Q	.																																																					
.	.	Q																																																					
Q	.	.																																																					
.	Q	.																																																					
.	.	Q																																																					
Q	.	.																																																					
.	Q	.																																																					
.	.	Q																																																					
Q	.	.																																																					
.	Q	.																																																					
.	.	Q																																																					
Q	.	.																																																					
.	Q	.																																																					
.	.	Q																																																					
Q	.	.																																																					
.	Q	.																																																					
.	.	Q																																																					

Code:

```

import random
import math

def get_user_input(n):
    board = []
    print(f"Enter the row positions (0 to {n-1}) of the queens for each column:")
    for col in range(n):
        while True:
            try:
                row = int(input(f"Column {col}: "))
                if 0 <= row < n:
                    board.append(row)
                    break
            except:
                pass
    return board

```

```

        print(f"Invalid input. Please enter a number between 0 and {n-1}.")
    except ValueError:
        print("Invalid input. Please enter an integer.")
    return board

def print_board(board):
    n = len(board)
    for row in range(n):
        line = ""
        for col in range(n):
            line += " Q " if board[col] == row else " . "
        print(line)
    print()

def heuristic(board):
    n = len(board)
    attacks = 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):
                attacks += 1
    return attacks

def random_neighbor(board):
    n = len(board)
    neighbor = list(board)
    col = random.randint(0, n-1)
    row = random.randint(0, n-1)
    while row == neighbor[col]:
        row = random.randint(0, n-1)
    neighbor[col] = row
    return neighbor

def simulated_annealing(n=8, max_iter=100000, initial_temp=100, cooling_rate=0.995):
    current_board = get_user_input(n)
    current_heuristic = heuristic(current_board)
    temperature = initial_temp
    iteration = 0

    print(f'Initial heuristic: {current_heuristic}')
    print_board(current_board)

    while temperature > 0.1 and current_heuristic > 0 and iteration < max_iter:
        neighbor = random_neighbor(current_board)
        neighbor_heuristic = heuristic(neighbor)
        delta_e = current_heuristic - neighbor_heuristic

        if delta_e > 0:
            current_board = neighbor
            current_heuristic = neighbor_heuristic
        else:
            probability = math.exp(delta_e / temperature)
            if random.random() < probability:
                current_board = neighbor
                current_heuristic = neighbor_heuristic

        temperature *= cooling_rate
        iteration += 1

```

```

if iteration % 1000 == 0:
    print(f"Iteration {iteration}, Temperature: {temperature:.2f}, Heuristic: {current_heuristic}")
    print_board(current_board)

if current_heuristic == 0:
    print("Solution found!")
else:
    print("Stopped without full solution. Best board found:")
print(f"Final heuristic: {current_heuristic}")
print_board(current_board)

if __name__ == "__main__":
    simulated_annealing()

```

Enter the row positions (0 to 7) of the queens for each column:

Column 0: 4

Column 1: 6

Column 2: 1

Column 3: 5

Column 4: 2

Column 5: 0

Column 6: 3

Column 7: 7

Initial heuristic: 0

```

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

```

Solution found!

Final heuristic: 0

```

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

```

## Program 6

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

Algorithm:

→ LAB-6 :- PROPOSITIONAL LOGIC  
 Q:- Create a knowledge base using propositional logic and show that the given query entails the knowledge base or not.

function to check entailment :-  
~~func~~ func check (KB, α, model, symbols)  
 if not true (KB, model)  
 return check (KB, α, model) is also true  
 else if (check true (KB, model))  
 continue  
 else  
 P ← symbol (T/F)  
 return (KB, α, Model, (P=True))  
 return check (KB, α, Model, (P=False))  
 end if  
 return.

Date 16/10/2023  
 Page \_\_\_\_\_

KB = ( $\neg Q \rightarrow P \wedge P \rightarrow \neg R \wedge \neg Q \vee R$ )						
P	Q	R	$\neg Q \rightarrow P$	$P \rightarrow \neg R$	$\neg Q \vee R$	KB
T	T	T	T	F	T	TT
T	T	F	T	F	T	FTF
T	F	T	T	T	T	TTT
T	F	F	T	T	F	FTT
F	T	T	F	T	T	FPT
F	T	F	F	T	T	FTF
F	F	T	T	F	T	FTF
F	F	F	T	F	F	FTT

① KB entails R? Yes.

Whenever KB is true, R should be true.  
 ∵ J+ is true, hence KB entails R

② KB ⊨ R → P

No, KB does not entail R → P as  
 for, P=F, R=T, KB becomes T but  
 R → P = T so, not equal.  
 Hence, it does not entail.

③ KB ⊨ Q → R

Yes, KB entails Q → R as, whenever  
 KB is T, Q → R is also T.

By  
 Seen

Code:

```
import itertools  
import pandas as pd  
import re
```

```
def replace_implications(expr):  
    """
```

Replace every  $X \Rightarrow Y$  with  $(\text{not } X \text{ or } Y)$ .

This uses regex with a callback to avoid partial string overwrites.

11

# Pattern: capture left side and right side around =>

*# Made more flexible to handle various expressions*

```
pattern = r'([>=<]+?)\s*=>\s*([>=<]+?)(?=\\s\\$|[&])])'
```

```
while re.search(pattern, expr):
```

```
expr = re.sub(pattern,  
              lambda m: f'  
              expr,  
              count=1)
```

return expr

```
def pl_true(sentence, model):
```

```
expr = sentence.strip()
```

```
expr = expr.replace("<=>", "=="
```

```
expr = replace implications(expr)
```

```

# Replace propositional symbols with their truth values safely
for sym, val in model.items():
    expr = re.sub(rf"\b{sym}\b", str(val), expr)

# Clean up spacing and add proper spacing for boolean operators
expr = re.sub(r"s+", ' ', expr) # Remove extra spaces
expr = expr.replace(" and ", " and ").replace(" or ", " or ").replace(" not ", " not ")

return eval(expr)

def get_symbols(KB, alpha):
    symbols = set()
    for sentence in KB + [alpha]:
        # Find all alphabetic tokens (propositional variables)
        for token in re.findall(r'\b[A-Za-z]+\b', sentence):
            if token not in ['and', 'or', 'not']: # Exclude boolean operators
                symbols.add(token)
    return sorted(list(symbols))

def tt_entails(KB, alpha):
    symbols = get_symbols(KB, alpha)
    rows = []
    entails = True

    for values in itertools.product([True, False], repeat=len(symbols)):
        model = dict(zip(symbols, values))

        try:
            kb_val = all(pl_true(sentence, model) for sentence in KB)
            alpha_val = pl_true(alpha, model)

            rows.append({**model, "KB": kb_val, "alpha": alpha_val})

            if kb_val and not alpha_val:
                entails = False
        except Exception as e:
            print(f"Error evaluating with model {model}: {e}")
            return False

    df = pd.DataFrame(rows)

    # Create a beautiful formatted table
    print("\n" + "="*50)
    print("          TRUTH TABLE")
    print("*"*50)

    # Get column widths for proper alignment
    col_widths = {}
    for col in df.columns:
        col_widths[col] = max(len(str(col)), df[col].astype(str).str.len().max())

    # Calculate total table width
    table_width = sum(col_widths.values()) + len(df.columns) * 3 - 1

    # Print top border
    print("—" * table_width + "—" + "\n")

```

```

# Print header
header = " | "
for col in df.columns:
    header += f" {col}:{^{col_widths[col]}} } | "
print(header)

# Print separator
separator = "├"
for col in df.columns:
    separator += "—" * (col_widths[col] + 2) + "┤"
    separator = separator[:-1] + "├"
print(separator)

# Print rows
for _, row in df.iterrows():
    row_str = " | "
    for col in df.columns:
        value = str(row[col])
        row_str += f" {value:{^{col_widths[col]}}} } | "
    print(row_str)

# Print bottom border
print("└" + "—" * table_width + "┘")

# Print result with styling
print("\n" + "="*50)
result_text = f"KB ENTAILS ALPHA: {'✓ YES' if entails else '✗ NO'}"
print(f'{result_text:^50}')
print("="*50)
return entails

# --- Interactive input ---
print("Enter Knowledge Base (KB) sentences, separated by commas.")
print("Use symbols like A, B, C and operators: and, or, not, =>, <=>")
kb_input = input("KB: ").strip()
KB = [x.strip() for x in kb_input.split(",")]
alpha = input("Enter query (alpha): ").strip()
result = tt_entails(KB, alpha)
print(f"Result: {result}")
#

```

Enter Knowledge Base (KB) sentences, separated by commas.

