

VISVESVARAYA TECHNOLOGICAL UNIVERSITY

“JnanaSangama”, Belgaum -590014, Karnataka.



LAB REPORT on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Anirudh Raghunand (1BM23CS036)

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



B.M.S. COLLEGE OF ENGINEERING
(Autonomous Institution under VTU)
BENGALURU-560019
Sep-2024 to Jan-2025

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



CERTIFICATE

This is to certify that the Lab work entitled “Artificial Intelligence (23CS5PCAIN)” carried out by **Anirudh Raghunand (1BM23CS036)**, who is bonafide student of **B.M.S. College of Engineering**. It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements in respect of an Artificial Intelligence (23CS5PCAIN) work prescribed for the said degree.

Dr K R Mamatha Associate Professor Department of ISE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE
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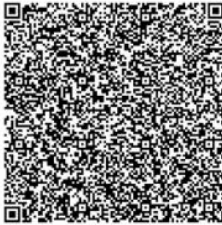
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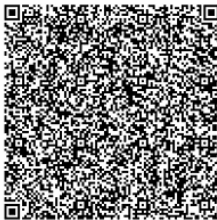
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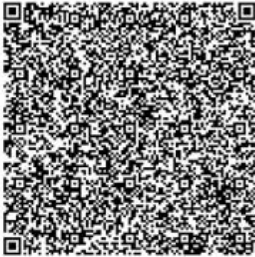
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Tic Tac Toe

▷ Tic - Tac - Toe

tic tac toe () $\frac{3}{2}$:

solution set = $\{ [0,1,2], [3,4,5], [6,7,8], [0,3,6], [1,4,7], [2,5,8], [0,4,8], [2,4,7] \}$

board = $\{ 0: "0", 1: "1", 2: "2", 3: "3", 4: "4", 5: "5", 6: "6", 7: "7", 8: "8" \}$

board =

turn = 0

for (i=0; i<9; i++) {

if (turn == 0) {

computer plays()
turn = 1

else

user plays()
turn = 0

}

user plays () {

print ("Please Play your turn")

x = int(input ())

if (board[x] == x) {

board[x] = "X"

}

if (i >= 5)

check ()

}

computer plays {
 if empty = 0
 for i in board values:
 if (board[i] != 'x')
 is empty = 0
 if (is empty) {
 board[i]: "O"

minimax(board, depth, is-maximizing):

result = checkwinner(board)

If result is not none:

if result == 'x' return -10

if result == 'O' return +10

if result == Draw return 0

if (is-maximizing)

bestscore = $-\infty$

for each empty cell in board

place "O" in cell

score = minimax(board, depth)

undo move

best-score = max(best-score, score)

return bestscore

else:

bestscore = ∞

for each empty cell in board

place x in cell

score = minimax(board, d+1, To)

undo move

best-score = min(bestscore, score)

return bestscore

Code:

```
import math
```

```
class TicTacToe:
```

```
    def __init__(self):
```

```
        self.board = []
```

```
    def create_board(self):
```

```
        self.board = [['-' for _ in range(3)] for _ in range(3)]
```

```
    def fix_spot(self, position, player):
```

```
        row = position // 3
```

```
        col = position % 3
```

```
        self.board[row][col] = player
```

```
    def is_spot_empty(self, position):
```

```
        row = position // 3
```

```
        col = position % 3
```

```
        return self.board[row][col] == '-'
```

```
    def is_player_win(self, player):
```

```
        n = len(self.board)
```

```
        # Check rows and columns
```

```
        for i in range(n):
```

```
            if all(self.board[i][j] == player for j in range(n)) or \
```

```
                all(self.board[j][i] == player for j in range(n)):
```

```
                return True
```

```
        # Check diagonals
```

```
        if all(self.board[i][i] == player for i in range(n)) or \
```

```
            all(self.board[i][n - 1 - i] == player for i in range(n)):
```

```
            return True
```

```
        return False
```

```
    def is_board_filled(self):
```

```
        for row in self.board:
```

```
            for item in row:
```

```
                if item == '-':
```

```

        return False
    return True

def show_board(self):
    print("\nCurrent Board:")
    for row in self.board:
        print(" ".join(row))
    print()

def show_positions(self):
    print("\nPosition Map:")
    positions = [str(i) for i in range(9)]
    for i in range(0, 9, 3):
        print(" ".join(positions[i:i + 3]))
    print()

def evaluate(self):
    if self.is_player_win('O'):
        return 1
    elif self.is_player_win('X'):
        return -1
    else:
        return 0

def minimax(self, depth, is_maximizing):
    score = self.evaluate()

    # Base conditions
    if score == 1:
        return score
    if score == -1:
        return score
    if self.is_board_filled():
        return 0

    if is_maximizing:
        best = -math.inf
        for i in range(9):
            if self.is_spot_empty(i):
                self.fix_spot(i, 'O')

