VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Hiran B (1BM23CS113)

in partial fulfillment for the award of the degree of

BACHELOR OF ENGINEERING

in

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B.M.S. COLLEGE OF ENGINEERING

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B.M.S. College of Engineering,

Bull Temple Road, Bangalore 560019

(Affiliated To Visvesvaraya Technological University, Belgaum)

Department of Computer Science and Engineering

CERTIFICATE

This is to certify that the Lab work entitled "Artificial Intelligence (23CS5PCAIN)" carried out by **Hiran B (1BM23CS113),** 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.

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

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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) :

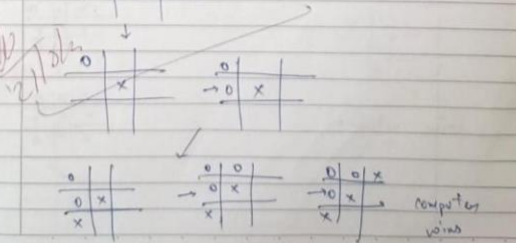
TIC TAC TOE

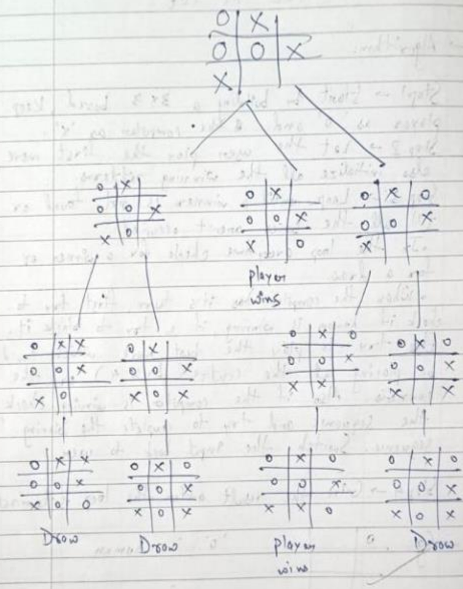
→ Algorithm:

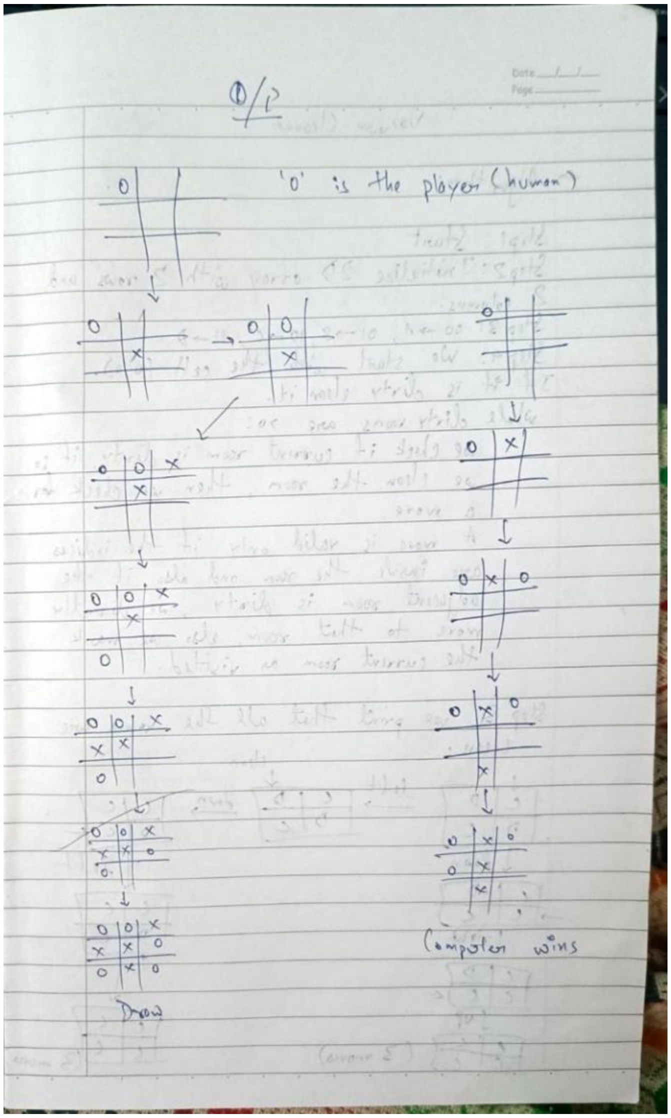
Step1 → Start by building a 3×3 board, keep player as 'O' and the computer as 'X'.
Step 2 → Let the user play the first move, also initialize all the winning patterns.
Step 3 → Loop until a winner is not found or till all the boxes aren't occupied.
• In the loop everytime check for a winner or for a draw.
• When the computer has it's turn, first try to check if human is winning, if so try to block it. Else try to play the best move which could be placing at the centre (block 4) or the corners. Also if the computer is winning, check the sequence and try to complete the winning sequence. Switch the input back to user.

Step4 → Give the result after the loop is terminated.

→ Eg: 'O' is human







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

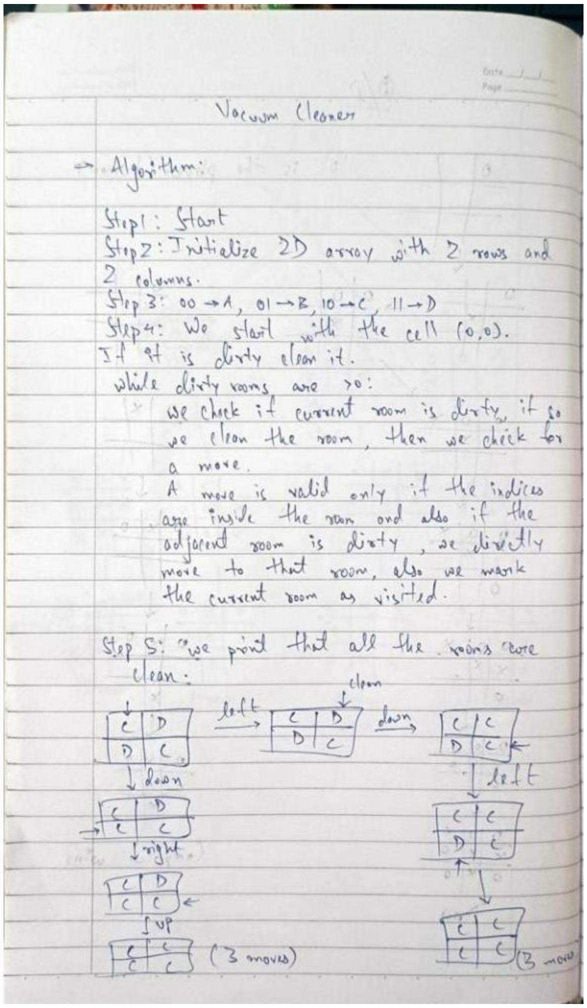
Switch turns turn = 'X' if turn
== 'O' else 'O'

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):