Use symbols like A, B, C and operators: and, or, not, =>, <=>

KB: not (S or T)

Enter query (alpha): T or (not T)

TRUTH TABLE

S	T	KB	alpha
True	True	False	True
True	False	False	True
False	True	False	True
False	False	True	True

KB ENTAILS ALPHA: ✓ YES

Result: True

## Program 7

Implement unification in first order logic

Algorithm:

Unification - FOL	
$\psi_1 = f(x)$	$\psi_2 = g(y)$
$\psi_1 = f(g(z))$	$\psi_2 = g(f(w))$
$\psi_1 = \psi_2$	$\psi_1 \neq \psi_2$
Unity ( $\psi_1, \psi_2$ )	$((\psi_1 \neq \psi_2) \vee (\psi_1 = \psi_2))$
(1) If $\psi_1$ & $\psi_2$ are identical, return NIL	
(2) If predicate symbol in $\psi_1$ and $\psi_2$ are not same, return NIL	
(3) If $\psi_1$ and $\psi_2$ have different number of arguments, then return FAIL.	
Else	
If $\psi_1$ is a variable, then:	
(i) If $\psi_1$ occurs in $\psi_2$ , return FAIL.	
(ii) Else return $\{(\psi_2 / \psi_1)\}$ .	
Else	
If $\psi_2$ is a variable, then:	
(i) If $\psi_2$ occurs in $\psi_1$ , then return FAIL.	
(ii) Else return $\{(\psi_1 / \psi_2)\}$ .	
(4) Start with empty SUBST $\rightarrow$ SUBST = {}.	
(5) For each pair in $\psi_1 \& \psi_2$ :	
(6) Unity each pair of corresponding elements.	
(7) If unification fails, return Failure.	
(8) If successful, add the new substitutions to SUBST.	
(9) Return SUBST.	

Date _____	Page _____
① $P(f(x), g(y), z)$	
$P(f(g(z)), g(f(x)), f(y))$	
② $\emptyset(x, f(x))$	
$\emptyset(g(y), y)$	
③ $\emptyset(x, g(x))$	
$P(g(y), g(g(x)))$	
find $\emptyset$ or MUV	
John	
(1) Same no. of arguments.	
$f(x) = f(g(z))$	
$\therefore x = g(z)$	
$y = f(x)$	
$\therefore y = f(g(z))$	
MUV or $\emptyset = f(g(z)) \rightarrow f(z)$	
$z$ is a free variable	
$\therefore \emptyset$ is unifiable	
(2) $x = g(y) -$	
$f(z) = y$	
$\therefore f(g(y)) = y$	
"y occurs in both sides."	
$\therefore \emptyset$ is not unifiable	
8/10/15	
2/10/15	

Code:

```
class Term:  
    """Base class for terms in first-order logic"""  
    pass  
  
class Constant(Term):  
    """Represents a constant"""  
    def __init__(self, name):  
        self.name = name  
  
    def __eq__(self, other):  
        return isinstance(other, Constant) and self.name == other.name  
  
    def __repr__(self):  
        return self.name  
  
    def __hash__(self):  
        return hash(('Constant', self.name))  
  
class Variable(Term):  
    """Represents a variable"""  
    def __init__(self, name):  
        self.name = name  
  
    def __eq__(self, other):  
        return isinstance(other, Variable) and self.name == other.name  
  
    def __repr__(self):  
        return self.name  
  
    def __hash__(self):  
        return hash(('Variable', self.name))  
  
class Predicate(Term):  
    """Represents a predicate with arguments"""  
    def __init__(self, name, args):  
        self.name = name  
        self.args = args if isinstance(args, list) else [args]  
  
    def __eq__(self, other):  
        return (isinstance(other, Predicate) and  
                self.name == other.name and  
                len(self.args) == len(other.args) and  
                all(a == b for a, b in zip(self.args, other.args)))  
  
    def __repr__(self):  
        return f'{self.name}({", ".join(str(arg) for arg in self.args)})'  
  
def occurs_check(var, term, subst):  
    """Check if variable occurs in term (prevents infinite structures)"""  
    if var == term:  
        return True  
    elif isinstance(term, Variable) and term in subst:  
        return occurs_check(var, subst[term], subst)  
    elif isinstance(term, Predicate):  
        return any(occurs_check(var, arg, subst) for arg in term.args)  
    return False
```

```

def apply_substitution(term, subst):
    """Apply substitution to a term"""
    if isinstance(term, Variable):
        if term in subst:
            return apply_substitution(subst[term], subst)
        return term
    elif isinstance(term, Predicate):
        new_args = [apply_substitution(arg, subst) for arg in term.args]
        return Predicate(term.name, new_args)
    else:
        return term

def unify(term1, term2, subst=None):
    """
    Unification Algorithm
    Returns substitution set if unification succeeds, None if it fails
    """
    if subst is None:
        subst = {}

    # Apply existing substitutions
    term1 = apply_substitution(term1, subst)
    term2 = apply_substitution(term2, subst)

    # Step 1: If term1 or term2 is a variable or constant
    # Step 1a: If both are identical
    if term1 == term2:
        return subst

    # Step 1b: If term1 is a variable
    elif isinstance(term1, Variable):
        if occurs_check(term1, term2, subst):
            return None # FAILURE
        else:
            new_subst = subst.copy()
            new_subst[term1] = term2
            return new_subst

    # Step 1c: If term2 is a variable
    elif isinstance(term2, Variable):
        if occurs_check(term2, term1, subst):
            return None # FAILURE
        else:
            new_subst = subst.copy()
            new_subst[term2] = term1
            return new_subst

    # Step 1d: Both are constants but not equal
    elif isinstance(term1, Constant) or isinstance(term2, Constant):
        return None # FAILURE

    # Step 2: Check if both are predicates with same name
    elif isinstance(term1, Predicate) and isinstance(term2, Predicate):
        if term1.name != term2.name:
            return None # FAILURE

    # Step 3: Check if they have same number of arguments
    if len(term1.args) != len(term2.args):

```

```

        return None # FAILURE

# Step 4 & 5: Unify arguments recursively
current_subst = subst.copy()
for arg1, arg2 in zip(term1.args, term2.args):
    current_subst = unify(arg1, arg2, current_subst)
    if current_subst is None: # If unification fails
        return None

return current_subst

else:
    return None # FAILURE

def print_substitution(subst):
    """Pretty print substitution set"""
    if subst is None:
        print("FAILURE: Unification failed")
    elif not subst:
        print("NIL: Terms are already unified")
    else:
        print("Substitution:")
        for var, term in subst.items():
            print(f" {var} -> {term}")

def parse_term(term_str):
    """Parse a string representation of a term into Term objects"""
    term_str = term_str.strip()

    # Check if it's a predicate (contains parentheses)
    if '(' in term_str:
        paren_idx = term_str.index('(')
        pred_name = term_str[:paren_idx].strip()

        # Extract arguments between parentheses
        args_str = term_str[paren_idx+1:term_str.rindex(')').strip()]

        # Split arguments by comma (handle nested predicates)
        args = []
        depth = 0
        current_arg = ""
        for char in args_str:
            if char == ',' and depth == 0:
                args.append(parse_term(current_arg))
                current_arg = ""
            else:
                if char == '(':
                    depth += 1
                elif char == ')':
                    depth -= 1
                current_arg += char

        if current_arg.strip():
            args.append(parse_term(current_arg))

        return Predicate(pred_name, args)

    # Check if it's a variable (lowercase first letter or starts with ?)