```

```

        best = max(best, self.minimax(depth + 1, False))
        self.fix_spot(i, '-') # Undo move
    return best
else:
    best = math.inf
    for i in range(9):
        if self.is_spot_empty(i):
            self.fix_spot(i, 'X')
            best = min(best, self.minimax(depth + 1, True))
            self.fix_spot(i, '-') # Undo move
    return best

def find_best_move(self):
    best_val = -math.inf
    best_move = -1

    for i in range(9):
        if self.is_spot_empty(i):
            self.fix_spot(i, 'O')
            move_val = self.minimax(0, False)
            self.fix_spot(i, '-')
            if move_val > best_val:
                best_move = i
                best_val = move_val

    return best_move

def start(self):
    self.create_board()
    player = 'X'
    computer = 'O'

    print("Welcome to Tic Tac Toe!")
    print("You are 'X' and the computer is 'O'.")
    self.show_positions()

    while True:
        self.show_board()
        try:
            position = int(input("Enter position (0-8): "))

```

```

except ValueError:
    print("Invalid input! Enter a number between 0 and 8.")
    continue

if position < 0 or position > 8:
    print("Invalid position! Enter between 0 and 8.")
    continue

if not self.is_spot_empty(position):
    print("That spot is already taken! Choose another.")
    continue

self.fix_spot(position, player)

if self.is_player_win(player):
    self.show_board()
    print("You win!")
    break

if self.is_board_filled():
    self.show_board()
    print("It's a draw!")
    break

print("Computer is making its move...")
best_move = self.find_best_move()
self.fix_spot(best_move, computer)
print(f"Computer chose position {best_move}")

if self.is_player_win(computer):
    self.show_board()
    print("Computer wins!")
    break
if self.is_board_filled():
    self.show_board()
    print("It's a draw!")
    break

# Start the game
tic_tac_toe = TicTacToe()
tic_tac_toe.start()

```

Output:

```
Welcome to Tic Tac Toe!
You are 'X' and the computer is 'O'.
```

```
Position Map:
0 1 2
3 4 5
6 7 8
```

```
Current Board:
- - -
- - -
- - -
```

```
Enter position (0-8): 4
Computer is making its move...
Computer chose position 0
```

```
Current Board:
O - -
- X -
- - -
```

```
Enter position (0-8): 5
Computer is making its move...
Computer chose position 3
```

```
Current Board:
O - -
O X X
- - -
```

```
Enter position (0-8): 6
Computer is making its move...
Computer chose position 2
```

```
Current Board:
O - O
O X X
X - -
```

```
Enter position (0-8): 1
Computer is making its move...
Computer chose position 7
```

Current Board:

O X O

O X X

X O -

Enter position (0-8): 8

Current Board:

O X O

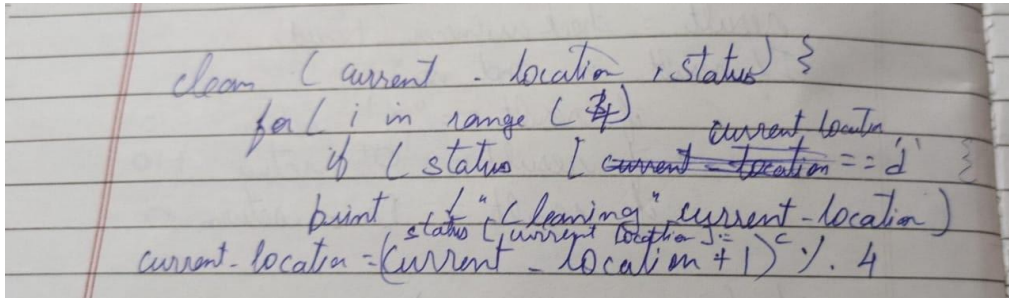
O X X

X O X

It's a draw!

Vacuum Cleaner

Pseudocode:



Code:

```
def vacuum_world():  
    goal_state = {'A': '0', 'B': '0'}  
    cost = 0  
    location_input = input("Enter Location of Vacuum: ")  
    status_input = input("Enter status of " + location_input + " : ")  
    status_input_complement = input("Enter status of other room : ")  
  
    print("Initial Location Condition {A : " + str(status_input_complement) +  
          ", B : " + str(status_input) + " }")  
  
    if location_input == 'A':  
        print("Vacuum is placed in Location A")  
        if status_input == '1':  
            print("Location A is Dirty.")  
            goal_state['A'] = '0'  
            cost += 1 # cost for suck  
            print("Cost for CLEANING A " + str(cost))  
            print("Location A has been Cleaned.")  
  
        if status_input_complement == '1':  
            print("Location B is Dirty.")  
            print("Moving right to the Location B.")  
            cost += 1  
            print("COST for moving RIGHT " + str(cost))  
            goal_state['B'] = '0'  
            cost += 1  
            print("COST for SUCK " + str(cost))
```



```

        print("Location B has been Cleaned.")
    else:
        print("No action " + str(cost))
        print("Location B is already clean.")

if status_input == '0':
    print("Location A is already clean")
    if status_input_complement == '1':
        print("Location B is Dirty.")
        print("Moving RIGHT to the Location B.")
        cost += 1
        print("COST for moving RIGHT " + str(cost))
        goal_state['B'] = '0'
        cost += 1
        print("Cost for SUCK " + str(cost))
        print("Location B has been Cleaned.")
    else:
        print("No action " + str(cost))
        print("Location B is already clean.")

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

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