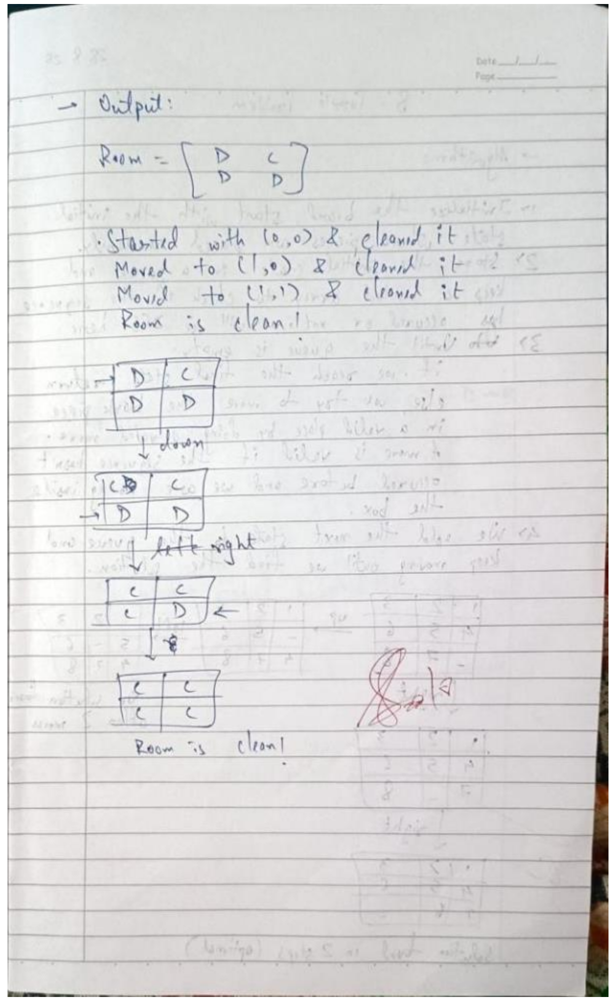


Vacuum Cleaner

→ Algorithm:

Step1: Start
Step2: Initialize 2D array with 2 rows and 2 columns.
Step 3: 00 → A, 01 → B, 10 → C, 11 → D
Step4: 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 are clean.



→ Output:

$$\text{Room} = \begin{bmatrix} D & C \\ D & D \end{bmatrix}$$

· Started with (0,0) & cleaned it
Moved to (1,0) & cleaned it
Moved to (1,1) & cleaned it
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'
```

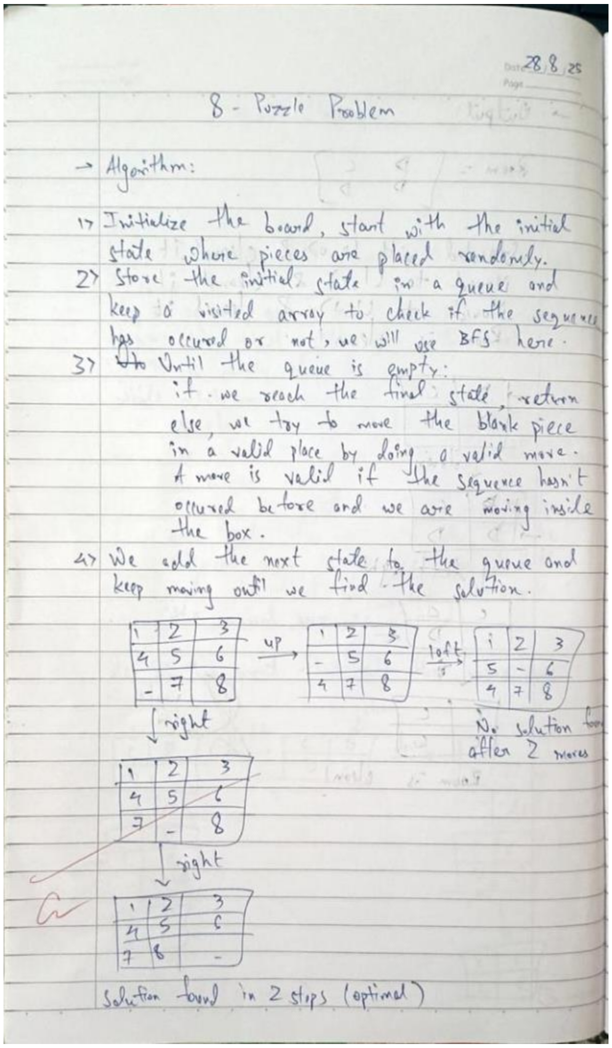
```
# Function to clean the current cell def
clean(x, y):
    room[x][y] = 'clean' print(f"Cleaned
    cell ({x},{y})")

# 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:



Date 28.8.25

8 - Puzzle Problem

→ 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 occured or not, we will use BFS here.

3> ~~to~~ 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 occured 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

up →

1	2	3
-	5	6
4	7	8

left →

1	2	3
5	-	6
4	7	8

No solution found after 2 moves

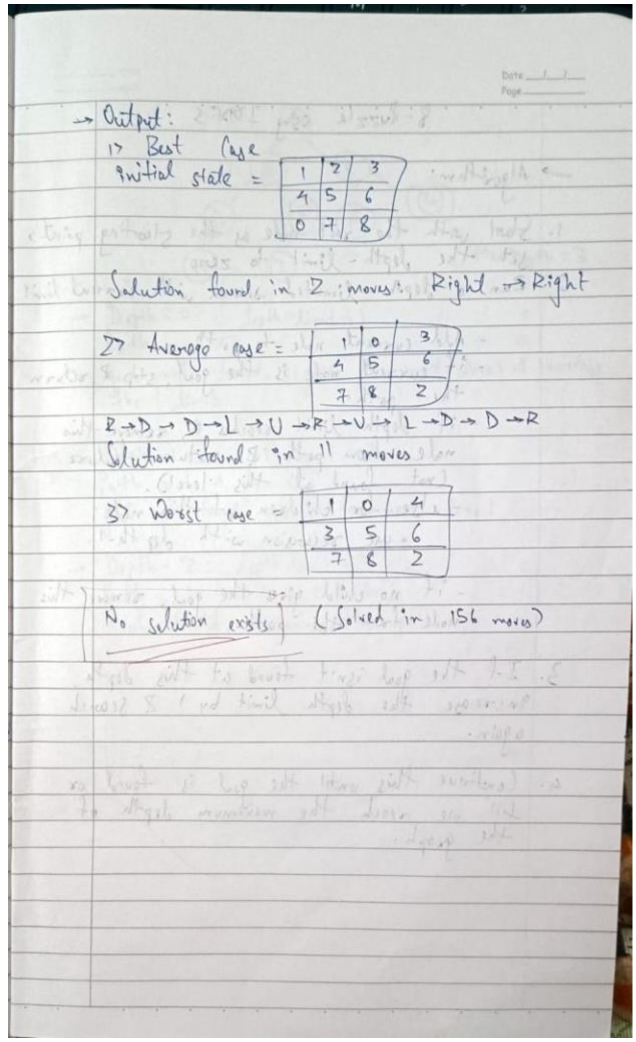
↓ right

1	2	3
4	5	6
7	-	8

↓ right

1	2	3
4	5	6
7	8	-

Solution found in 2 steps (optimal)



