

# VISVESVARAYA TECHNOLOGICAL UNIVERSITY

“JnanaSangama”, Belgaum -590014, Karnataka.



## LAB REPORT

on

## Artificial Intelligence (23CS5PCAIN)

*Submitted by*

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*in partial fulfillment for the award of the degree of*

**BACHELOR OF ENGINEERING**

*in*

**COMPUTER SCIENCE AND ENGINEERING**



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

(Autonomous Institution under VTU)

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**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 **Hitish Rao P (1BM23CS116)**, who is a bonafide student of **B.M.S. College of Engineering**. It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements in respect of an Artificial Intelligence (23CS5PCAIN) work prescribed for the said degree.

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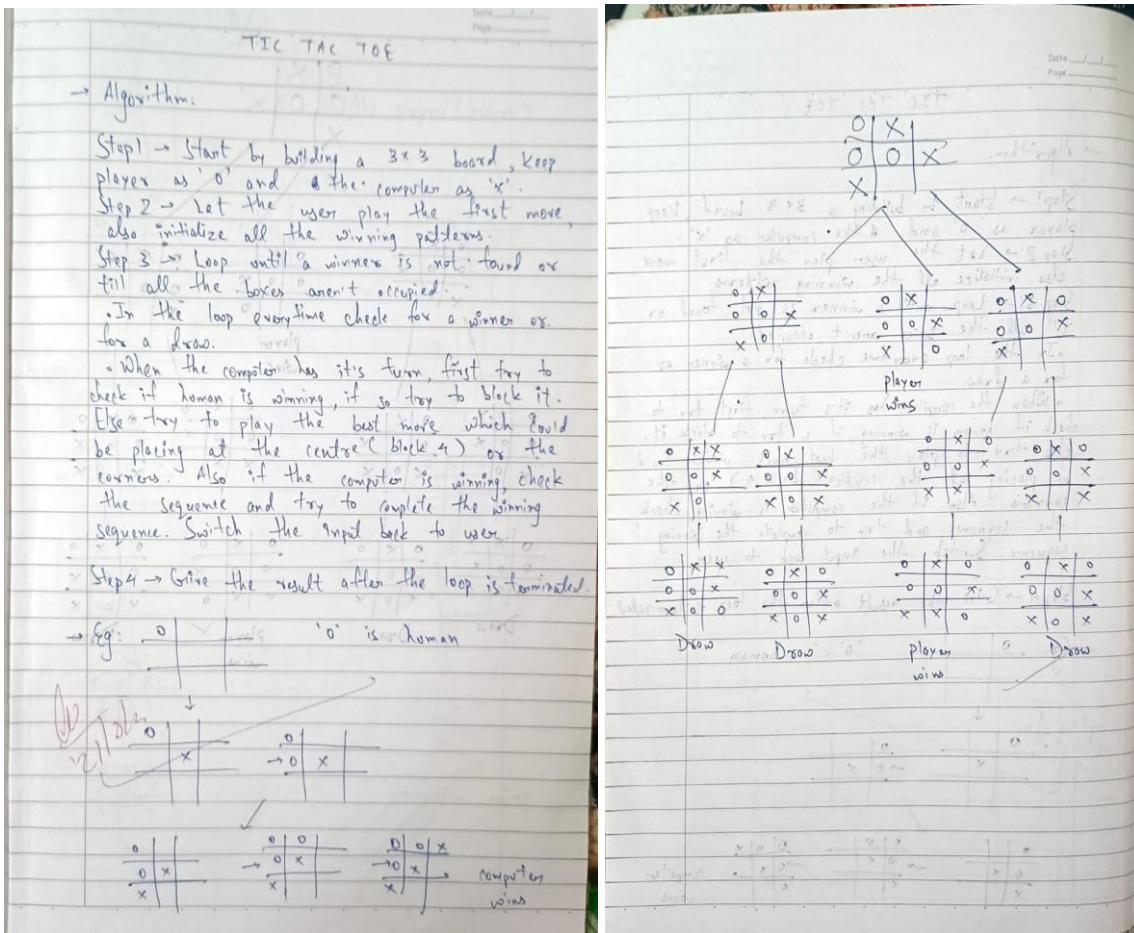
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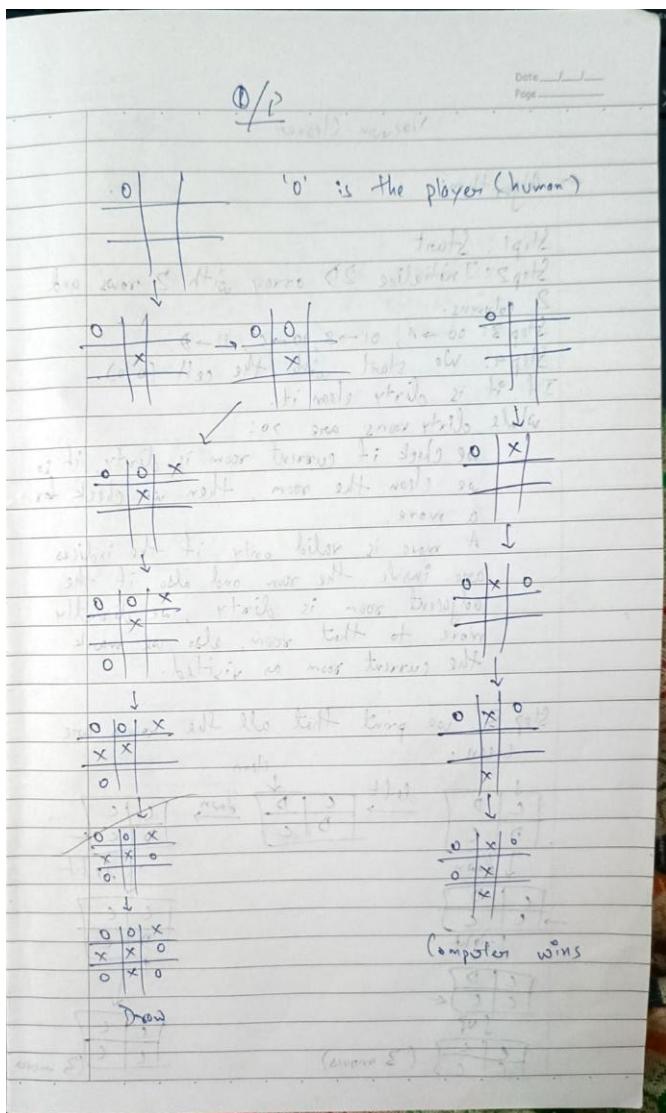
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GITHUB: <https://github.com/Hitish-Rao-P/AI-1BM23CS116>