```

```

        print("Location A is already clean.")

    if status_input_complement == '1':
        print("Location A is Dirty.")
        print("Moving LEFT to the Location A.")
        cost += 1
        print("COST for moving LEFT " + str(cost))
        goal_state['A'] = '0'
        cost += 1
        print("Cost for SUCK " + str(cost))
        print("Location A has been Cleaned.")
    else:
        print("No action " + str(cost))
        print("Location A is already clean.")

print("GOAL STATE: ")
print(goal_state)
print("Performance Measurement: " + str(cost))

vacuum_world()

```

Output:

```

Python 3.11.9 (tags/v3.11.9:de54cf5, Apr  2 2024
Type "help", "copyright", "credits" or "license(
=====
Enter Location of Vacuum: A
Enter status of A : 0
Enter status of other room : 1
Initial Location Condition {A : 1, B : 0 }
Vacuum is placed in Location A
Location A is already clean
Location B is Dirty.
Moving RIGHT to the Location B.
COST for moving RIGHT 1
Cost for SUCK 2
Location B has been Cleaned.
GOAL STATE:
{'A': '0', 'B': '0'}
Performance Measurement: 2

```

Iterative Deepening Depth First Search

Pseudocode:

Bajna Group
Date: Page:

1. DDFS Algorithm

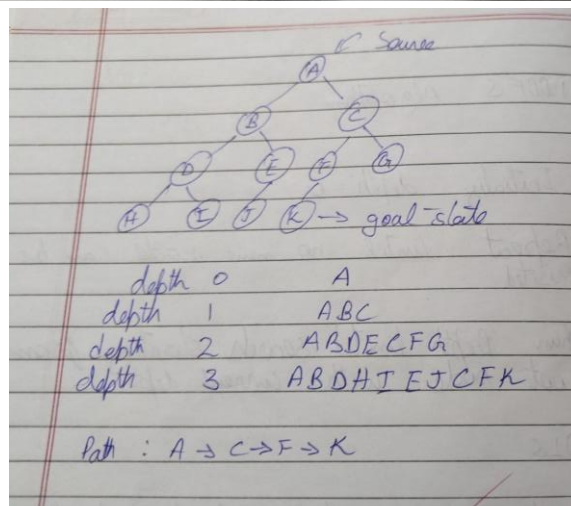
1. Initialize depth = 0
2. Repeat until no more nodes can be visited
3. Run Depth limited search starting from root node with current depth

DLS

1. Visit current node, if it is target return success and the path
2. if depth = 0, stop exploring
3. else for each neighbour of the current node, call DLS recursively with depth + 1

If target found, stop algorithm.
else repeat by increasing depth by 1

~~Search~~
~~status~~



8 Puzzle using IDDFS

Pseudocode:

Bafna Gold
Date: Page:

IDDFS

8-puzzle problem with misplaced tiles.

1. Represent puzzle state
 - use a tuple to represent the beginning configuration.
 - Track position of blank tile.
- Set depth limit = 0
- Increase depth limit until goal is found.
- Perform DLS
- For each state:
 - check if it matches the goal, return solution path.
 - If depth limit is reached, stop exploring.
 - generate all valid moves by sliding the blank tile (up, down, left, right).
 - apply each move to create a new state.
 - Recursively search from new state, reducing depth limit by 1.
5. ~~Keep track of visited states in current path to avoid cycles.~~
6. If no solution is found, increase the depth limit and repeat the search.