→ Output:

1> Best Case
initial state =

1	2	3
4	5	6
0	7	8

Solution found in 2 moves: Right → Right

2> Average case =

1	0	3
4	5	6
7	8	2

R → D → D → L → U → R → U → L → D → D → R
Solution found in 11 moves

3> 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_s
        tate):
            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]
-----
```

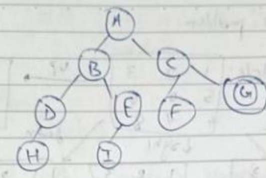
Program 3: Implement IDDFS

ALGORITHM :

8-Puzzle using IDDFS

→ Algorithm:

1. Start with the root node as the starting point, set the depth-limit to zero
2. Run a depth-limited search with current limit
   - Add current node to path
   - if current node is the goal, stop & return the path.
   - if depth limit reaches 0, remove this node from path & return failure (not found at this level).
   - else for children of this node:
     - use recursion with depth-1.
   - if no child gives the goal, remove this node from the path.
3. If the goal isn't found at this depth, increase the depth limit by 1 & search again.
4. Continue this until the goal is found or till we reach the maximum depth of the graph.



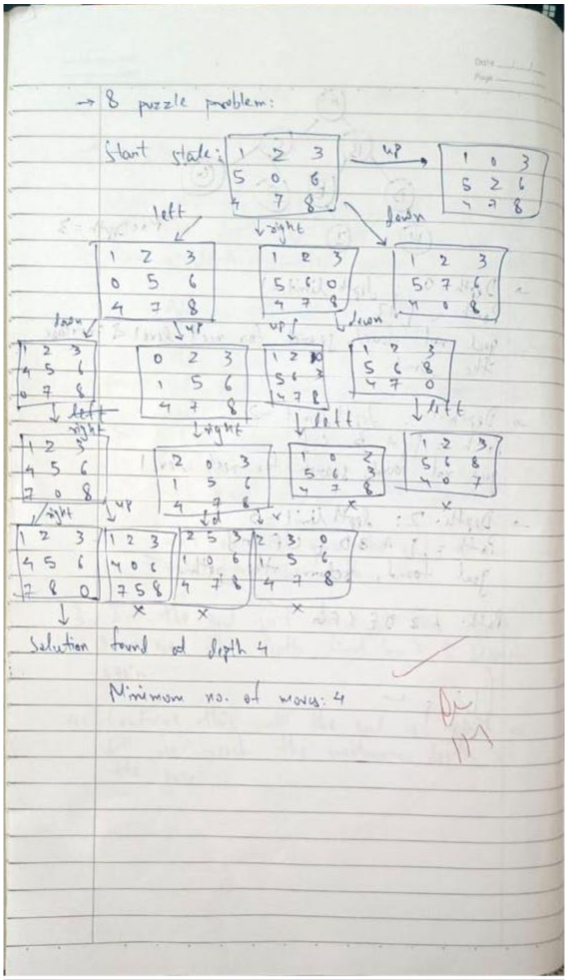
Max Depth = 3

→ Depth = 0 : depth limit = 1
Path = [A]
goal not found, search for next level & increase the limit

→ Depth-1 : depth limit = 2
Path = [A B C]
goal not found, search for next level

→ Depth-2 : depth limit = 3
Path = [A B D E C F G]
goal found, return the path.

Path: A B D E C F G



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.")
```

<u>OUTPUT :</u>

```
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:

Date 9/10/25

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Hill Climbing and Simulated Annealing

→ Algorithm:

• Hill Climbing

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

ii) 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.

iii) Finally return the best found solution.

Pseudocode

```
function hill climb(problem):
    current = initial_state(problem)
    loop:
        neighbours = generate(current)
        b = best(neighbour)
        if value(b) > value(current):
                current = b
        else:
            break
    return current
```

Date

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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 pair 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 .
. . . .
. Q . Q
. . . .
```

Move to board with 1 attacks:

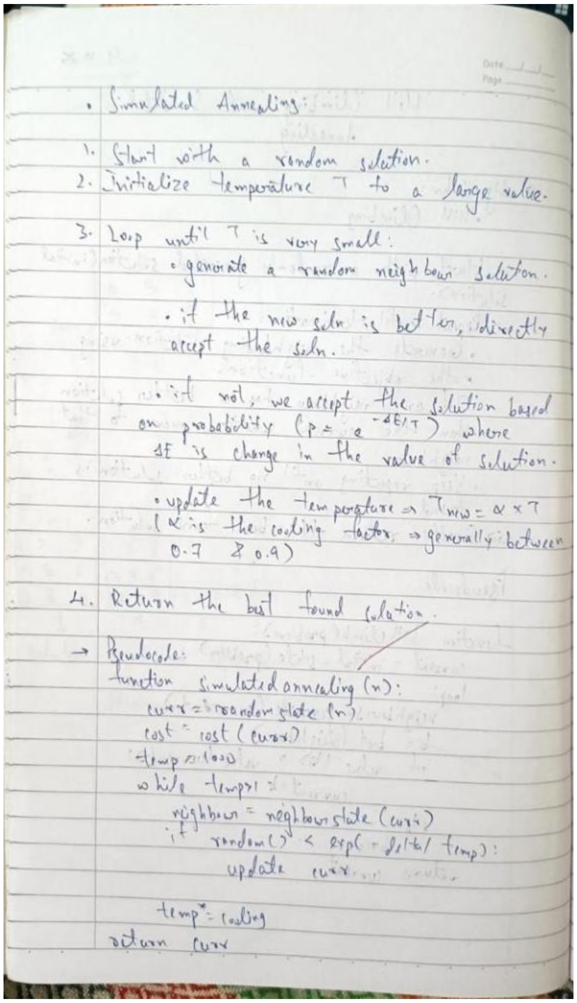
```
Q . Q .
. . . .
. . . Q
. Q . .
```

Move to board with 0 attacks:

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

Solution found:

Steps taken = 2

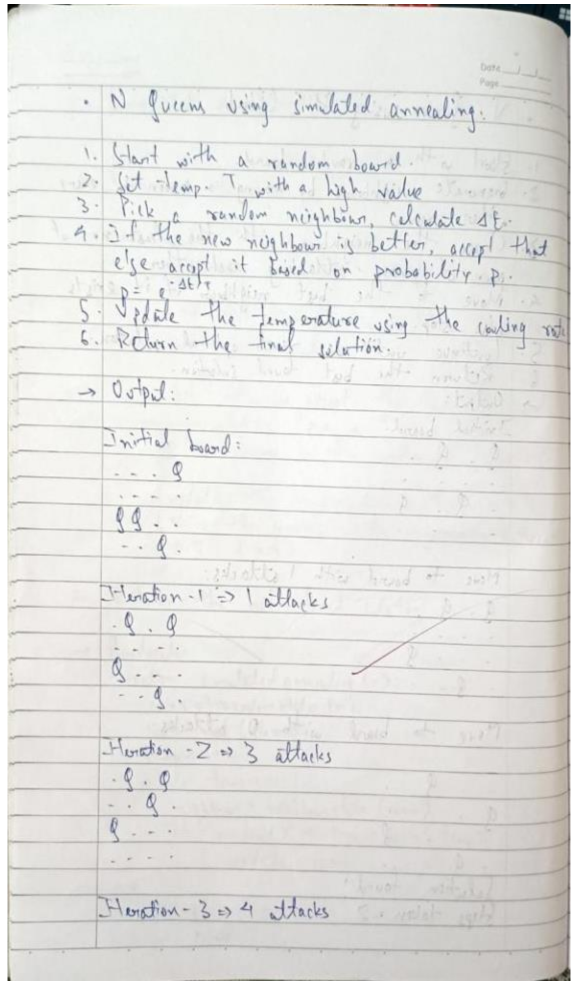


- Simulated Annealing:

1. Start with a random solution.
2. Initialize temperature T to a large value.
3. 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 ΔE is change in the value of solution.
   - update the temperature ⇒ $T_{new} = \alpha \times T$ (α is the cooling factor, ⇒ generally between 0.7 & 0.9)
4. Return the best found solution.

→ Pseudocode:

```
function simulatedannealing (n):
    curr = random state (n)
    cost = cost (curr)
    temp = 1000
    while temp>1 :
        neighbour = neighbourstate (curr)
        if random() < exp( - delta/ temp):
            update curr

        temp*= cooling
return curr
```



- N Queens using simulated annealing:

1. Start with a random board.
2. Set temp. T with a high value
3. Pick a random neighbour, calculate ΔE.
4. If the new neighbour is better, accept that else accept it based on probability P. $P = e^{-\Delta E / T}$
5. Update the temperature using the cooling rate
6. Return the final solution.

→ Output:

Initial board:

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

Iteration-1 ⇒ 1 attacks

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

Iteration-2 ⇒ 3 attacks

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

Iteration-3 ⇒ 4 attacks

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

  @staticmethod   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) *
```

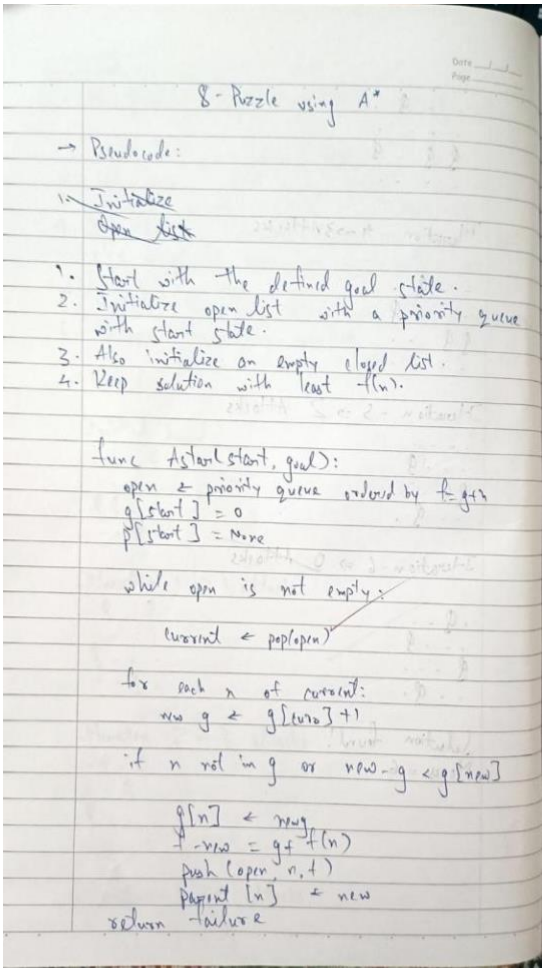
```
decimal.Decimal(self.temperature)))

            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 :



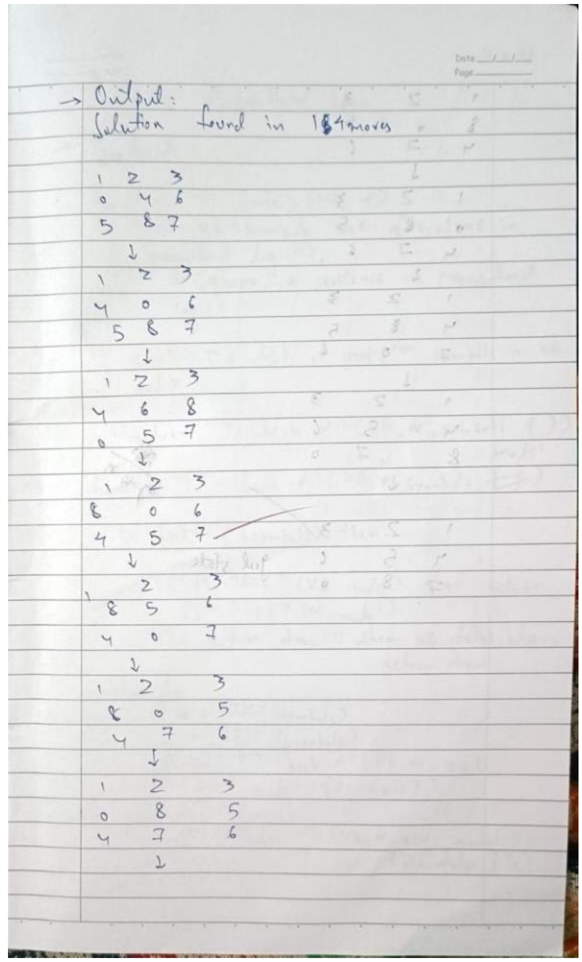
8-Puzzle using A*

→ Pseudocode:

1. ~~Initialize Open list~~

1. Start with the defined goal state.
2. Initialize open list with a priority queue with start state.
3. Also initialize an empty closed list.
4. Keep solution with least f(n).