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

### ALGORITHM (Tic-Tac-Toe) :





## CODE (Tic-Tac-Toe) :

```
import math
import random

def print_board(board):
    """Prints the current state of the game board."""
    for row in [board[i:i+3] for i in range(0, 9, 3)]:
        print('| ' + ' | '.join(row) + ' |')

def available_moves(board):
    """Returns a list of available spots on the board."""
    return [i for i, spot in enumerate(board) if spot == ' ']

def check_winner(board, player):
    """Checks if the given player has won the game."""
    # Check for winning rows
    for i in range(0, 9, 3):
        if all(s == player for s in board[i:i+3]):
            return True

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

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

    return False

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

'X' is the maximizing player (computer), 'O' is the minimizing player (human).

""""

ai\_player = 'X'

human\_player = 'O'

if check\_winner(board, ai\_player):

    return 1, None

if check\_winner(board, human\_player):

    return -1, None

if not available\_moves(board):

    return 0, None

if is\_maximizing:

    best\_score = -math.inf

    best\_move = None

    for move in available\_moves(board):

        board[move] = ai\_player

        score, \_ = minimax(board, False)

        board[move] = ''

        if score > best\_score:

            best\_score = score

            best\_move = move

    return best\_score, best\_move

else:

    best\_score = math.inf

    best\_move = None

    for move in available\_moves(board):

        board[move] = human\_player

        score, \_ = minimax(board, True)

        board[move] = ''

        if score < best\_score:

            best\_score = score

            best\_move = move

```

    return best_score, best_move

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

    ai_player = 'X'
    human_player = 'O'

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

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

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

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

```

```

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

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

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

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

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

```

```

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

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

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

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

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

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

if __name__ == "__main__":
    play_game()

```

## OUTPUT:

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

## ALGORITHM (Vacuum Cleaner):

Vacuum Cleaner

Algorithmic with 2x2

Step 1: Start

Step 2: Initialize 2D array with 2 rows and 2 columns.

Step 3: 00 → A, 01 → B, 10 → C, 11 → D

Step 4: We start with the cell (0,0). If it is dirty clean it.

while dirty rooms are > 0:

- We check if current room is dirty, if so we clean the room, then we check for a move.
- A move is valid only if the indices are inside the room and also if the adjacent room is dirty, we directly move to that room, also we mark the current room as visited.

Step 5: we print that all the rooms were clean:

→ Output: [D, C; D, D]

Room = [D, C; D, D]

Starting with (0,0) & cleaned it  
Moved to (1,0) & cleaned it  
Moved to (1,1) & cleaned it  
Room is cleaned as because all rooms with value 'C'

Room is clean!

## CODE (Vacuum cleaner) :

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

```

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

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

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

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

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

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

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

```

## OUTPUT:

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

## Program 2: Implement 8-puzzle

### ALGORITHM:

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→ Algorithm:

- 1) Initialize the board, start with the initial state where pieces are placed randomly.
- 2) Store the initial state in a queue and keep a visited array to check if the sequence has occurred or not, we will use BFS here.
- 3) Until the queue is empty:
  - if we reach the final state, return else, we try to move the blank piece in a valid place by doing a valid move. A move is valid if the sequence hasn't occurred before and we are moving inside the box.
  - 4) We add the next state to the queue and keep moving until we find the solution.

1	2	3
4	5	6
-	7	8

↑ right

1	2	3
-	5	6
4	7	8

↑ left

1	2	3
4	5	6
7	-	8

↑ right

1	2	3
4	5	6
7	8	-

↓

Solution found in 2 steps (optimal)

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Page \_\_\_\_\_

→ Output: 28/8/25

→ Best case  
Initial state =

1	2	3
4	5	6
0	7	8

Solution found in 2 moves. Right → Right

→ Average case =

1	0	3
4	5	6
7	8	2

R → D → D → L → U → R → L → D → R

Solution found in 11 moves

→ Worst case =

1	0	4
3	5	6
7	8	2

No solution exists (Solved in 156 moves)

### CODE:

```
from collections import deque
import copy
```

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

```

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

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

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

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

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

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

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

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

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

```

```

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

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

solution = bfs(start_state)