Code:

```
from copy import deepcopy
```

```
class Puzzle:
```

```
    def __init__(self, board, goal):
        self.board = board
        self.goal = goal
        self.size = 3
```

```
    def find_blank(self, state):
        for i in range(self.size):
            for j in range(self.size):
                if state[i][j] == 0:
                    return i, j
```

```
    def is_goal(self, state):
        return state == self.goal
```

```
    def get_moves(self, state):
        x, y = self.find_blank(state)
        moves = []
        directions = [(-1,0),(1,0),(0,-1),(0,1)]
        for dx, dy in directions:
            nx, ny = x+dx, y+dy
            if 0 <= nx < self.size and 0 <= ny < self.size:
                new_state = deepcopy(state)
                new_state[x][y], new_state[nx][ny] = new_state[nx][ny], new_state[x][y]
                moves.append(new_state)
        return moves
```

```
    def dls(self, state, depth, path, visited):
        if self.is_goal(state):
            return path + [state]
        if depth == 0:
            return None
        visited.append(state)
        for move in self.get_moves(state):
            if move not in visited:
                new_path = self.dls(move, depth - 1, path + [state], visited)
                if new_path:
```

```

        return new_path
    return None

def iddfs(self, start):
    depth = 0
    while True:
        visited = []
        result = self.dls(start, depth, [], visited)
        if result:
            return result
        depth += 1

def input_state(prompt):
    print(prompt)
    state = []
    for _ in range(3):
        row = list(map(int, input().split()))
        state.append(row)
    return state

start = input_state("Enter the initial state row-wise (use 0 for blank):")
goal = input_state("Enter the goal state row-wise (use 0 for blank):")

puzzle = Puzzle(start, goal)
path = puzzle.iddfs(start)

print("\nTotal moves:", len(path)-1)
for step, state in enumerate(path):
    print(f"\nMove {step}:")
    for row in state:
        print(*row)

```

Output:

Enter the initial state row-wise (use 0 for blank):

1 2 3

0 4 6

7 5 8

Enter the goal state row-wise (use 0 for blank):

1 2 3

4 5 6

7 8 0

Total moves: 3

Move 0:

1 2 3

0 4 6

7 5 8

Move 1:

1 2 3

4 0 6

7 5 8

Move 2:

1 2 3

4 5 6

7 0 8

Move 3:

1 2 3

4 5 6

7 8 0

|

8 Puzzle problem using A*

Pseudocode:

Q) 8 puzzle using A* algorithm

Astar function (start-state, goal-state)

if not is_reachable (start-state)
return "unsolvable"

start = start-state.key (start-state)
goal = goal-state.key (goal-state)

if start == goal key
~~return~~
return start key

g-score[start.key] = 0
f-score[start.key] = manhattan (start-key, goal-key)

open = priority queue
open.push (f-score, g-score, start-key)

closed = set()

while open is not empty:

```

for neighbour in neighbours:
    tentative_g = g.score.get(current, parent)

    close.add(neighbour.state)

    if tentative_g >= g.score.get(neighbour):
        continue

    if tentative_g < g.score.get(neighbour):
        g.score[current.key] = tentative_g

    f_score(current.key) = tentative_g
    + manhattan(neighbour.key)
    open.push(f_score, manhattan(current, key, goal key), current.key)

```

Code:

class Node:

```
def __init__(self, data, level, fval):
```

```
    self.data = data
```

```
    self.level = level
```

```
    self.fval = fval
```

```
def generate_child(self):
```

```
    x, y = self.find(self.data, '_')
```

```
    directions = [[x - 1, y], [x + 1, y], [x, y - 1], [x, y + 1]]
```

```
    children = []
```

```
    for i, j in directions:
```

```
        child = self.shuffle(self.data, x, y, i, j)
```

```
        if child is not None:
```

```
            child_node = Node(child, self.level + 1, 0)
```

```
            children.append(child_node)
```

```
    return children
```

```
def shuffle(self, puz, x1, y1, x2, y2):
```

```
    if 0 <= x2 < len(self.data) and 0 <= y2 < len(self.data):
```

```
        temp_puz = self.copy(puz)
```

```

        temp_puz[x1][y1], temp_puz[x2][y2] = temp_puz[x2][y2], temp_puz[x1][y1]
    return temp_puz
return None

def copy(self, root):
    return [row[:] for row in root]

def find(self, puz, x):
    for i in range(len(self.data)):
        for j in range(len(self.data)):
            if puz[i][j] == x:
                return i, j

class Puzzle:
    def __init__(self, size=3):
        self.n = size
        self.open = []
        self.closed = []

    def accept(self):
        puz = []
        for i in range(self.n):
            row = input().split()
            puz.append(row)
        return puz

    def f(self, start, goal):
        return self.h(start.data, goal) + start.level

    def h(self, start, goal):
        mismatch = 0
        for i in range(self.n):
            for j in range(self.n):
                if start[i][j] != goal[i][j] and start[i][j] != '_':
                    mismatch += 1
        return mismatch

    def process(self):
        print("Enter the start state matrix (use _ for blank):")

```

```

start = self.accept()
print("Enter the goal state matrix (use _ for blank):")
goal = self.accept()

start_node = Node(start, 0, 0)
start_node.fval = self.f(start_node, goal)
self.open.append(start_node)

print("\nSolving...\n")
move = 0
while True:
    cur = self.open[0]
    print(f"\nMove {move}:")
    for row in cur.data:
        print(' '.join(row))
    if self.h(cur.data, goal) == 0:
        print("\nGoal state reached!")
        break

    for child in cur.generate_child():
        child.fval = self.f(child, goal)
        self.open.append(child)

    self.closed.append(cur)
    del self.open[0]
    self.open.sort(key=lambda x: x.fval)
    move += 1

if __name__ == "__main__":
    Puzzle().process()

```

Output:

Enter the start state matrix (use _ for blank):

1 2 3

_ 4 6

7 5 8

Enter the goal state matrix (use _ for blank):

1 2 3

4 5 6

7 8 _

Solving...