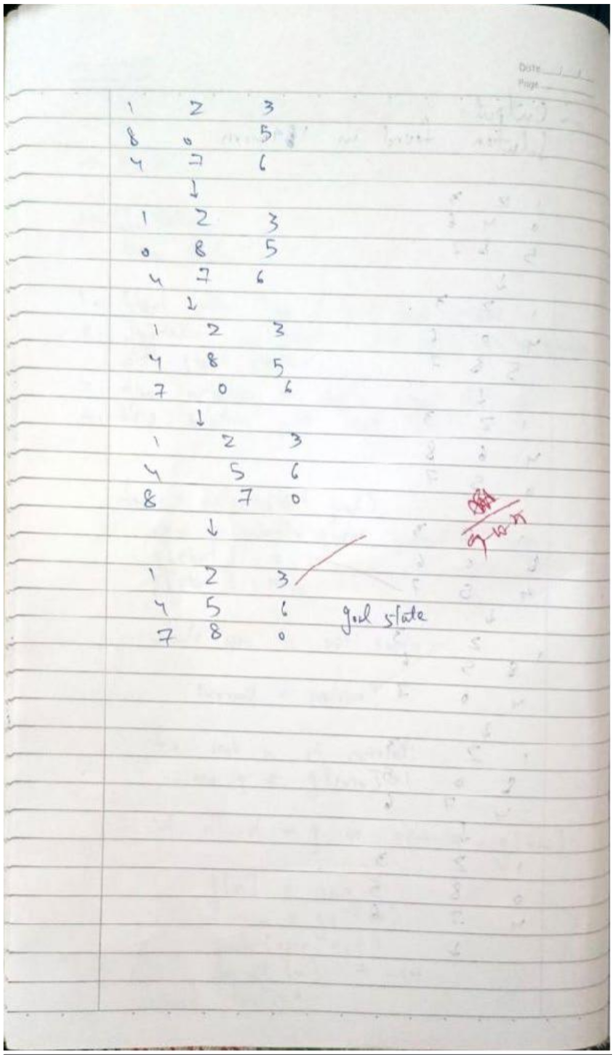
```
func Astar(start, goal):
    open ← priority queue ordered by f=g+h
    g[start] = 0
    p[start] = None

    while open is not empty:

        current ← pop(open)

    for each n of current:
        new g ← g[curr] +1

    if n not in g or new_g < g[new]

        g[n] ← new_g
        f_new = g+f(n)
        push(open, n, f)
        parent[n] ← new
return failure
```



→ Output:

Solution found in 14 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 5 6
4 0 7
  ↓
1 2 3
8 0 5
4 7 6
  ↓
1 2 3
0 8 5
4 7 6
  ↓
```



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(ope
    ned, 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 :

Date 16/10/25

Propositional Logic

→ Pseudocode

```
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

    return TT-Check-All (KB, α, symbols, { })

function TT-Check-All (KB, α, symbols, model)

  if EMPTY? (symbols) then

      if PL-TRUE? (KB, model) then return
         PL-TRUE? (α, model)
      else return true // when KB false, always
                           return true

  else do
      P ← FIRST (symbols)
     rest ← REST (symbols)
     return (TT-Check-All (KB, α, rest,
              model ∪ {P = true})
           and
        TT-Check-All (KB, α, rest, model ∪
                  {P = false}))
```

Q. i> $Q \to P$
ii> $P \to \sim Q$
iii> $Q \vee R$

- Truth Table

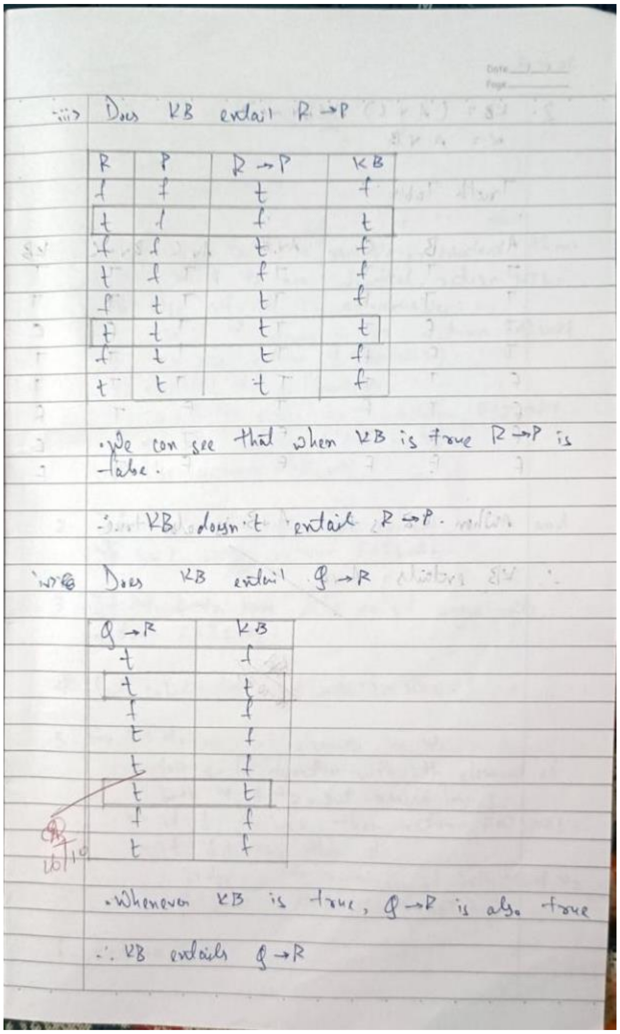
P	Q	R	$\sim Q$	$Q \to P$	$P \to \sim Q$	$Q \vee R$	KB
f	f	f	t	t	t	f	f
f	f	t	t	t	t	t	t
f	t	f	f	f	t	t	f
f	t	t	f	f	f	t	f
t	f	f	t	t	t	f	f
t	f	t	t	t	t	t	t
t	t	f	f	t	f	t	f
t	t	t	f	t	f	t	f

ii> Does KB entail R

R	KB
f	f
t	t
f	f
t	f
f	f
t	t
f	f
t	f

- Whenever KB is true, R is also true.

∴ KB entails R



iii> Does KB entail $R \to P$

R	P	$R \to P$	KB
f	f	t	f
t	f	f	t
f	f	t	f
t	f	f	f
f	t	t	f
f	t	t	t
f	t	t	f
t	t	t	f

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

∴ KB doesn't entail $R \to P$.

iv> Does KB entail $Q \to R$

$Q \to R$	KB
t	f
t	t
f	f
t	f
t	f
t	t
f	f
t	f

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

∴ KB entails $Q \to R$

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(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 → P | P → ¬Q | Q v R | KB (all true) | R | R → P | Q → 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 | T | T | F | F | T | 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 → P? False
Does KB entail Q → R? True
```

Program 7: Unification

Algorithm:

Date 30, 10, 25

Unification

→ Algorithm
Unify (Ψ_1, Ψ_2)

1. If Ψ_1 or Ψ_2 is a variable or constant, then:
   a) if Ψ_1 & Ψ_2 are identical, return NIL.
   b) else if Ψ_1 is a variable:
      i) if Ψ_1 occurs in Ψ_2, return FAILURE.
      ii) else return $\{(\Psi_2/\Psi_1)\}$
   c) else if Ψ_2 is variable:
      i) if Ψ_2 occurs in Ψ_1, return FAILURE.
      ii) else return $\{(\Psi_1/\Psi_2)\}$
   d) else return FAILURE.