```

```

elif term_str[0].islower() or term_str[0] == '?':
    return Variable(term_str)

# Otherwise it's a constant (uppercase first letter)
else:
    return Constant(term_str)

def run_interactive():
    """Interactive mode for user input"""
    print("== Unification Algorithm (Interactive Mode) ==")
    print("Enter terms to unify. Use:")
    print(" - Variables: lowercase letters (x, y, z) or ?x, ?y")
    print(" - Constants: uppercase letters (John, Mary, A)")
    print(" - Predicates: Name(arg1, arg2, ...) e.g., P(x, y)")
    print(" - Type 'quit' to exit\n")

    while True:
        print("-" * 50)
        term1_str = input("Enter first term: ").strip()

        if term1_str.lower() == 'quit':
            print("Exiting...")
            break

        term2_str = input("Enter second term: ").strip()

        if term2_str.lower() == 'quit':
            print("Exiting...")
            break

        try:
            term1 = parse_term(term1_str)
            term2 = parse_term(term2_str)

            print(f"\nUnifying: {term1} and {term2}")
            result = unify(term1, term2)
            print_substitution(result)
            print()

        except Exception as e:
            print(f"Error parsing terms: {e}")
            print("Please check your input format.\n")

    def run_examples():
        """Run predefined examples"""
        print("== Unification Algorithm Examples ==\n")

        # Example 1: Unifying variables
        print("Example 1: Unify(x, y)")
        x = Variable('x')
        y = Variable('y')
        result = unify(x, y)
        print_substitution(result)
        print()

        # Example 2: Unifying variable with constant
        print("Example 2: Unify(x, John)")
        x = Variable('x')

```

```

john = Constant('John')
result = unify(x, john)
print_substitution(result)
print()

# Example 3: Unifying predicates
print("Example 3: Unify(P(x, y), P(John, z))")
p1 = Predicate('P', [Variable('x'), Variable('y')])
p2 = Predicate('P', [Constant('John'), Variable('z')])
result = unify(p1, p2)
print_substitution(result)
print()

# Example 4: Unifying complex predicates
print("Example 4: Unify(P(x, f(y)), P(a, f(b)))")
p1 = Predicate('P', [Variable('x'), Predicate('f', [Variable('y')])])
p2 = Predicate('P', [Constant('a'), Predicate('f', [Constant('b')])])
result = unify(p1, p2)
print_substitution(result)
print()

# Example 5: Failure case - occurs check
print("Example 5: Unify(x, f(x)) - Occurs Check")
x = Variable('x')
fx = Predicate('f', [x])
result = unify(x, fx)
print_substitution(result)
print()

# Example 6: Failure case - different predicates
print("Example 6: Unify(P(x), Q(x)) - Different Predicates")
p1 = Predicate('P', [Variable('x')])
p2 = Predicate('Q', [Variable('x')])
result = unify(p1, p2)
print_substitution(result)
print()

# Example 7: Failure case - different constants
print("Example 7: Unify(John, Mary) - Different Constants")
john = Constant('John')
mary = Constant('Mary')
result = unify(john, mary)
print_substitution(result)

# Main program
if __name__ == "__main__":
    print("Choose mode:")
    print("1. Run predefined examples")
    print("2. Interactive mode (enter your own terms)")

    choice = input("\nEnter choice (1 or 2): ").strip()
    print()

    if choice == '1':
        run_examples()
    elif choice == '2':
        run_interactive()
    else:

```

```
print("Invalid choice. Running examples by default...\n")  
run_examples()
```

Choose mode:

1. Run predefined examples
2. Interactive mode (enter your own terms)

Enter choice (1 or 2): 1

==== Unification Algorithm Examples ====

Example 1: Unify(x, y)

Substitution:

x -> y

Example 2: Unify(x, John)

Substitution:

x -> John

Example 3: Unify(P(x, y), P(John, z))

Substitution:

x -> John

y -> z

Example 4: Unify(P(x, f(y)), P(a, f(b)))

Substitution:

x -> a

y -> b

Example 5: Unify(x, f(x)) - Occurs Check

FAILURE: Unification failed

Example 6: Unify(P(x), Q(x)) - Different Predicates

FAILURE: Unification failed

Example 7: Unify(John, Mary) - Different Constants

FAILURE: Unification failed

## Program 8

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

Algorithm:

<p>Date 06/11/2025 Page _____</p> <p>Q:- Prove using Forward Reasoning Create Knowledge base consisting of FOL and prove the given query using Forward Reasoning.</p> <ul style="list-style-type: none"> <li>• <math>\text{Man}(\text{Marius})</math>: Marius is a man.</li> <li>• <math>\text{Pompeian}(\text{Marius})</math>: Marius is a Pompeian.</li> <li>• <math>\forall(x) (\text{Pompeian}(x) \rightarrow \text{Roman}(x))</math>: All Pompeians are Romans.</li> <li>• <math>\forall(x) (\text{Roman}(x) \rightarrow \text{Loyal}(x))</math>: All Romans are loyal.</li> <li>• <math>\forall(x) (\text{Man}(x) \rightarrow \text{Person}(x))</math>: All men are persons.</li> <li>• <math>\forall(x) (\text{Person}(x) \rightarrow \text{Mortal}(x))</math>: All persons are mortal.</li> </ul> <p>→ Converting to CNF :-</p> <ul style="list-style-type: none"> <li>• <math>(\text{Man}(\text{Marius}))</math></li> <li>• <math>(\text{Pompeian}(\text{Marius}))</math></li> <li>• <math>\forall(x) (\neg \text{Pompeian}(x) \vee \text{Roman}(x))</math> <del><math>\neg \text{Pompeian}(x) \vee \text{Roman}(x)</math></del></li> <li>• <math>\forall(x) (\neg \text{Roman}(x) \vee \text{Loyal}(x))</math> <del><math>\neg \text{Roman}(x) \vee \text{Loyal}(x)</math></del></li> <li>• <math>\forall(x) (\neg \text{Man}(x) \vee \text{Person}(x))</math> <del><math>\neg \text{Man}(x) \vee \text{Person}(x)</math></del></li> <li>• <math>\forall(x) (\neg \text{Person}(x) \vee \text{Mortal}(x))</math> <del><math>\neg \text{Person}(x) \vee \text{Mortal}(x)</math></del></li> </ul>	<p>Date 06/11/2025 Page _____</p> <p>To solve:- <u>Mortal (Marius)</u></p> <pre> graph TD     ManMarius[Man(Marius)] --&gt; PersonMarius[Person(Marius)]     PersonMarius --&gt; MortalMarius[Mortal(Marius)]     PompeianMarius[Pompeian(Marius)] --&gt; RomanMarius[Roman(Marius)]     RomanMarius --&gt; LoyalMarius[Loyal(Marius)]     </pre> <p style="text-align: center;"><del>Not Satisfied</del></p>
---	---