Move 0:

1 2 3

_ 4 6

7 5 8

Move 1:

1 2 3

4 _ 6

7 5 8

Move 2:

1 2 3

4 5 6

7 _ 8

Move 3:

1 2 3

4 5 6

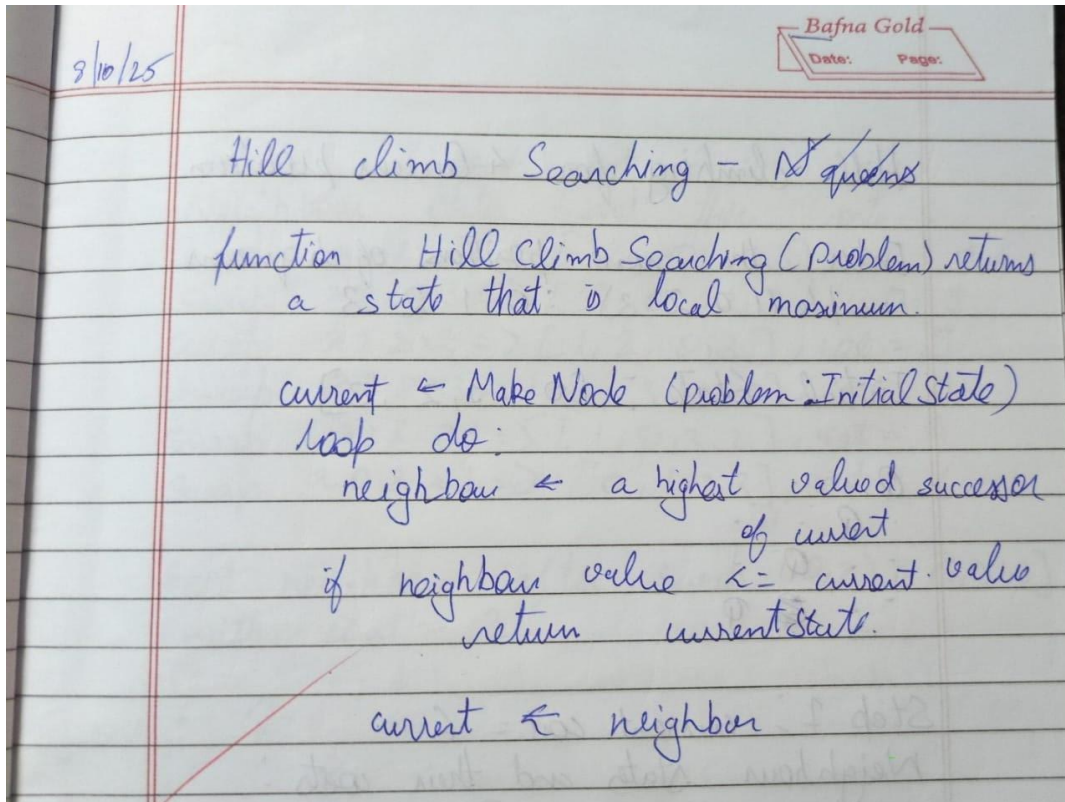
7 8 _

Goal state reached!

|

Hill Climb Searching

Pseudocode:



N queens using Hill Climb Searching:

Code:

```
def print_board(state):  
    """Prints the 4x4 board representation with 'Q' and '.'."""  
    n = len(state)  
    for row in range(n):  
        for col in range(n):  
            if state[col] == row:  
                print("Q", end=" ")  
            else:  
                print(".", end=" ")  
        print()  
    print()
```

```
def calculate_cost(state):  
    """Returns number of attacking pairs of queens."""
```

```

cost = 0
n = len(state)
for i in range(n):
    for j in range(i + 1, n):
        # same row
        if state[i] == state[j]:
            cost += 1
        # same diagonal
        elif abs(state[i] - state[j]) == abs(i - j):
            cost += 1
return cost

```

```

def get_neighbors(state):
    """Generates all neighbors by swapping two queen positions."""
    neighbors = []
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            neighbor = state.copy()
            neighbor[i], neighbor[j] = neighbor[j], neighbor[i]
            neighbors.append((neighbor, (i, j)))
    return neighbors

```

```

def hill_climbing(state):
    print("\nInitial State:", state)
    print_board(state)
    current_cost = calculate_cost(state)
    step = 1

    while True:
        print(f'Step {step}: Current cost = {current_cost}')
        neighbors = get_neighbors(state)
        neighbor_costs = []

        # Calculate cost for all neighbors
        for neighbor, swapped in neighbors:
            cost = calculate_cost(neighbor)
            neighbor_costs.append((cost, neighbor, swapped))