2. If the initial predicate symbol in Ψ_1 and Ψ_2 isn't same, return FAILURE.

3. If Ψ_1 & Ψ_2 have diff no. of arguments, return FAILURE.

4. Set substitution set(SUBST) = NIL.

5. For i=1 to no. of elements in Ψ_1
   a) Call unify function with ith element of both Ψ_1 & Ψ_2, put result in S.
   b) if S = failure then return FAILURE.
   c) if S ≠ NIL, then do
      i) Apply S to remainder of both Ψ_1 & Ψ_2
      ii) SUBST = APPEND(S, SUBST)

6. Return SUBST

Date __/__/__
Page ____

1) $P(f(x), g(y), y)$
$P(f(g(z)), g(f(a)), f(a))$

i) $f(x)$ and $f(g(z))$
$x \to g(z)$ (as both have same predicate)

∴ we replaced x with $g(z)$

$\theta = \{(x/g(z))\}$
$P(f(g(z)), g(y), y)\}$ and $P(f(g(z)), g(f(a)), f(a))$
ii) $g(y)$ and $g(f(a))$

$y \to f(a)$ (as both have same predicate)

$\theta = \{(x/g(z)), (y/f(a))\}$

$P(f(g(z)), g(f(a)), f(a))$
(substitute y here as well)
$P(f(g(z)), g(f(a)), f(a))$

A. $\theta = \{(x/g(z)), (y/f(a))\}$

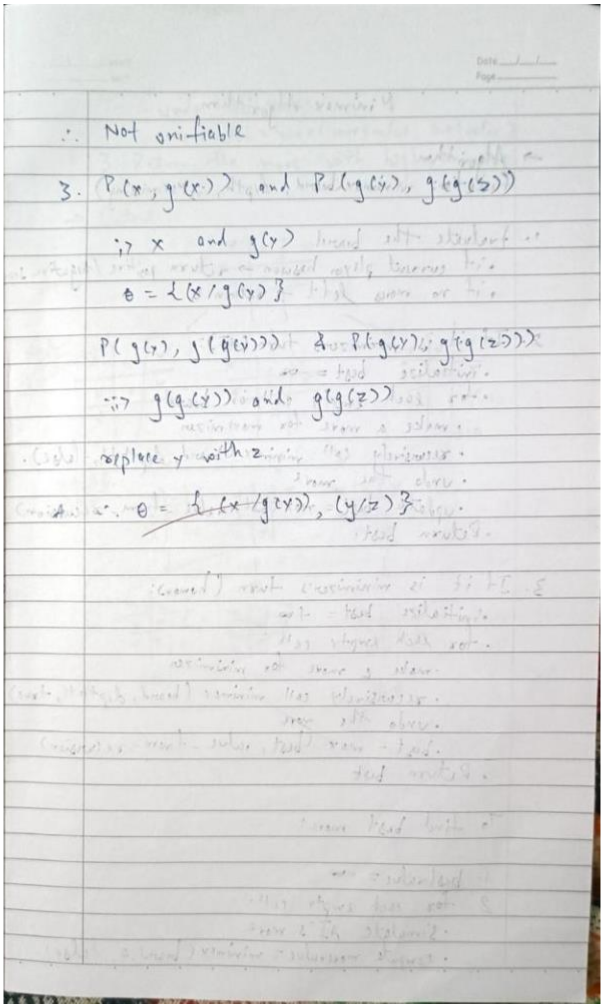
2. $g(x, f(x))$ and $g(f(y), y)$

i) x and $f(y)$.

∴ $\theta = \{x/f(y)\}$

$g(f(y), f(f(y)))$ and $g(f(y), y\}$

ii) $f(f(y))$ and y
∵ y occurs on both sides



∴ Not unifiable

3. P(x, g(x)) and P(g(y), g(g(z)))

i) x and g(y)

$\theta = \{x/g(y)\}$

P(g(y), g(g(y))) & P(g(y), g(g(z)))

ii) g(g(y)) and g(g(z))

replace y with z

∴ $\theta = \{$~~(x/g(y))~~$, (y/z)\}$

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
```

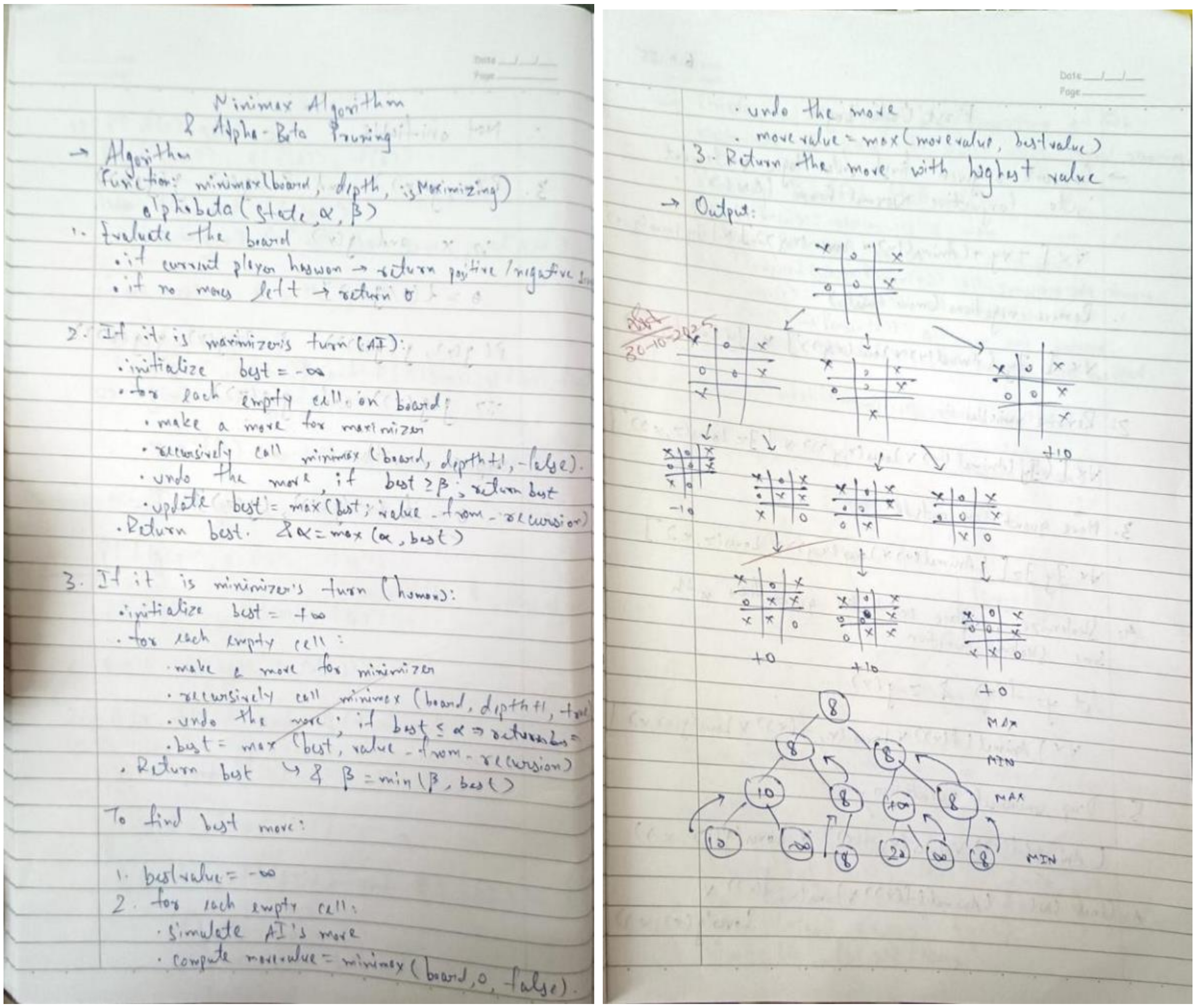
```
x, y, z = Variable('x'), Variable('y'), Variable('z')
a, b = Constant('a'), Constant('b') f = Function('f',
[x, Constant('b')]) g = Function('g',
[Constant('a'), y]) h = Function('h', [z])