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

```

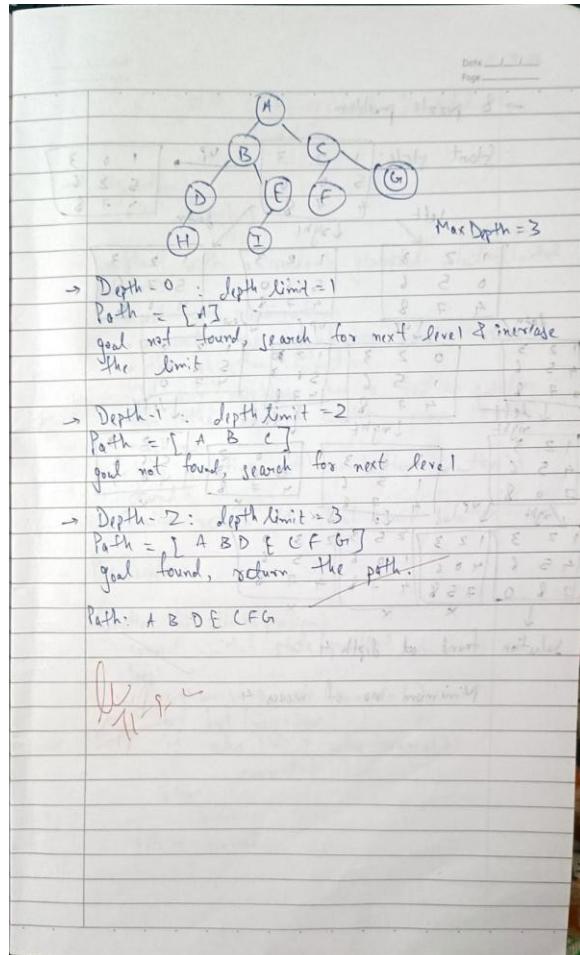
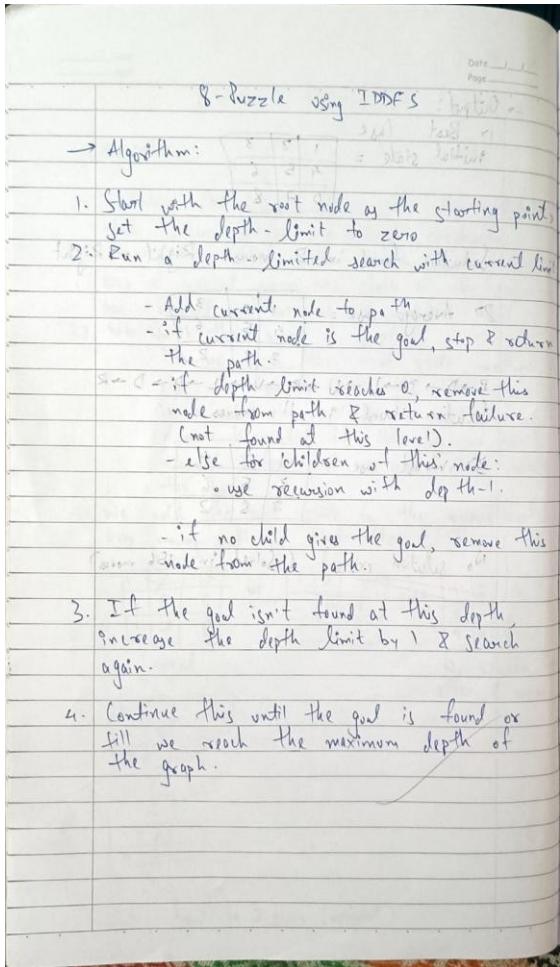
## OUTPUT:

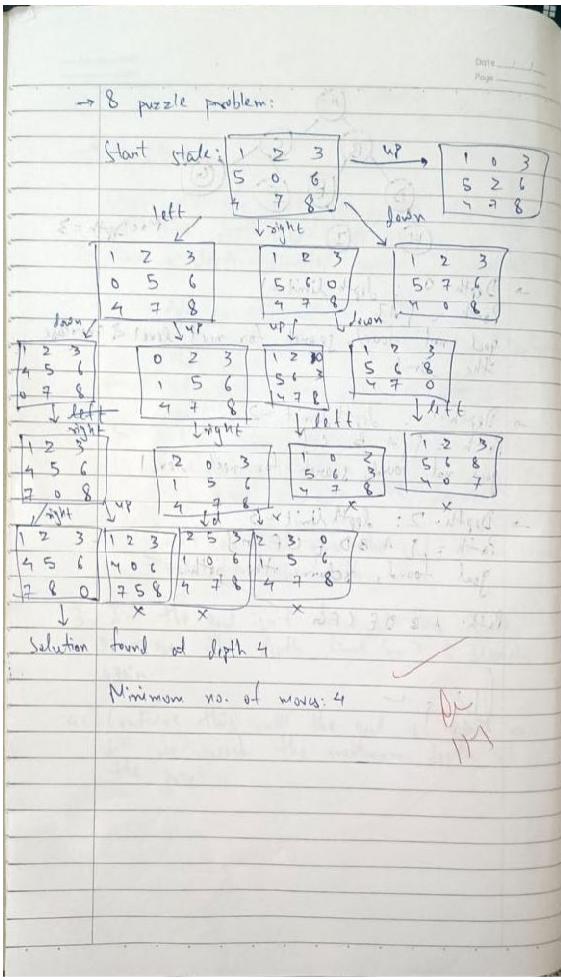
```

Solution found in 3 moves:
[1, 2, 3]
[0, 4, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 0, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 8, 0]
-----
```

## Program 3: Implement IDDFS

### ALGORITHM :





## CODE :

```
from collections import deque
```

```
# Directions for movement
```

```
MOVES = {
    'Up': -3,
    'Down': 3,
    'Left': -1,
    'Right': 1
}
```

```
# Define the goal state
```

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

```
# Valid indices for moves
```

```
def valid_moves(index):
```

```

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

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

return moves

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

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

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

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

    if depth == 0:
        return None

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

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

```

```

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

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

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

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

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

```

## OUTPUT:

Initial State:

(1, 2, 3)

(4, 5, 6)

(0, 7, 8)

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

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

--- Iteration 3: Depth Limit = 2 ---

Solution found in 2 moves:

Move: Right

(1, 2, 3)

(4, 5, 6)

(7, 0, 8)

Move: Right

(1, 2, 3)

(4, 5, 6)

(7, 8, 0)

# Program 4: Implement Hill Climbing & Simulated Annealing

## ALGORITHM:

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### Hill Climbing and Simulated Annealing

→ Algorithm:

- Hill Climbing

is Start with a randomly generated solution (initial solution).

for Repeat until termination:

- Generate the neighbouring solution using the objective function.
- If, any neighbour has a better solution than the current solution, move to that neighbour.
- Keep repeating until no better solution is found.

Finally return the best found solution.

Pseudocode

```
function hillClimb(problem):
    current = initialState(problem)
    loop:
        neighbours = generate(current)
        b = best(neighbours)
        if value(b) > value(current):
            current = b
        else:
            break
    return current
```

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### N Queens using Hill Climb

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

→ Output:

Initial board:

Q . Q . . . . . . . .

Move to board with 1 attack:

Q . . . . . . . .

Move to board with 0 attacks:

Q . . . . . . . .

Solution found!

Steps taken = 2

• Simulated Annealing:

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

→ Pseudocode:

```

function simulated_annealing(n):
    curr = random_state(n)
    cost = cost(curr)
    temp = 1000
    while temp > 0:
        neighbour = neighbour_state(curr)
        if random() < exp(-delta / temp):
            update curr
        temp *= cooling
    return curr
  
```

• N Queen using simulated annealing:

- Start with a random board.
- Set temp.  $T$  with a high value
- Pick a random neighbour, calculate  $\Delta E$ .
- If the new neighbour is better, accept that else accept it based on probability  $P$ .  

$$P = e^{-\Delta E/T}$$
- Update the temperature using the cooling rule
- Return the final solution.

→ Output:

Initial board:

```

  Q . .
  . Q .
  . . Q .
  . . . Q
  
```

Iteration -1  $\Rightarrow$  1 attacks

```

  Q . .
  . Q .
  . . Q .
  . . . Q
  
```

Iteration -2  $\Rightarrow$  3 attacks

```

  Q . .
  . Q .
  . . Q .
  . . . Q
  
```

Iteration -3  $\Rightarrow$  4 attacks

```

  Q . .
  . Q .
  . . Q .
  . . . Q
  
```

## CODE (Hill Climbing) :

```

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

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

    restart_count = 0
  
```

```

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

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

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

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

```

## OUTPUT (Hill Climbing) :

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

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

## CODE (Simulated Annealing):

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

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

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

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

    def calculateCost(self):
        threat = 0

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

        return threat

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

```

queen_count = len(queens)

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

return threat

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

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

    return board_string

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

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

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

def __str__(self):
    board_string = ""

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

    return board_string

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

```

```

self.startTime = datetime.now()

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

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

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

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

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

    return self.elapsedTime

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

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

```

```
SimulatedAnnealing(board).run()
```

### **OUTPUT (Simulated Annealing):**

```
Board:
```

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

```
Solution:
```

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

```
Success, Elapsed Time: 7.9ms
```

## Program 5: A\* Algorithm

### ALGORITHM :

8 - Puzzle using A\*

→ Pseudo code:

1. Initialize open list

2. Start with the defined goal state.

3. Initialize open list with a priority queue with start state.

4. Also initialize an empty closed list.

5. Keep solution with least  $f(n)$ .

6. until  $S$  or  $E$  is visited

func Astart(start, goal):

```
open ← priority queue ordered by f-g
g[start] = 0
p[start] = None
```

while open is not empty:

    current ← pop(open)

    for each n of current:

        new\_g ← g[current] + 1

        if n not in g or new\_g < g[n]:

            g[n] ← new\_g
            f ← new\_g + h(n)
            push(open, n, f)
            parent[n] ← current

    return failure

→ Output:

Solution found in 18 moves

1 2 3  
0 4 6  
5 8 7

↓  
1 2 3  
4 0 6  
5 8 7

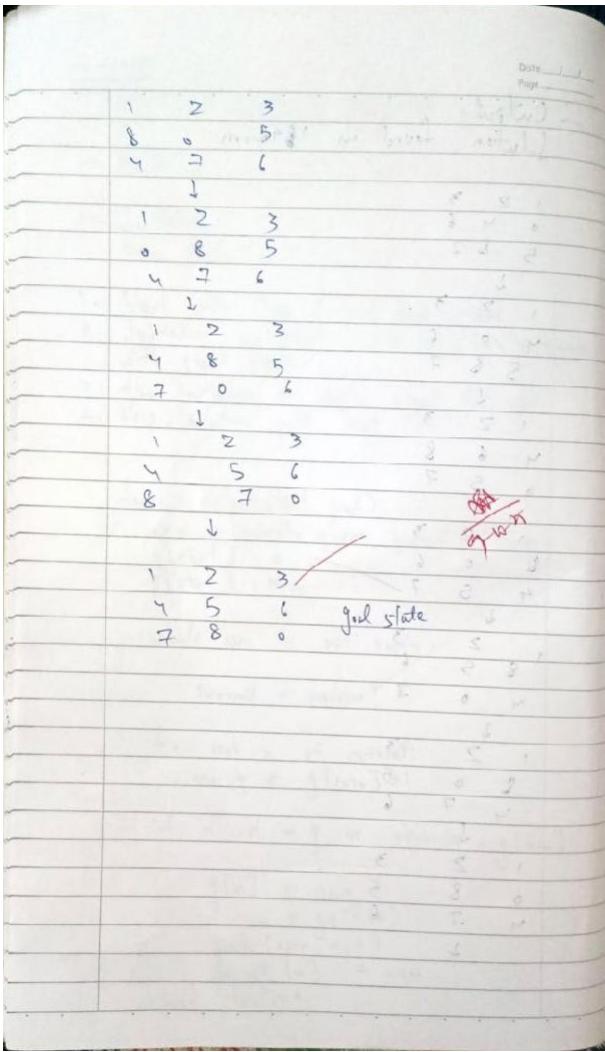
↓  
1 2 3  
4 6 8  
0 5 7

↓  
1 2 3  
8 0 6  
4 5 7

↓  
1 2 3  
8 0 5  
4 7 6

↓  
1 2 3  
0 8 5  
4 7 6

↓  
1 2 3



## CODE :

```
import heapq

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

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

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

```

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

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

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

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

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

```

```

heapq.heappush(opened, s)

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

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

    closed.add(tuple(cur.board))

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

return None, nodes

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

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

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

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

```

```

print("No solution.")

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

```

## OUTPUT:

```

A* (Misplaced Tiles)

Steps:

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

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

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

Total Moves: 2
Nodes Expanded: 3

A* (Manhattan Distance)

Steps:

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

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

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

Total Moves: 2
Nodes Expanded: 3