```



```

# Sort by cost and then by smallest column pair as per rules
neighbor_costs.sort(key=lambda x: (x[0], x[2][0], x[2][1]))

# Display neighbor costs
print("Neighbor states and their costs:")
for cost, neighbor, swapped in neighbor_costs:
    print(f'Swap x {swapped[0]} & x {swapped[1]} => {neighbor}, Cost = {cost}')

best_cost, best_state, swap = neighbor_costs[0]
print("\nBest Neighbor after swap", swap, "is", best_state, "with cost =", best_cost)
print_board(best_state)

if best_cost >= current_cost: # No improvement (local minimum)
    print("No better neighbor found. Hill Climbing terminated.")
    print("Final state:", state)
    print_board(state)
    break
else:
    state = best_state
    current_cost = best_cost

if current_cost == 0:
    print("Goal state reached!")
    print_board(state)
    break

step += 1

# ----- MAIN -----
if __name__ == "__main__":
    print("Hill Climbing for 4-Queens Problem")
    print("Enter the row positions of 4 queens (each between 0 and 3):")
    state = list(map(int, input("Example (1 2 0 3): ").split()))
    hill_climbing(state)

```

Output:

```
Hill Climbing for 4-Queens Problem
Enter the row positions of 4 queens (each between 0 and 3):
Example (1 2 0 3): 0 1 2 3

Initial State: [0, 1, 2, 3]
Q . . .
. Q . .
. . Q .
. . . Q

Step 1: Current cost = 6
Neighbor states and their costs:
Swap x0 & x1 => [1, 0, 2, 3], Cost = 2
Swap x0 & x3 => [3, 1, 2, 0], Cost = 2
Swap x1 & x2 => [0, 2, 1, 3], Cost = 2
Swap x2 & x3 => [0, 1, 3, 2], Cost = 2
Swap x0 & x2 => [2, 1, 0, 3], Cost = 4
Swap x1 & x3 => [0, 3, 2, 1], Cost = 4

Best Neighbor after swap (0, 1) is [1, 0, 2, 3] with cost = 2
. Q . .
Q . . .
. . Q .
. . . Q

Step 2: Current cost = 2
Neighbor states and their costs:
Swap x0 & x2 => [2, 0, 1, 3], Cost = 1
Swap x0 & x3 => [3, 0, 2, 1], Cost = 1
Swap x1 & x2 => [1, 2, 0, 3], Cost = 1
Swap x1 & x3 => [1, 3, 2, 0], Cost = 1
Swap x2 & x3 => [1, 0, 3, 2], Cost = 4
Swap x0 & x1 => [0, 1, 2, 3], Cost = 6

Best Neighbor after swap (0, 2) is [2, 0, 1, 3] with cost = 1
. Q . .
. . Q .
Q . . .
. . . Q

Step 3: Current cost = 1
Neighbor states and their costs:
Swap x2 & x3 => [2, 0, 3, 1], Cost = 0
Swap x0 & x1 => [0, 2, 1, 3], Cost = 2
Swap x0 & x2 => [1, 0, 2, 3], Cost = 2
Swap x1 & x3 => [2, 3, 1, 0], Cost = 2
Swap x0 & x3 => [3, 0, 1, 2], Cost = 4
Swap x1 & x2 => [2, 1, 0, 3], Cost = 4

Best Neighbor after swap (2, 3) is [2, 0, 3, 1] with cost = 0
```