Code:

```
class Term:
    """Base class for terms in first-order logic"""
    pass
```

```
class Constant(Term):
    """Represents a constant"""
    def __init__(self, name):
        self.name = name
```

```

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

def __repr__(self):
    return self.name

def __hash__(self):
    return hash(('Constant', self.name))

class Variable(Term):
    """Represents a variable"""
    def __init__(self, name):
        self.name = name

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

    def __repr__(self):
        return self.name

    def __hash__(self):
        return hash(('Variable', self.name))

class Predicate(Term):
    """Represents a predicate with arguments"""
    def __init__(self, name, args):
        self.name = name
        self.args = args if isinstance(args, list) else [args]

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

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

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

class Rule:
    """Represents an implication rule: premises => conclusion"""
    def __init__(self, premises, conclusion):
        self.premises = premises if isinstance(premises, list) else [premises]
        self.conclusion = conclusion

    def __repr__(self):
        premises_str = ' \wedge '.join(str(p) for p in self.premises)
        return f'{premises_str} \Rightarrow {self.conclusion}'

# Variable counter for standardization
_var_counter = 0

def get_new_variable():
    """Generate a new unique variable"""
    global _var_counter
    _var_counter += 1

```

```

return Variable(f"v{_var_counter}")

def standardize_variables(rule):
    """Replace all variables in rule with new unique variables"""
    var_mapping = {}

def replace_vars(term):
    if isinstance(term, Variable):
        if term not in var_mapping:
            var_mapping[term] = get_new_variable()
        return var_mapping[term]
    elif isinstance(term, Predicate):
        new_args = [replace_vars(arg) for arg in term.args]
        return Predicate(term.name, new_args)
    else:
        return term

new_premises = [replace_vars(p) for p in rule.premises]
new_conclusion = replace_vars(rule.conclusion)
return Rule(new_premises, new_conclusion)

def occurs_check(var, term, subst):
    """Check if variable occurs in term"""
    if var == term:
        return True
    elif isinstance(term, Variable) and term in subst:
        return occurs_check(var, subst[term], subst)
    elif isinstance(term, Predicate):
        return any(occurs_check(var, arg, subst) for arg in term.args)
    return False

def apply_substitution(term, subst):
    """Apply substitution to a term"""
    if isinstance(term, Variable):
        if term in subst:
            return apply_substitution(subst[term], subst)
        return term
    elif isinstance(term, Predicate):
        new_args = [apply_substitution(arg, subst) for arg in term.args]
        return Predicate(term.name, new_args)
    else:
        return term

def unify(term1, term2, subst=None):
    """Unification algorithm"""
    if subst is None:
        subst = {}
    term1 = apply_substitution(term1, subst)
    term2 = apply_substitution(term2, subst)

    if term1 == term2:
        return subst
    elif isinstance(term1, Variable):
        if occurs_check(term1, term2, subst):
            return None
        else:
            new_subst = subst.copy()

```

```

new_subst[term1] = term2
return new_subst
elif isinstance(term2, Variable):
    if occurs_check(term2, term1, subst):
        return None
    else:
        new_subst = subst.copy()
        new_subst[term2] = term1
        return new_subst
elif isinstance(term1, Constant) or isinstance(term2, Constant):
    return None
elif isinstance(term1, Predicate) and isinstance(term2, Predicate):
    if term1.name != term2.name or len(term1.args) != len(term2.args):
        return None

    current_subst = subst.copy()
    for arg1, arg2 in zip(term1.args, term2.args):
        current_subst = unify(arg1, arg2, current_subst)
    if current_subst is None:
        return None
    return current_subst
else:
    return None

def unify_all(premises, kb_facts, subst=None):
    """Try to unify all premises with facts in KB"""
    if subst is None:
        subst = {}

    if not premises:
        return [subst]

    first_premise = premises[0]
    remaining_premises = premises[1:]

    all_substitutions = []

    for fact in kb_facts:
        theta = unify(first_premise, fact, subst.copy())
        if theta is not None:
            # Apply substitution to remaining premises
            substituted_remaining = [apply_substitution(p, theta) for p in remaining_premises]
            # Recursively unify remaining premises
            result_substs = unify_all(substituted_remaining, kb_facts, theta)
            all_substitutions.extend(result_substs)

    return all_substitutions

def fol_fc_ask(kb_facts, kb_rules, query, max_iterations=100):
    """
    Forward Chaining Algorithm for First-Order Logic
    """

```

Args:

- kb\_facts: List of atomic sentences (facts) in KB
- kb\_rules: List of implication rules in KB
- query: The query to prove (atomic sentence)
- max\_iterations: Maximum number of iterations to prevent infinite loops

```

>Returns:
    Substitution if query can be proved, None otherwise
"""

print("==> Forward Chaining Algorithm ==>\n")
print(f"Query: {query}\n")
print("Initial KB Facts:")
for fact in kb_facts:
    print(f" {fact}")
print("\nKB Rules:")
for rule in kb_rules:
    print(f" {rule}")
print("\n" + "="*50 + "\n")

iteration = 0

while iteration < max_iterations:
    iteration += 1
    new = []

    print(f"Iteration {iteration}:")

    # For each rule in KB
    for rule in kb_rules:
        # Standardize variables in the rule
        std_rule = standardize_variables(rule)

        # Try to find substitutions that satisfy all premises
        substitutions = unify_all(std_rule.premises, kb_facts)

        # For each valid substitution
        for theta in substitutions:
            # Apply substitution to conclusion
            inferred = apply_substitution(std_rule.conclusion, theta)

            # Check if this fact is new
            if inferred not in kb_facts and inferred not in new:
                new.append(inferred)
                print(f" Inferred: {inferred}")
                print(f" From rule: {std_rule}")
                print(f" With substitution: {theta}")

            # Check if inferred fact unifies with query
            result = unify(inferred, query)
            if result is not None:
                print(f"\n*** Query proved! ***")
                print(f"Substitution: {result}")
                return result

    # If no new facts inferred, we're done
    if not new:
        print(" No new facts inferred.")
        print("\nForward chaining completed. Query cannot be proved.")
        return None

    # Add new facts to KB
    kb_facts.extend(new)
    print()

```

```

print(f"Maximum iterations ({max_iterations}) reached.")
return None

def parse_term(term_str):
    """Parse a string into a Term object"""
    term_str = term_str.strip()

    if '(' in term_str:
        paren_idx = term_str.index('(')
        pred_name = term_str[:paren_idx].strip()
        args_str = term_str[paren_idx+1:term_str.rindex(')').strip()]

        args = []
        depth = 0
        current_arg = ""
        for char in args_str:
            if char == ',' and depth == 0:
                args.append(parse_term(current_arg))
                current_arg = ""
            else:
                if char == '(':
                    depth += 1
                elif char == ')':
                    depth -= 1
                current_arg += char

        if current_arg.strip():
            args.append(parse_term(current_arg))

        return Predicate(pred_name, args)
    elif term_str[0].islower():
        return Variable(term_str)
    else:
        return Constant(term_str)

def parse_rule(rule_str):
    """Parse a rule string like 'P(x) ∧ Q(x) => R(x)"""
    if '=>' in rule_str:
        parts = rule_str.split('=>')
        conclusion_str = parts[1].strip()
        premises_str = parts[0].strip()

        # Split premises by ∧ or AND
        premise_parts = [p.strip() for p in premises_str.replace('AND', '∧').split('∧')]

        premises = [parse_term(p) for p in premise_parts]
        conclusion = parse_term(conclusion_str)

        return Rule(premises, conclusion)
    else:
        # It's just a fact
        return parse_term(rule_str)

# Example usage
if __name__ == "__main__":
    print("Choose mode:")
    print("1. Run example (Animal reasoning)")
    print("2. Interactive mode")