```

## Program 6: Propositional Logic

### ALGORITHM :

<p style="text-align: right;">Date 16/10/25 Page _____</p> <p style="text-align: center;"><u>Propositional Logic</u></p> <p>→ Pseudocode</p> <pre> function TT-Entails(KB, α)     inputs: KB (knowledge base, a sentence in propositional logic),            α (query, a sentence in propositional logic)     symbols → a list of proposition symbols in KB and α     solution TT-Check-All(KB, α, symbols, { }) </pre> <p>function TT-Check-All(KB, α, symbols, model)</p> <pre> if EMPTY? (symbols) then     if P1-TRUE? (KB, model) then return         P1-TRUE? (α, model)     else return false // When KB false, always return true else do     P ← FIRST(symbols)     rest ← REST(symbols)     return (TT-Check-All(KB, α, rest,                          model ∪ {P = true}) ∨             TT-Check-All(KB, α, rest, model ∪                          {P = false})) </pre>	<p style="text-align: right;">Date _____ Page _____</p> <p>Q. in <math>q \rightarrow p</math> <math>\Rightarrow p \rightarrow \neg q</math> <math>\Rightarrow q \vee r</math></p> <p>o Truth Table</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>P</th> <th>Q</th> <th>R</th> <th><math>\neg p</math></th> <th><math>q \rightarrow p</math></th> <th><math>p \rightarrow \neg q</math></th> <th><math>q \vee r</math></th> <th><math>\neg q</math></th> </tr> </thead> <tbody> <tr><td>f</td><td>f</td><td>f</td><td>t</td><td>t</td><td>t</td><td>t</td><td>f</td></tr> <tr><td>f</td><td>f</td><td>t</td><td>t</td><td>t</td><td>t</td><td>t</td><td>f</td></tr> <tr><td>f</td><td>t</td><td>f</td><td>f</td><td>t</td><td>f</td><td>t</td><td>f</td></tr> <tr><td>f</td><td>t</td><td>t</td><td>f</td><td>t</td><td>t</td><td>t</td><td>f</td></tr> <tr><td>t</td><td>f</td><td>f</td><td>t</td><td>t</td><td>t</td><td>f</td><td>f</td></tr> <tr><td>t</td><td>f</td><td>t</td><td>t</td><td>t</td><td>t</td><td>f</td><td>f</td></tr> <tr><td>t</td><td>t</td><td>f</td><td>f</td><td>t</td><td>t</td><td>t</td><td>f</td></tr> <tr><td>t</td><td>t</td><td>t</td><td>f</td><td>t</td><td>t</td><td>t</td><td>f</td></tr> </tbody> </table> <p>⇒ Does KB entail P</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>P</th> <th>KB</th> </tr> </thead> <tbody> <tr><td>f</td><td>f</td></tr> <tr><td>t</td><td>t</td></tr> <tr><td>f</td><td>t</td></tr> <tr><td>t</td><td>f</td></tr> <tr><td>f</td><td>f</td></tr> <tr><td>t</td><td>t</td></tr> <tr><td>f</td><td>t</td></tr> <tr><td>t</td><td>f</td></tr> </tbody> </table> <p>• Whenever KB is true, P is also true.</p> <p>• If KB entails P</p>	P	Q	R	$\neg p$	$q \rightarrow p$	$p \rightarrow \neg q$	$q \vee r$	$\neg q$	f	f	f	t	t	t	t	f	f	f	t	t	t	t	t	f	f	t	f	f	t	f	t	f	f	t	t	f	t	t	t	f	t	f	f	t	t	t	f	f	t	f	t	t	t	t	f	f	t	t	f	f	t	t	t	f	t	t	t	f	t	t	t	f	P	KB	f	f	t	t	f	t	t	f	f	f	t	t	f	t	t	f
P	Q	R	$\neg p$	$q \rightarrow p$	$p \rightarrow \neg q$	$q \vee r$	$\neg q$																																																																																				
f	f	f	t	t	t	t	f																																																																																				
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Date \_\_\_\_\_  
Page \_\_\_\_\_

→ Does KB entail  $R \rightarrow P$  (Ans) Yes

$R$	$P$	$R \rightarrow P$	KB
f	f	t	f (not true)
t	f	f	t
f	t	t	f
t	t	t	t
t	f	f	f
t	t	f	t
f	t	t	f
t	f	f	t
t	t	t	t

∴ We can see that when KB is true  $R \rightarrow P$  is false.

→ Does KB entail  $Q \rightarrow R$  (Ans) No

→ Does KB entail  $Q \rightarrow R$  (Ans) Yes

$Q \rightarrow R$	KB
t	f
t	t
f	f
t	f
t	t
f	f
t	f

Whenever KB is true,  $Q \rightarrow R$  is also true

∴ KB entails  $Q \rightarrow R$

## CODE :

```
import itertools
```

```
# Logical operations
```

```
def implies(a, b):
```

```
    return not a or b
```

```
def or_operator(a, b):
```

```
    return a or b
```

```
def not_operator(a):
```

```
    return not a
```

```
# Constructing the truth table
```

```
def construct_truth_table():
```

```
    truth_values = [True, False]
```

```

truth_table = []

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

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

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

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

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

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

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

```

```

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

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

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

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

```

**OUTPUT :**

Q	P	R	$Q \rightarrow P$	$P \rightarrow \neg Q$	$Q \vee R$	KB (all true)	R	$R \rightarrow P$	$Q \rightarrow R$
T	T	T	T	F	T	F	T	T	T
T	T	F	T	F	T	F	F	T	F
T	F	T	F	T	T	F	T	F	T
T	F	F	F	F	T	T	F	F	F
F	T	T	T	T	T	T	T	T	T
F	T	F	T	T	F	F	F	T	T
F	F	T	T	T	T	T	T	F	T
F	F	F	T	T	F	F	F	T	T

-----

T	T	T	T	F	T	F	T	T	T
T	T	F	T	F	T	F	F	T	F
T	F	T	F	T	T	F	T	F	T
T	F	F	F	F	T	T	F	F	F
F	T	T	T	T	T	T	T	T	T
F	T	F	T	T	F	F	F	T	T
F	F	T	T	T	T	T	T	F	T
F	F	F	T	T	F	F	F	T	T