Best Neighbor after swap (2, 3) is [2, 0, 3, 1] with cost = 0

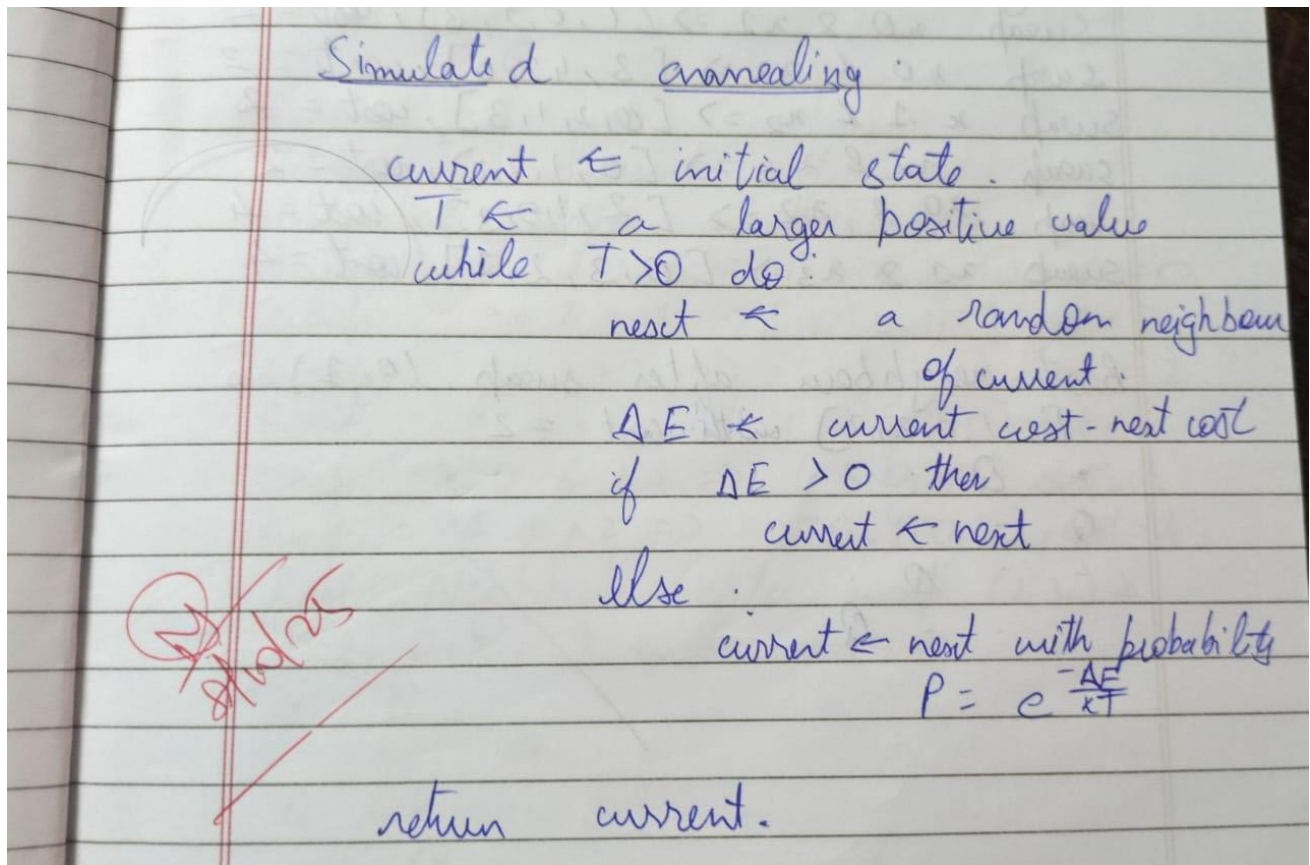
```
. Q . .  
. . . Q  
Q . . .  
. . Q .
```

Goal state reached!

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

Simulated Annealing

Pseudocode:



N Queens using Simulated Annealing

Pseudocode:

import random

import math

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

```

print()

def calculate_cost(state):
    cost = 0
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                cost += 1
    return cost

def get_all_neighbors(state):
    neighbors = []
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            neighbor = state.copy()
            neighbor[i], neighbor[j] = neighbor[j], neighbor[i]
            neighbors.append((neighbor, (i, j)))
    return neighbors

def hill_climbing(state):
    print("\n--- Starting Hill Climbing ---")
    current_state = state.copy()
    current_cost = calculate_cost(current_state)
    step = 1

    print("Initial State:", current_state, "with Cost:", current_cost)
    print_board(current_state)

    while True:
        print(f"--- Step {step} ---")
        neighbors = get_all_neighbors(current_state)
        neighbor_costs = []

        for neighbor, swapped in neighbors:
            cost = calculate_cost(neighbor)
            neighbor_costs.append((cost, neighbor, swapped))

        neighbor_costs.sort(key=lambda x: (x[0], x[2][0], x[2][1]))

```

```

best_cost, best_neighbor, best_swap = neighbor_costs[0]

print(f'Current State: {current_state}, Cost: {current_cost}')
print(f'Best neighbor is {best_neighbor} with cost {best_cost} (Swap columns
{best_swap[0]} & {best_swap[1]})')

if best_cost >= current_cost:
    print("\nNo better neighbor found. Reached a local minimum or plateau.")
    print("Final State:", current_state)
    print_board(current_state)
    print("Final Cost:", current_cost)
    break

current_state = best_neighbor
current_cost = best_cost
print_board(current_state)

if current_cost == 0:
    print("\nGoal state reached!")
    print("Final State:", current_state)
    print_board(current_state)
    print("Final Cost:", current_cost)
    break

step += 1

def get_random_neighbor(state):
    n = len(state)
    neighbor = state.copy()
    i, j = random.sample(range(n), 2)
    neighbor[i], neighbor[j] = neighbor[j], neighbor[i]
    return neighbor

def simulated_annealing(state, initial_temp=100.0, cooling_rate=0.95, max_steps=1000):
    print("\n--- Starting Simulated Annealing ---")
    current_state = state.copy()
    current_cost = calculate_cost(current_state)
    temp = initial_temp