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 :


Minimax Algorithm
& Alpha-Beta Pruning
→ Algorithm
Function: minimax(board, depth, isMaximizing)
alphabeta(state, α, β)
1. Evaluate the board
• if current player has won → return positive / negative
• if no moves left → return 0
2. If it is maximizer's turn (AI):
• initialize best = -∞
• for each empty cell on board:
• make a move for maximizer
• recursively call minimax (board, depth+1, false).
• undo the move, if best ≥ β, return best
• update best = max(best, value_from_recursion)
• Return best. & α = max(α, best)
3. If it is minimizer's turn (human):
• initialize best = +∞
• for each empty cell:
• make a move for minimizer
• recursively call minimax (board, depth+1, true)
• undo the move; if best ≤ α ⇒ return best
• best = max (best, value_from_recursion)
• Return best & β = min(β, best)
To find best move:
1. bestvalue = -∞
2. for each empty cell:
• Simulate AI's move
• compute movevalue = minimax (board, 0, false).
• undo the move
• movevalue = max(movevalue, bestvalue)
3. Return the move with highest value
→ Output:
+10
-10
+0
+10
+0
MAX
MIN
MAX
MIN

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],
```

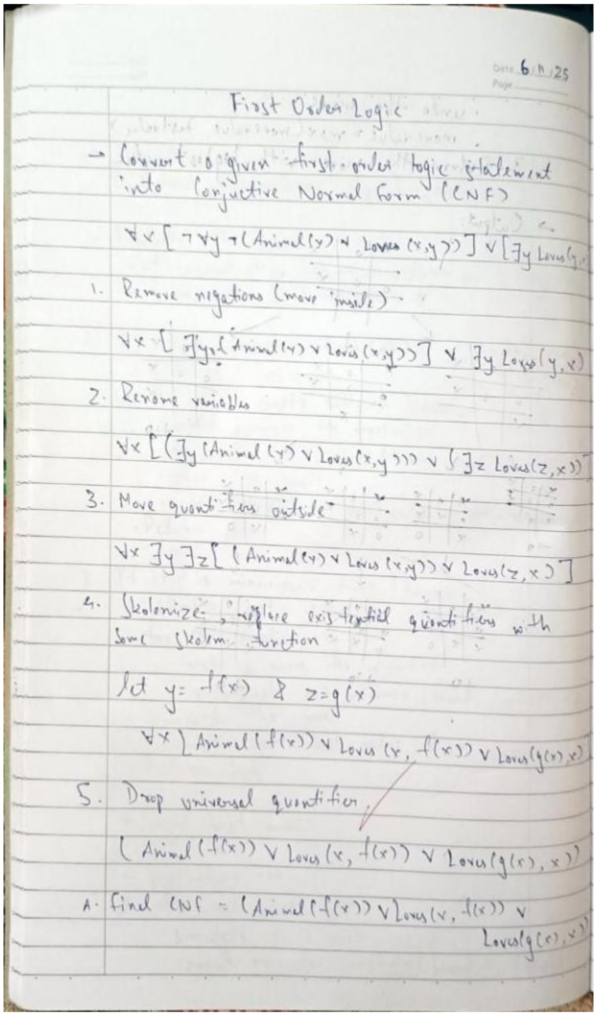
```
            [13, 14]
        ],
    ],
    [
        [
            [5, 2],
            [4, 1]
        ],
        [
            [3, 22],
            [20, 21]
        ],
    ]
]

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 :



Date 6/11/25

First Order Logic

→ Convert a given first order logic statement into Conjunctive Normal Form (CNF)

∀x [¬∀y ¬(Animal(y) ∧ Loves(x,y))] ∨ [∃y Loves(y,x)]

1. Remove negations (move inside)

∀x [∃y (Animal(y) ∨ Loves(x,y))] ∨ ∃y Loves(y,x)

2. Rename variables

∀x [(∃y (Animal(y) ∨ Loves(x,y))) ∨ (∃z Loves(z,x))]

3. Move quantifiers outside

∀x ∃y ∃z [(Animal(y) ∨ Loves(x,y)) ∨ Loves(z,x)]

4. Skolemize: replace existential quantifiers with some skolem function

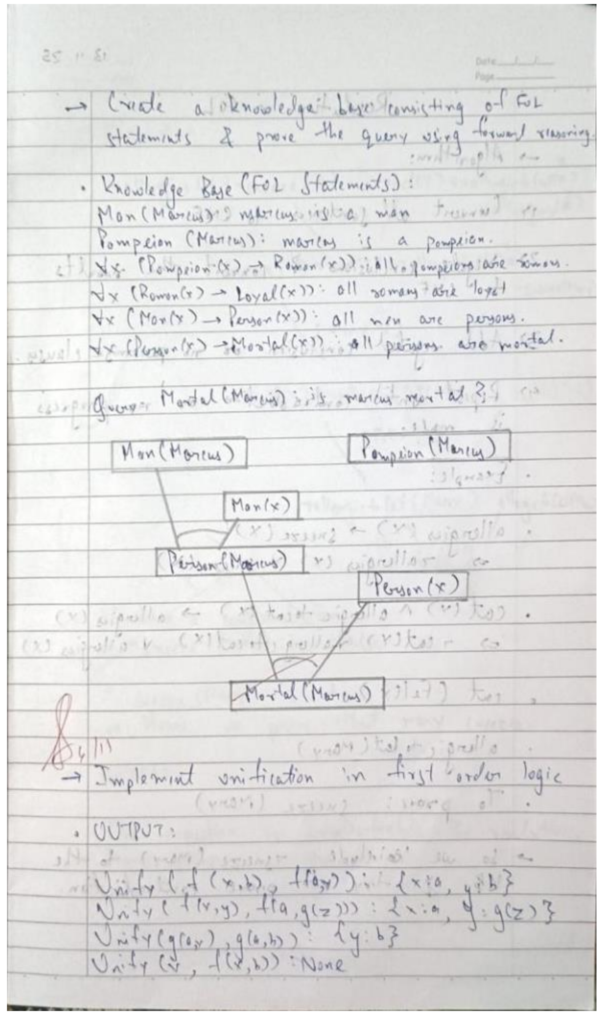
let y = f(x) & z = g(x)

∀x [Animal(f(x)) ∨ Loves(x, f(x)) ∨ Loves(g(x),x)]

5. Drop universal quantifier

[Animal(f(x)) ∨ Loves(x, f(x)) ∨ Loves(g(x), x)]

A. Final CNF = (Animal(f(x)) ∨ Loves(x, f(x)) ∨ Loves(g(x), x))



→ Create a knowledge base consisting of FOL statements & prove the query using forward reasoning.