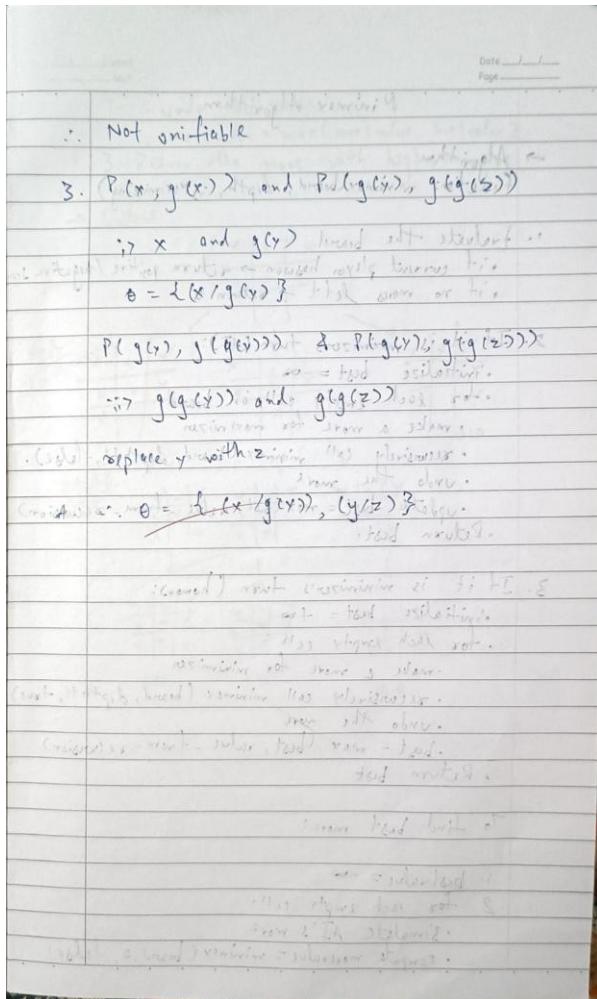
Entailment Results:

Does KB entail R? True  
 Does KB entail  $R \rightarrow P$ ? False  
 Does KB entail  $Q \rightarrow R$ ? True

## Program 7: Unification

## Algorithm:

Unification	Date 30/10/25 Page _____	Date _____ Page _____
<p>→ Algorithm (Goal, <math>\psi_1</math>, <math>\psi_2</math>)  <b>Unify</b> (<math>\psi_1</math>, <math>\psi_2</math>)  <math>\psi_1 \rightarrow \psi_1' \psi_2 \rightarrow \psi_2'</math></p> <p>(1) If <math>\psi_1</math> &amp; <math>\psi_2</math> is a variable or constant, then:      a) if <math>\psi_1</math> &amp; <math>\psi_2</math> are identical, return NIL.      b) else if <math>\psi_1</math> is a variable:          i) if <math>\psi_1</math> occurs in <math>\psi_2</math>, return FAILURE.          ii) else return <math>\{(\psi_2/\psi_1)\}</math>.      c) else if <math>\psi_2</math> is variable:          i) if <math>\psi_2</math> occurs in <math>\psi_1</math>, return FAILURE.          ii) else return <math>\{(\psi_1/\psi_2)\}</math>.      d) else return FAILURE.</p> <p>2. If the initial predicate symbol in <math>\psi_1</math> and <math>\psi_2</math> isn't same, return FAILURE.</p> <p>3. If <math>\psi_1</math> &amp; <math>\psi_2</math> have diff no. of arguments, return FAILURE.</p> <p>4. Set substitution <math>\theta</math> (<math>\text{SUBST} = \text{NIL}</math>).      a) for <math>i=1</math> to no. of elements in <math>\psi_1</math>, <math>\psi_2</math>:          i) call unify function with <math>i</math>th element of both <math>\psi_1</math> &amp; <math>\psi_2</math>, put result in <math>S</math>.          ii) if <math>S = \text{failure}</math> then return FAILURE.          iii) if <math>S \neq \text{NIL}</math>, then do:              i) Apply <math>S</math> to <math>i</math>th element of both <math>\psi_1</math> &amp; <math>\psi_2</math>              ii) <math>\text{SUBST} = \text{APPEND}(S, \text{SUBST})</math>.</p> <p>5. Return <math>\text{SUBST}</math></p>	<p>→ <math>P(f(x), g(y), z)</math>  <math>P(f(g(z)), g(f(a)), f(c))</math></p> <p>∴ <math>f(x)</math> and <math>f(g(z))</math>  <math>x \rightarrow g(z)</math> (as both have same predicate)      we replace <math>x</math> with <math>g(z)</math>      ∴ we replaced <math>x</math> with <math>g(z)</math></p> <p><math>\Theta = \{x/g(z)\}</math></p> <p><math>P(f(g(z)), g(f(a)), f(c))</math> and <math>P(f(f(g(z))), g(f(a)), f(c))</math></p> <p><math>g(f(z))</math> and <math>g(f(a))</math> of type      f(f(g(z))) and f(f(a)) of type  <math>y \rightarrow f(a)</math> (as both have same predicate)</p> <p>∴ <math>\Theta = \{x/g(z), y/f(a)\}</math></p> <p><math>P(f(g(z)), g(f(a)), f(c))</math> and <math>P(f(f(g(z))), g(f(a)), f(c))</math></p> <p><math>f(f(g(z)))</math> and <math>f(f(a))</math> of type      f(f(f(g(z)))) and f(f(f(a))) of type  <math>y \rightarrow f(a)</math> (as both have same predicate)</p> <p>∴ <math>\Theta = \{x/f(y)\}</math></p> <p><math>f(f(g(y)))</math> and <math>f(f(f(y)))</math> and <math>f(f(f(y)))</math></p> <p><math>y \rightarrow f(a)</math> (as both have same predicate)</p>	<p>Date _____ Page _____</p>



## CODE:

```

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

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

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

```

  def __repr__(self):
    return self.name
  
```

```

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

```

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

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

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

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

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

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

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

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

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

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

```

```

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

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

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

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

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

```

```

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

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

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

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

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

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

```

## **OUTPUT :**

```

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

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