```

```

choice = input("\nEnter choice (1 or 2): ").strip()
print()

if choice == '1':
    # Example: Animal reasoning
    # Facts
    kb_facts = [
        Predicate('Animal', [Constant('Dog')]),
        Predicate('Animal', [Constant('Cat')]),
        Predicate('Loves', [Constant('John'), Constant('Dog')]),
        Predicate('Owns', [Constant('John'), Constant('Dog')])
    ]

    # Rules
    kb_rules = [
        # Animal(x) ∧ Loves(y, x) => Loves(x, y)
        Rule([Predicate('Animal', [Variable('x')]),
              Predicate('Loves', [Variable('y'), Variable('x')]),
              Predicate('Loves', [Variable('x'), Variable('y')])]),

        # Owns(x, y) ∧ Animal(y) => KeepsAsPet(x, y)
        Rule([Predicate('Owns', [Variable('x'), Variable('y')]),
              Predicate('Animal', [Variable('y')]),
              Predicate('KeepsAsPet', [Variable('x'), Variable('y')]))]
    ]

    # Query: Does Dog love John?
    query = Predicate('Loves', [Constant('Dog'), Constant('John')])

    result = fol_fc_ask(kb_facts, kb_rules, query)

elif choice == '2':
    print("==== Interactive Forward Chaining ===")
    print("Enter facts and rules for the knowledge base.\n")

    kb_facts = []
    kb_rules = []

    # Input facts
    print("Enter facts (one per line, empty line to finish):")
    print("Example: Animal(Dog), Loves(John, Dog)")
    while True:
        fact_str = input("Fact: ").strip()
        if not fact_str:
            break
        try:
            fact = parse_term(fact_str)
            kb_facts.append(fact)
        except Exception as e:
            print(f"Error parsing fact: {e}")

    # Input rules
    print("\nEnter rules (one per line, empty line to finish):")
    print("Example: Animal(x) ∧ Loves(y,x) => Loves(x,y)")
    print("You can also use 'AND' instead of ∧")
    while True:
        rule_str = input("Rule: ").strip()

```

```

if not rule_str:
    break
try:
    rule = parse_rule(rule_str)
    kb_rules.append(rule)
except Exception as e:
    print(f"Error parsing rule: {e}")

# Input query
print("\nEnter query:")
query_str = input("Query: ").strip()
try:
    query = parse_term(query_str)
    result = fol_fc_ask(kb_facts, kb_rules, query)
except Exception as e:
    print(f"Error parsing query: {e}")

else:
    print("Invalid choice.")

```

Choose mode:

1. Run example (Animal reasoning)
2. Interactive mode

Enter choice (1 or 2): 2

==== Interactive Forward Chaining ====

Enter facts and rules for the knowledge base.

Enter facts (one per line, empty line to finish):

Example: Animal(Dog), Loves(John, Dog)

Fact: Owns(A, T1)

Fact: Missile(T1)

Fact: American(Robert)

Fact: Enemy(A, America)

Fact:

Enter rules (one per line, empty line to finish):

Example: Animal(x) ∧ Loves(y,x) => Loves(x,y)

You can also use 'AND' instead of ∧

Rule: American(p) ∧ Weapon(q) ∧ Sells(p,q,r) ∧ Hostile(r) => Criminal(p)

Rule: Missile(x) ∧ Owns(A,x) => Sells(Robert,x,A)

Rule: Missile(x) => Weapon(x)

Rule: Enemy(x,America) => Hostile(x)

Rule:

Enter query:

Query: Criminal(Robert)

==== Forward Chaining Algorithm ====

Query: Criminal(Robert)

Initial KB Facts:

Owns(A, T1)

Missile(T1)

American(Robert)

Enemy(A, America)

KB Rules:

American(p)  $\wedge$  Weapon(q)  $\wedge$  Sells(p, q, r)  $\wedge$  Hostile(r)  $\Rightarrow$  Criminal(p)  
Missile(x)  $\wedge$  Owns(A, x)  $\Rightarrow$  Sells(Robert, x, A)  
Missile(x)  $\Rightarrow$  Weapon(x)  
Enemy(x, America)  $\Rightarrow$  Hostile(x)

---

Iteration 1:

Inferred: Sells(Robert, T1, A)  
From rule: Missile(v4)  $\wedge$  Owns(A, v4)  $\Rightarrow$  Sells(Robert, v4, A)  
With substitution: {v4: T1}  
Inferred: Weapon(T1)  
From rule: Missile(v5)  $\Rightarrow$  Weapon(v5)  
With substitution: {v5: T1}  
Inferred: Hostile(A)  
From rule: Enemy(v6, America)  $\Rightarrow$  Hostile(v6)  
With substitution: {v6: A}

Iteration 2:

Inferred: Criminal(Robert)  
From rule: American(v7)  $\wedge$  Weapon(v8)  $\wedge$  Sells(v7, v8, v9)  $\wedge$  Hostile(v9)  $\Rightarrow$  Criminal(v7)  
With substitution: {v7: Robert, v8: T1, v9: A}

\*\*\* Query proved! \*\*\*

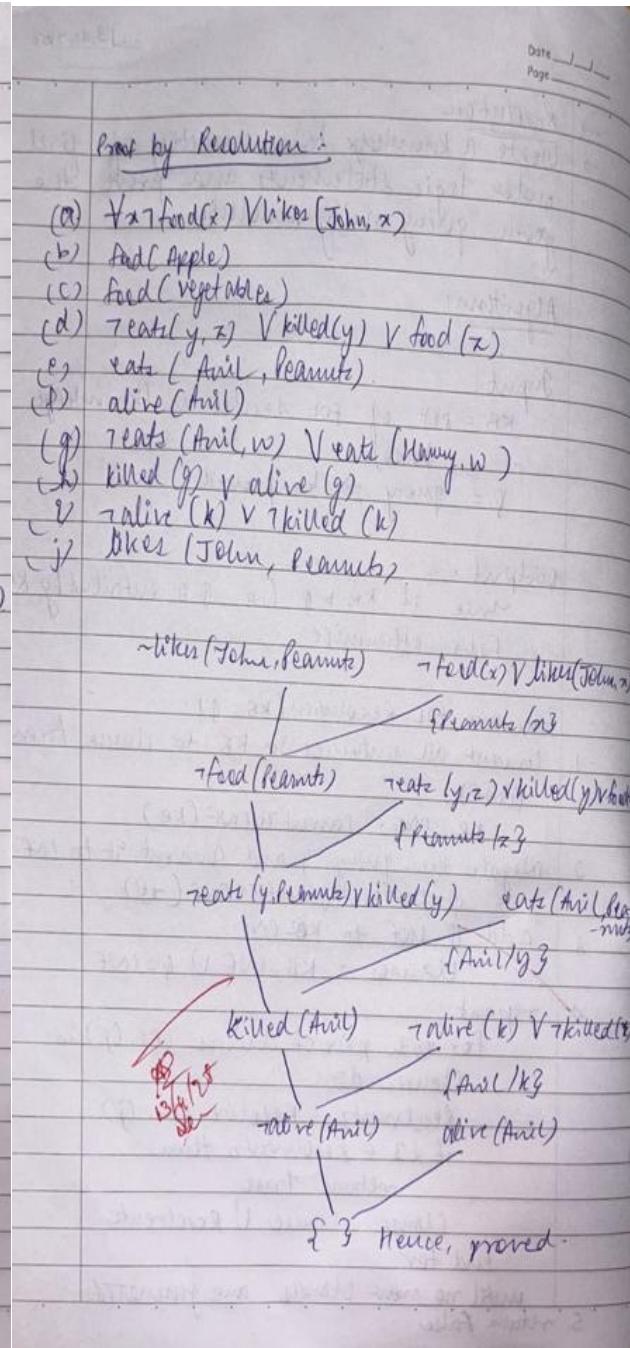
Substitution: {}

## Program 9

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

Algorithm:

→ Resolution
→ Create a knowledge base consisting of first order logic statements and prove the given query using Resolution.
<u>Algorithm:</u>
<u>Input:</u>
KB = set of f-o sentences (knowledge base)
Q = query to be proved.
<u>Output:</u>
True if $\text{KB} \vdash Q$ (i.e., Q is entailed by KB)
False otherwise.
<u>Procedure for Resolution (KB, Q):</u>
1. Convert all sentences in KB to clause form (CNF).
KB-CNF = ConvertToCNF(KB)
2. Negate the query Q and convert it to CNF.
Q-CNF = ConvertToCNF( $\neg Q$ )
3. Add Q-CNF to KB-CNF.
Clauses = KB-CNF $\cup$ Q-CNF
4. repeat
for each pair of clauses $(C_i, C_j)$ in Clauses do
Resolvents = Resolve( $C_i, C_j$ )
if $\exists 3 \in \text{Resolvents}$ then
return True
Clauses = Clauses $\cup$ Resolvents
end for
until no more clauses are generated.
5. return False



Code:

```
import re
import itertools

VAR_RE = re.compile(r'^[a-z](\d+)?$') # single-letter variable optionally standardized (x_0, y_3)

def is_variable(token: str) -> bool:
```

```

return bool(VAR_RE.fullmatch(token))

def parse_literal(text):
    text = text.strip()
    neg = False
    if text.startswith('¬') or text.startswith('~'):
        neg = True
        text = text[1:].strip()
    if '(' in text:
        pred = text[:text.index('(')].strip()
        args = [a.strip() for a in text[text.index('(')+1:-1].split(',')]
    else:
        pred = text
        args = []
    return {'neg': neg, 'pred': pred, 'args': args}

def clause_to_str(clause):
    if clause == []:
        return '⊥'
    parts = []
    for lit in clause:
        s = ('¬' if lit['neg'] else '') + (lit['pred'] + '(' + ', '.join(lit['args']) + ')' if lit['args'] else lit['pred'])
        parts.append(s)
    return ' ∨ '.join(parts)

def standardize_apart_clause(clause, idx):
    # only rename variables (single-letter) to var_index form
    mapping = {}
    new_clause = []
    for lit in clause:
        new_args = []
        for a in lit['args']:
            if is_variable(a):
                if a not in mapping:
                    mapping[a] = f'{a}_{idx}'
                    new_args.append(mapping[a])
                else:
                    new_args.append(a)
            else:
                new_args.append(a)
        new_clause.append({'neg': lit['neg'], 'pred': lit['pred'], 'args': new_args})
    return new_clause

# ----- Unification for flat args (no nested function terms) -----
def occurs_check(var, val, subs):
    # var and val are token strings
    if var == val:
        return True
    if is_variable(val) and val in subs:
        return occurs_check(var, subs[val], subs)
    return False

def apply_subs_token(tok, subs):
    if is_variable(tok):
        while tok in subs:
            tok = subs[tok]
        return tok
    return tok

def apply_subs_literal(lit, subs):

```

```

new_args = [apply_subs_token(a, subs) for a in lit['args']]
return {'neg': lit['neg'], 'pred': lit['pred'], 'args': new_args}

def unify_tokens(x, y, subs):
    # x,y are token strings (variables or constants)
    if x == y:
        return subs
    if is_variable(x):
        if x in subs:
            return unify_tokens(subs[x], y, subs)
        if occurs_check(x, y, subs):
            return None
        new = subs.copy()
        new[x] = y
        return new
    if is_variable(y):
        return unify_tokens(y, x, subs)
    # both constants and different => fail
    return None

def unify_arg_lists(a_list, b_list):
    if len(a_list) != len(b_list):
        return None
    subs = {}
    for a, b in zip(a_list, b_list):
        a_ap = a if not is_variable(a) else a
        b_ap = b if not is_variable(b) else b
        subs = unify_tokens(apply_subs_token(a_ap, subs), apply_subs_token(b_ap, subs), subs)
        if subs is None:
            return None
    return subs

# ----- Resolution -----
def is_tautology_clause(clause):
    # clause is a list of literals (after substitution). If it contains A and ¬A same args -> tautology
    seen = {}
    for lit in clause:
        key = (lit['pred'], tuple(lit['args']))
        if key in seen:
            if seen[key] != lit['neg']:
                return True
        else:
            seen[key] = lit['neg']
    return False

def resolve_pair(c1, c2):
    # c1, c2 are lists of literals (each literal dict)
    for i, l1 in enumerate(c1):
        for j, l2 in enumerate(c2):
            if l1['pred'] == l2['pred'] and l1['neg'] != l2['neg']:
                # try to unify their args
                subs = unify_arg_lists(l1['args'], l2['args'])
                if subs is None:
                    continue
                # apply substitution to the remainder of both clauses
                new_clause = []
                for k, lit in enumerate(c1):
                    if k == i: continue

```

```

new_clause.append(apply_subs_literal(lit, subs))
for k, lit in enumerate(c2):
    if k == j: continue
    new_clause.append(apply_subs_literal(lit, subs))
# remove duplicates (syntactic)
uniq = []
for lit in new_clause:
    if not any(lit['pred']==u['pred'] and lit['neg']==u['neg'] and lit['args']==u['args'] for u in uniq):
        uniq.append(lit)
if is_tautology_clause(uniq):
    continue
return uniq, subs, (i, j)
return None, None, None

# ----- Build derivation tree nodes -----
class Node:
    def __init__(self, clause, parents=None, label=None):
        self.clause = clause
        self.parents = parents if parents else []
        self.label = label

def resolution_with_tree(initial_clauses, goal_clause):
    # standardize apart initial clauses
    clauses_nodes = []
    for idx, c in enumerate(initial_clauses):
        std = standardize_apart_clause(c, idx)
        clauses_nodes.append(Node(std, parents=[], label=f'C{idx}'))

    # add negated goal as a fresh clause (standardize apart too)
    neg_goal = []
    # goal_clause is a clause list (we take its first literal if single-literal goal)
    for lit in goal_clause:
        # negate each literal in goal clause (if goal is a single positive literal user passed)
        neg_goal.append({'neg': not lit['neg'], 'pred': lit['pred'], 'args': lit['args'][::]})

    neg_goal_std = standardize_apart_clause(neg_goal, len(clauses_nodes))
    goal_node = Node(neg_goal_std, parents=[], label="~Goal")
    clauses_nodes.append(goal_node)

    # mapping from index -> Node
    idx = len(clauses_nodes)
    seen_clauses = {clause_to_str(n.clause): i for i, n in enumerate(clauses_nodes)}

    # perform breadth-first-ish resolution (pairwise), record parents as indices
    for a_index in range(len(clauses_nodes)):
        pass # placeholder, we'll use dynamic loop below

    frontier_changed = True
    while True:
        new_added = False
        # iterate pairs over current clauses
        n = len(clauses_nodes)
        pairs = [(i,j) for i in range(n) for j in range(i+1, n)]
        for i,j in pairs:
            c1 = clauses_nodes[i].clause
            c2 = clauses_nodes[j].clause
            resolvent, subs, which = resolve_pair(c1, c2)
            if resolvent is None:
                continue
            new_added = True
            new_clause.append(resolvent)
            for k, lit in enumerate(c2):
                if k == j: continue
                new_clause.append(apply_subs_literal(lit, subs))
            # remove duplicates (syntactic)
            uniq = []
            for lit in new_clause:
                if not any(lit['pred']==u['pred'] and lit['neg']==u['neg'] and lit['args']==u['args'] for u in uniq):
                    uniq.append(lit)
            if is_tautology_clause(uniq):
                continue
            return uniq, subs, (i, j)
        if not new_added:
            break