• Knowledge Base (FOL Statements):

Man(Marcus): Marcus is a man

Pompeian(Marcus): Marcus is a pompeian.

∀x (Pompeian(x) → Roman(x)): all pompeians are romans.

∀x (Roman(x) → Loyal(x)): all romans are loyal

∀x (Man(x) → Person(x)): all men are persons.

∀x (Person(x) → Mortal(x)): all persons are mortal.

Query: Mortal(Marcus): is marcus mortal?

→ Implement unification in first order logic

• OUTPUT:

Unify(f(x,b), f(a,y)) : {x:a, y:b}

Unify(f(x,y), f(a,g(z))) : {x:a, y:g(z)}

Unify(g(a,y), g(a,b)) : {y:b}

Unify(x, f(x,b)) : None

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)
                        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('[∀∃].', 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'(~[∀V∃].)'
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:
```

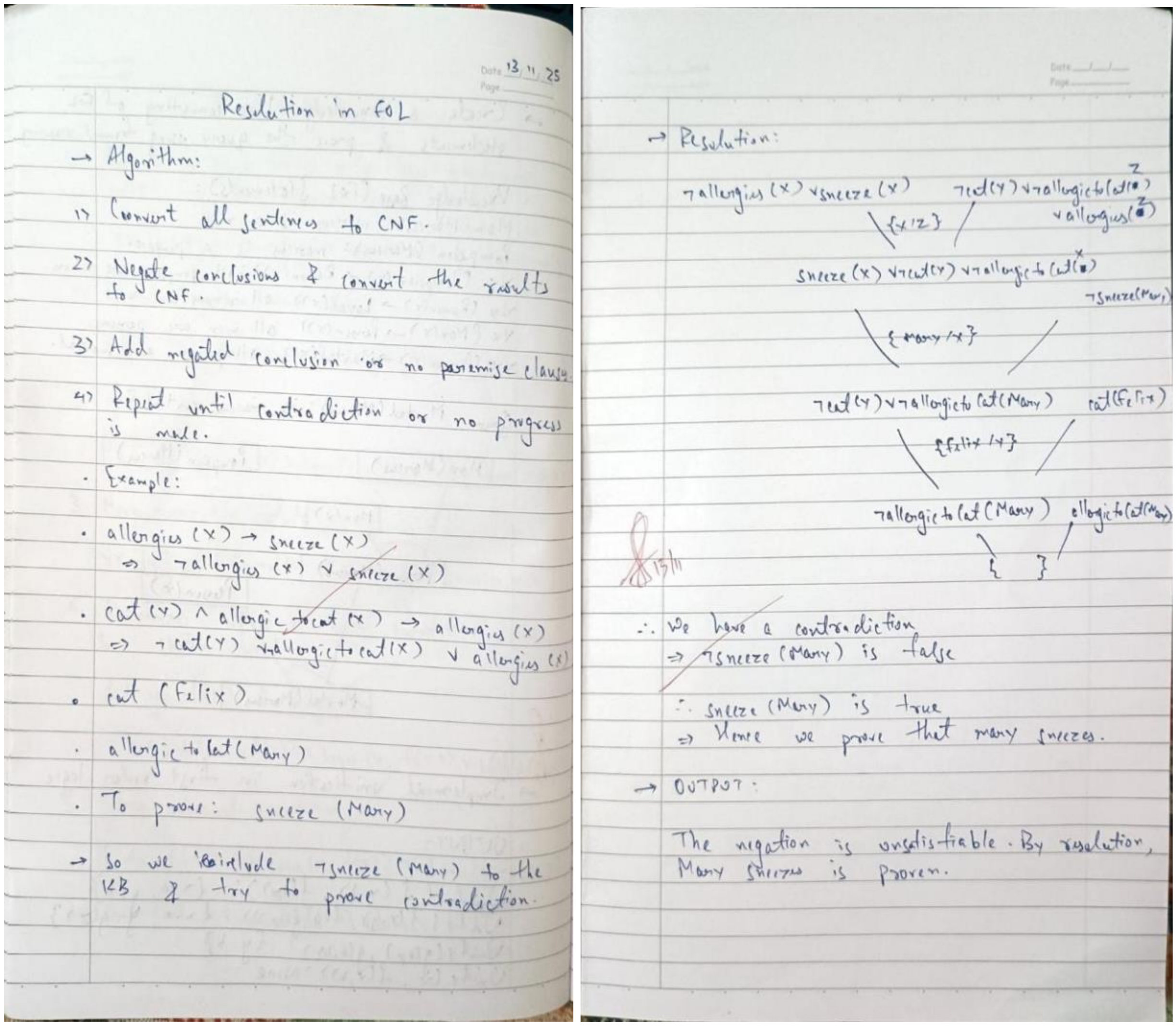
```
        raw_cnf = fol_to_cnf(fol) result
        =          Skolemization(raw_cnf)
        cleaned  =  clean_output(result)
        print(f"Original:            {fol}")
        print(f"CNF Form: {cleaned}")
    except Exception as e: print("\nError: Could not
        parse the formula.") print("Details:", 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)VLoves(x,y))]V[∃y Loves(y,x)]
--------------------------------------------------
Original:   ∀x[~∀y~(Animal(y)VLoves(x,y))]V[∃y Loves(y,x)]
CNF Form:   Animal(y)VLoves(x,y))]V[ Loves(y,x
==================================================
```

Program 10: Resolution

ALGORITHM :



Date 13/11/25

Resolution in FOL

→ Algorithm:

1) Convert all sentences to CNF.

2) Negate conclusions & convert the results to CNF.

3) Add negated conclusion or no paremise clause.

4) Repeat until contradiction or no progress is made.

- Example:

- allergies (X) → sneeze (X)
  ⇒ ¬allergies (X) ∨ sneeze (X)

- cat (Y) ∧ allergic to cat (X) → allergies (X)
  ⇒ ¬cat(Y) ∨ ¬allergic to cat (X) ∨ allergies (X)

- cat (Felix)

- allergic to cat (Mary)

- To prove: sneeze (Mary)

→ So we include ¬sneeze (Mary) to the KB & try to prove contradiction.

→ Resolution:

¬allergies (X) ∨ sneeze (X)   ¬cat(Y) ∨ ¬allergic to cat(Z) ∨ allergies(Z)

{X/Z}

sneeze (X) ∨ ¬cat(Y) ∨ ¬allergic to cat(X)   ¬sneeze(Mary)

{Mary/X}

¬cat (Y) ∨ ¬allergic to cat(Mary)   cat(Felix)

{Felix/Y}

¬allergic to cat (Mary)   allergic to cat(Mary)

{ }

13/11

∴ We have a contradiction
⇒ ¬sneeze (Mary) is false

∴ sneeze (Mary) is true
⇒ Hence we prove that mary sneezes.

→ OUTPUT:

The negation is unsatisfiable. By resolution, Mary sneezes is proven.

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!")
```

<u>OUTPUT :</u>

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