```

## **Program 8:** MinMax & AlphaBeta

### **ALGORITHM :**

Date / /	Page _____	Date / /	Page _____
<h3 style="text-align: center;">Minimax Algorithm</h3> <p style="text-align: center;">&amp; Alpha-Beta Pruning</p> <p><b>Algorithm</b></p> <p>function: minimax(board, depth, isMaximizing)</p> <ul style="list-style-type: none"> <li>• evaluate the board           <ul style="list-style-type: none"> <li>• if current player has won <math>\rightarrow</math> return positive/negative</li> <li>• if no moves left <math>\rightarrow</math> return 0</li> </ul> </li> </ul> <p>2. If it is maximizer's turn (AI):</p> <ul style="list-style-type: none"> <li>• initialize best = <math>-\infty</math></li> <li>• for each empty cell on board:           <ul style="list-style-type: none"> <li>• make a move for maximizer</li> <li>• recursively call minimax (board, depth+1, false).</li> <li>• undo the move, if <math>best \geq \beta \rightarrow</math> return best</li> <li>• update <math>best = \max(best, value - from - recursion)</math></li> </ul> </li> <li>• Return best. <math>\&amp; \alpha = \max(\alpha, best)</math></li> </ul> <p>3. If it is minimizer's turn (human):</p> <ul style="list-style-type: none"> <li>• initialize best = <math>+\infty</math></li> <li>• for each empty cell:           <ul style="list-style-type: none"> <li>• make a move for minimizer</li> <li>• recursively call minimax (board, depth+1, true)</li> <li>• undo the move, if <math>best \leq \alpha \rightarrow</math> return best</li> <li>• update <math>best = \min(best, value - from - recursion)</math></li> </ul> </li> <li>• Return best. <math>\&amp; \beta = \min(\beta, best)</math></li> </ul> <p>To find best move:</p> <ol style="list-style-type: none"> <li>1. bestValue = <math>-\infty</math></li> <li>2. for each empty cell:           <ul style="list-style-type: none"> <li>• simulate AI's move</li> <li>• compute moveValue = minimax (board, 0, false).</li> </ul> </li> </ol>		<p>• undo the move</p> <p>• moveValue = <math>\max(moveValue, bestValue)</math></p> <p>3. Return the move with highest value</p> <p><b>Output:</b></p>	

## **CODE :**

```
def alpha_beta(node, depth, alpha, beta, maximizing_player, path):
```

```
# Base case: if node is a leaf (integer), return its value and path
```

```
if isinstance(node, int):
```

return node, path

if maximizing player:

```
value = float('-inf')
```

best path = None

```

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

    if child_value > value:
        value = child_value
        best_path = child_path

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

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

return value, best_path

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

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

        if child_value < value:
            value = child_value
            best_path = child_path

        beta = min(beta, value)

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

    return value, best_path

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

```

```

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

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

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

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

```

## OUTPUT:

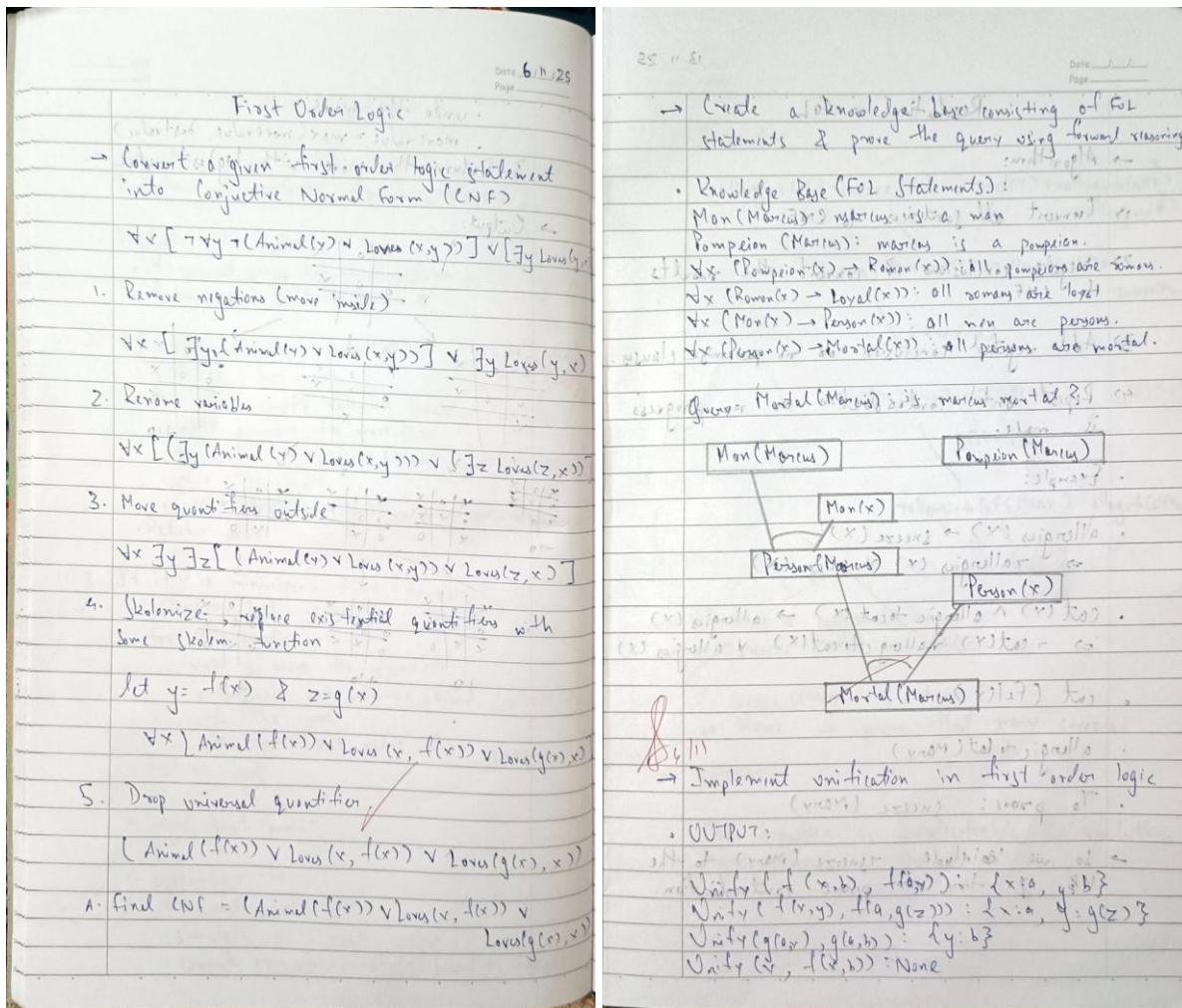
```

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