```

```

s = clause_to_str(resolvent)
if s in seen_clauses:
    continue
# add node
new_node = Node(resolvent, parents=[i, j], label=f'R{idx}')
clauses_nodes.append(new_node)
seen_clauses[s] = idx
new_added = True
idx += 1
if resolvent == []:
    # build bottom-up tree node for ⊥
    root = new_node
    return clauses_nodes, seen_clauses, idx-1 # return nodes, map, index of empty clause node
if not new_added:
    return clauses_nodes, seen_clauses, None

# ----- ASCII print bottom-up (root bottom) -----
def print_bottom_up_tree(nodes, root_index):
    # recursively print node; ensure parents printed above
    def recurse(node_index, prefix="", is_last=True):
        node = nodes[node_index]
        connector = "└── " if is_last else "├── "
        print(prefix + connector + clause_to_str(node.clause))
        # if this node has parents, print them above (parents as children in recursion so they appear above)
        parents = node.parents
        for k, pidx in enumerate(parents):
            recurse(pidx, prefix + ("  " if is_last else " | "), k == len(parents)-1)
    recurse(root_index, "", True)

# ----- Runner -----
if __name__ == "__main__":
    print("*70")
    print("FIRST-ORDER LOGIC RESOLUTION SYSTEM (FIXED)")
    print("*70")
    print("Enter CNF clauses (one per line). End with a blank line.")
    raw = []
    while True:
        try:
            line = input().strip()
        except EOFError:
            break
        if line == "":
            break
        raw.append(line)
    clauses = [ [parse_literal(tok.strip()) for tok in re.split(r"V", line)] for line in raw ]

    # read goal
    goal_line = input("\nEnter GOAL clause (single literal form): ").strip()
    goal_clause = [parse_literal(goal_line)]

    nodes, seen_map, root_idx = resolution_with_tree(clauses, goal_clause)
    if root_idx is None:
        print("\nNo empty clause could be derived — goal not entailed by KB.")
    else:
        print("\nDERIVATION TREE (bottom-up):")
        print_bottom_up_tree(nodes, root_idx)
        print("\nResolution complete — ⊥ derived.")

```

---

---

FIRST-ORDER LOGIC RESOLUTION SYSTEM

---

---

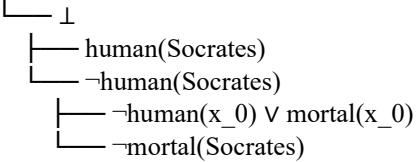
Enter CNF clauses (one per line). End with a blank line.

$\neg\text{human}(x) \vee \text{mortal}(x)$

$\text{human}(\text{Socrates})$

Enter GOAL clause (single literal form):  $\text{mortal}(\text{Socrates})$

DERIVATION TREE (bottom-up):

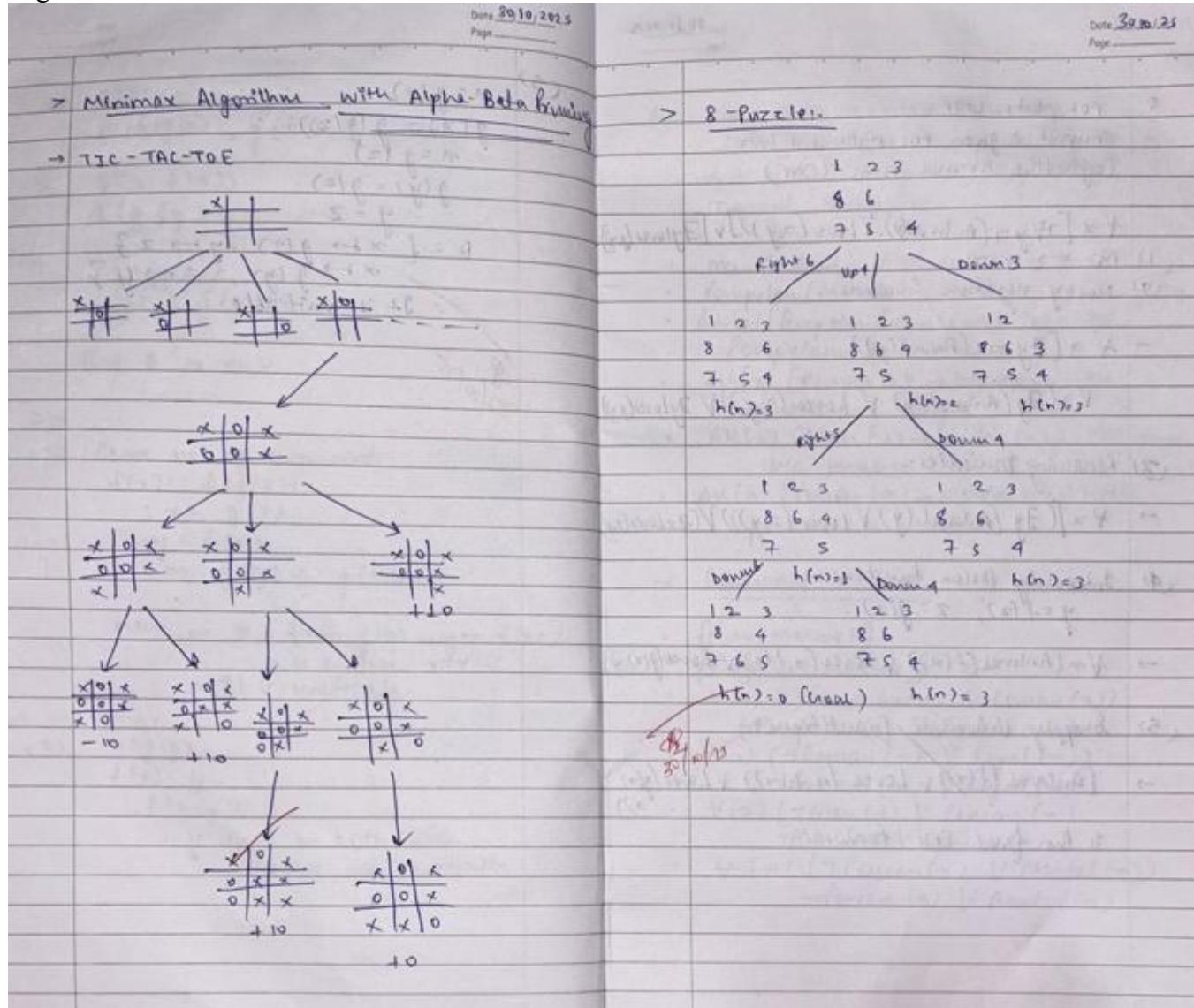


Resolution complete —  $\perp$  derived.