```

## Program 9: Forward Chaining & Conversion to CNF

### ALGORITHM :



### CODE (Forward Chaining) :

```

import re

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

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

def getPredicates(string):

```

```

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

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

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

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

    def __repr__(self):
        return self.expression

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

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

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

```

```

        matched = True
        break
    if not matched:
        return None

    return self.rhs.substitute(substitutions)

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

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

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

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

    def display(self):
        print("\nAll facts in Knowledge Base:")
        for i, f in enumerate(sorted([f.expression for f in self.facts])):
            print(f'\t{i+1}. {f}')

def main():

```

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

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

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

## OUTPUT (Forward Chaining) :

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

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

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

## CODE (CNF) :

```
import re

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

def getPredicates(string):
```

```

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

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

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

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

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

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

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


```

```

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

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

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

    expr = expr.strip('[] ')

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

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

```

```

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

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

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

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

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

```

```

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

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

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

expr = r'~\[[^\]]+\]'

statements = re.findall(expr, statement)
for s in statements:
    statement = statement.replace(s, DeMorgan(s))

return statement

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

```

```

try:
    raw_cnf = fol_to_cnf(fol)
    result = Skolemization(raw_cnf)
    cleaned = clean_output(result)
    print(f"Original: {fol}")
    print(f"CNF Form: {cleaned}")

except Exception as e:
    print("\nError: Could not parse the formula.")
    print("Details:", e)
    print("*"*50 + "\n")

if __name__ == "__main__":
    main()

```

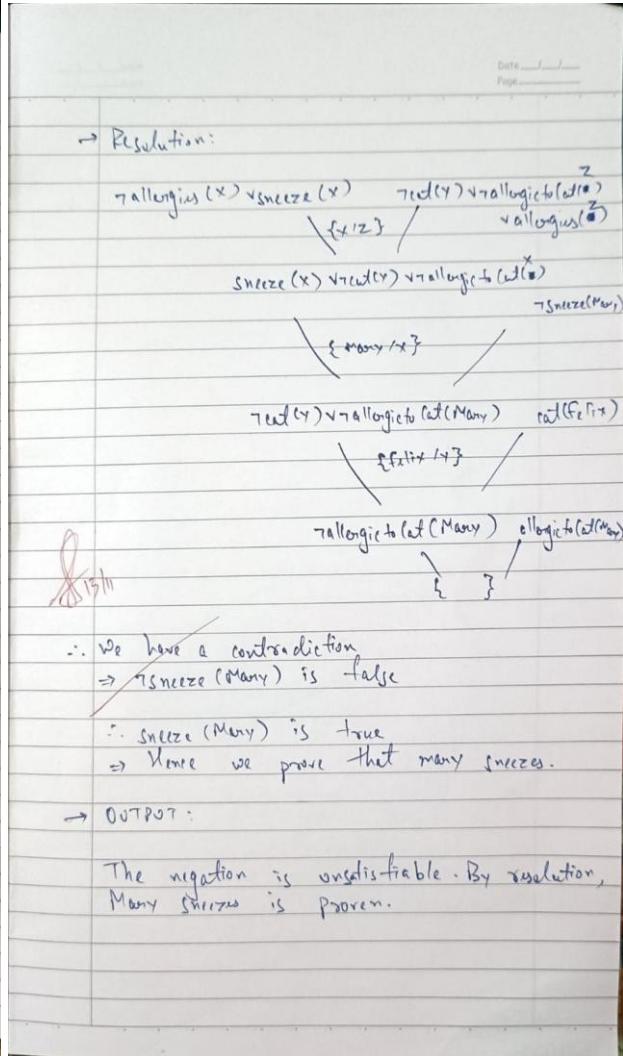
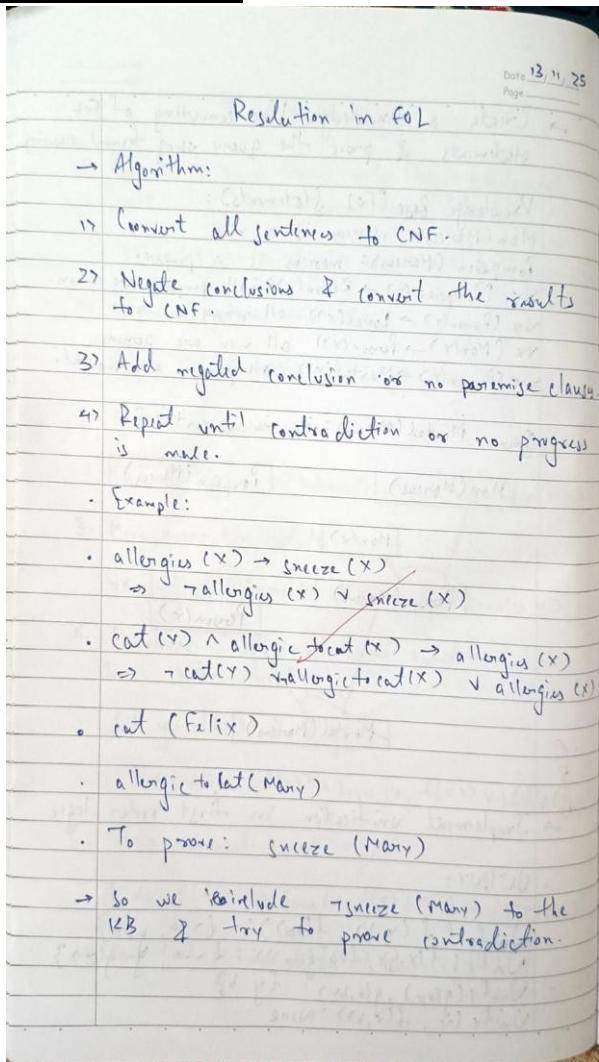
## OUTPUT (CNF):

```

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

## Program 10: Resolution

### ALGORITHM :



### CODE :

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

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

```

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

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

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

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

# Check satisfiability
sat_result = satisfiable(combined)

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

```

## OUTPUT :

```
The negation is unsatisfiable. By resolution, John likes peanuts is proven!
```