## Program 10

### Implement Alpha-Beta Pruning.

### Algorithm:



Code:

```
import networkx as nx
import matplotlib.pyplot as plt
import math

# --- Alpha-Beta Pruning ---
def alpha_beta(node, depth, alpha, beta, maximizing, tree, values, pruned_nodes, path):
    # Leaf node
    if depth == 0 or node not in tree:
        return values.get(node, None)

    if maximizing:
        value = -math.inf
        for child in tree[node]:
            val = alpha_beta(child, depth - 1, alpha, beta, False, tree, values, pruned_nodes, path)
            if val > value:
                value = val
            if value > beta:
                break
        return value
    else:
        value = math.inf
        for child in tree[node]:
            val = alpha_beta(child, depth - 1, alpha, beta, True, tree, values, pruned_nodes, path)
            if val < value:
                value = val
            if value < alpha:
                break
        return value
```

```

if val is None:
    continue
value = max(value, val)
alpha = max(alpha, value)
if beta <= alpha:
    # Prune remaining children
    prune_index = tree[node].index(child) + 1
    for c in tree[node][prune_index:]:
        pruned_nodes.append(c)
    break
values[node] = value
return value
else:
    value = math.inf
    for child in tree[node]:
        val = alpha_beta(child, depth - 1, alpha, beta, True, tree, values, pruned_nodes, path)
        if val is None:
            continue
        value = min(value, val)
        beta = min(beta, value)
        if beta <= alpha:
            prune_index = tree[node].index(child) + 1
            for c in tree[node][prune_index:]:
                pruned_nodes.append(c)
            break
    values[node] = value
    return value

```

```

# --- Draw Game Tree ---
def draw_game_tree(G, path, pruned):
    pos = nx.nx_agraph.graphviz_layout(G, prog="dot")
    plt.figure(figsize=(9, 6))

    edge_colors = []
    for (u, v) in G.edges():
        if u in path and v in path:
            edge_colors.append('green')
        elif v in pruned:
            edge_colors.append('red')
        else:
            edge_colors.append('black')

    node_colors = []
    for node in G.nodes():
        if node in path:
            node_colors.append('green')
        elif node in pruned:
            node_colors.append('red')
        else:
            node_colors.append('skyblue')

    nx.draw(
        G, pos, with_labels=True,
        node_color=node_colors,
        edge_color=edge_colors,
        node_size=1200,
        font_size=10
    )

```

```

)
plt.title("Alpha-Beta Pruning Game Tree\nGreen = Optimal Path | Red = Pruned Nodes")
plt.show()

# --- Main Program ---
def main():
    tree = {}
    G = nx.DiGraph()

    n = int(input("Enter number of non-leaf nodes: "))
    for _ in range(n):
        parent = input("\nEnter parent node: ").strip()
        children = input("Enter children of " + parent + " (space separated): ").split()
        tree[parent] = children
        for c in children:
            G.add_edge(parent, c)

    leaf_count = int(input("\nEnter number of leaf nodes: "))
    values = {}
    for _ in range(leaf_count):
        leaf, val = input("Enter leaf node and its value (e.g. E 3): ").split()
        values[leaf] = int(val)

    root = input("\nEnter root node: ").strip()
    depth = int(input("Enter total depth of tree: "))

    pruned_nodes = []
    path = []

    print("\n-----")
    result = alpha_beta(root, depth, -math.inf, math.inf, True, tree, values, pruned_nodes, path)
    print(f"Final Optimal Value: {result}")
    print(f"Pruned Nodes: {pruned_nodes}")
    print("-----")

    draw_game_tree(G, path=[root, 'C', 'G'], pruned=pruned_nodes)

if __name__ == "__main__":
    main()

```

Enter number of non-leaf nodes: 4

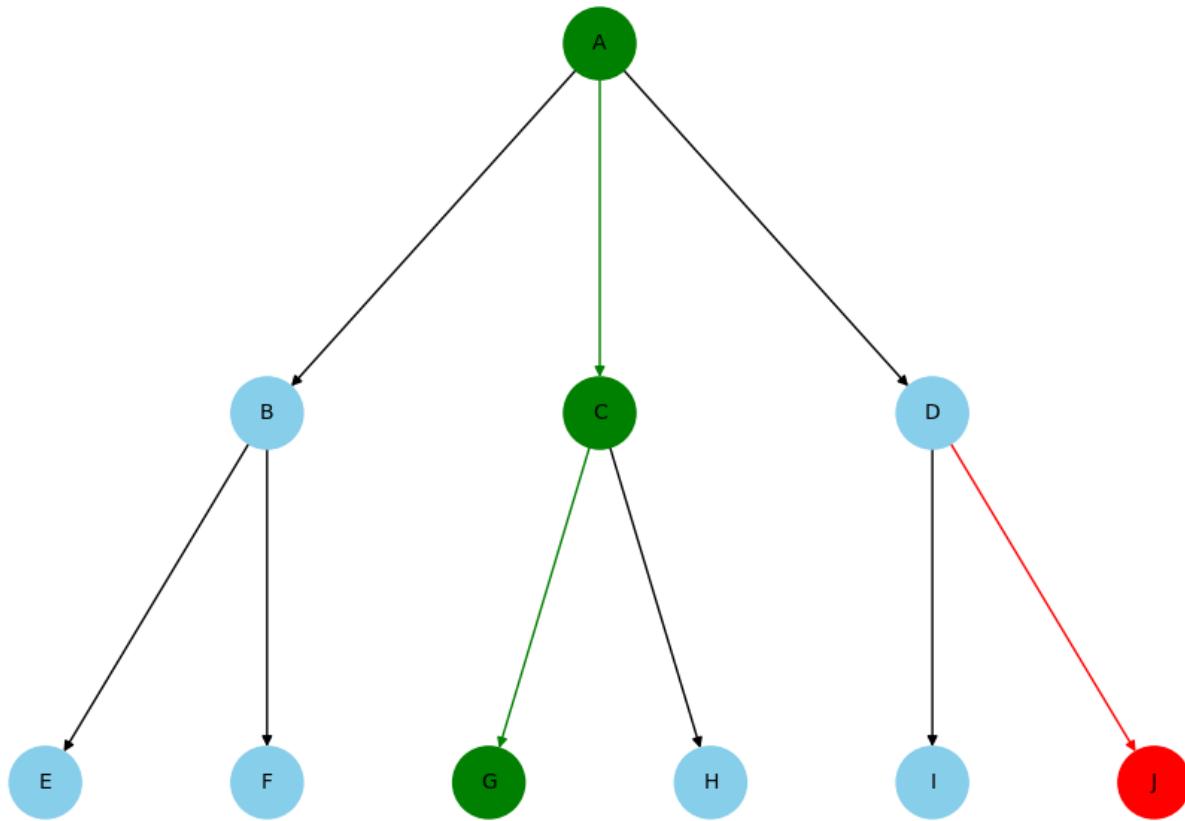
Enter parent node: A  
 Enter children of A (space separated): B C D

Enter parent node: B  
 Enter children of B (space separated): E F

Enter parent node: C  
 Enter children of C (space separated): G H

Enter parent node: D

Alpha-Beta Pruning Game Tree  
Green = Optimal Path | Red = Pruned Nodes



Enter children of D (space separated): I J

Enter number of leaf nodes: 6

Enter leaf node and its value (e.g. E 3): E 3

Enter leaf node and its value (e.g. E 3): F 5

Enter leaf node and its value (e.g. E 3): G 6

Enter leaf node and its value (e.g. E 3): H 9

Enter leaf node and its value (e.g. E 3): I 1

Enter leaf node and its value (e.g. E 3): J 2

Enter root node: A

Enter total depth of tree: 3

---

Final Optimal Value: 6

Pruned Nodes: ['J']

---