```

```

print("Initial State:", current_state, "with Cost:", current_cost)
print_board(current_state)

for step in range(max_steps):
    if temp < 0.01:
        print("\nTemperature cooled down. Algorithm terminated.")
        break

    if current_cost == 0:
        print(f"\nGoal state reached in {step+1} steps!")
        break

    neighbor_state = get_random_neighbor(current_state)
    neighbor_cost = calculate_cost(neighbor_state)
    delta_cost = neighbor_cost - current_cost

    if delta_cost < 0:
        print(f'Step {step+1}: Good move. Moved to {neighbor_state} (Cost: {neighbor_cost})')
        current_state = neighbor_state
        current_cost = neighbor_cost
    else:
        acceptance_prob = math.exp(-delta_cost / temp)
        if random.random() < acceptance_prob:
            print(f'Step {step+1}: Bad move accepted! Moved to {neighbor_state} (Cost:
{neighbor_cost}) with prob {acceptance_prob:.2f}')
            current_state = neighbor_state
            current_cost = neighbor_cost
        else:
            print(f'Step {step+1}: Bad move rejected. Staying at {current_state} (Cost:
{current_cost})')

    temp *= cooling_rate

print("\nFinal State:", current_state)
print_board(current_state)
print("Final Cost:", current_cost)

if __name__ == "__main__":
    print("--- 4-Queens Problem Solver ---")
    print("The state is a list of 4 numbers representing the row of the queen in each column.")

```



```
print("Example: 1 3 0 2 means -> Q in col 0 row 1, col 1 row 3, col 2 row 0, col 3 row 2\n")
```

```
try:
```

```
    initial_state = list(map(int, input("Enter the initial state (e.g., 2 0 3 1): ").split()))
```

```
    if len(initial_state) != 4 or not all(0 <= x <= 3 for x in initial_state):
```

```
        print("Invalid input. Please enter 4 numbers between 0 and 3.")
```

```
    else:
```

```
        simulated_annealing(initial_state)
```

```
except ValueError:
```

```
    print("Invalid input format. Please enter numbers separated by spaces.")
```

Output:

```
Enter the initial state (e.g., 2 0 3 1): 0 1 2 3

--- Starting Simulated Annealing ---
Initial State: [0, 1, 2, 3] with Cost: 6
Board State:
Q . . .
. Q . .
. . Q .
. . . Q

Step 1: Good move. Moved to [0, 1, 3, 2] (Cost: 2)
Step 2: Bad move accepted! Moved to [1, 0, 3, 2] (Cost: 4) with prob 0.98
Step 3: Bad move accepted! Moved to [3, 0, 1, 2] (Cost: 4) with prob 1.00
Step 4: Good move. Moved to [3, 1, 0, 2] (Cost: 1)
Step 5: Bad move accepted! Moved to [3, 2, 0, 1] (Cost: 2) with prob 0.99
Step 6: Good move. Moved to [3, 1, 0, 2] (Cost: 1)
Step 7: Bad move accepted! Moved to [3, 2, 0, 1] (Cost: 2) with prob 0.99
Step 8: Good move. Moved to [0, 2, 3, 1] (Cost: 1)
Step 9: Bad move accepted! Moved to [3, 2, 0, 1] (Cost: 2) with prob 0.99
Step 10: Good move. Moved to [3, 1, 0, 2] (Cost: 1)
Step 11: Bad move accepted! Moved to [3, 0, 1, 2] (Cost: 4) with prob 0.95
Step 12: Bad move accepted! Moved to [3, 2, 1, 0] (Cost: 6) with prob 0.97
Step 13: Good move. Moved to [3, 0, 1, 2] (Cost: 4)
Step 14: Good move. Moved to [3, 1, 0, 2] (Cost: 1)
Step 15: Bad move accepted! Moved to [3, 1, 2, 0] (Cost: 2) with prob 0.98
Step 16: Bad move accepted! Moved to [3, 2, 1, 0] (Cost: 6) with prob 0.92
Step 17: Good move. Moved to [3, 2, 0, 1] (Cost: 2)
Step 18: Bad move accepted! Moved to [2, 3, 0, 1] (Cost: 4) with prob 0.95
Step 19: Bad move accepted! Moved to [2, 1, 0, 3] (Cost: 4) with prob 1.00
Step 20: Good move. Moved to [1, 2, 0, 3] (Cost: 1)
Step 21: Bad move accepted! Moved to [1, 0, 2, 3] (Cost: 2) with prob 0.97
Step 22: Bad move accepted! Moved to [0, 1, 2, 3] (Cost: 6) with prob 0.89
Step 23: Good move. Moved to [1, 0, 2, 3] (Cost: 2)
Step 24: Good move. Moved to [1, 2, 0, 3] (Cost: 1)
Step 25: Good move. Moved to [1, 3, 0, 2] (Cost: 0)

Goal state reached in 26 steps!

Final State: [1, 3, 0, 2]
Board State:
. . Q .
Q . . .
. . . Q
. Q . .

Final Cost: 0
|
```

Propositional Logic

Pseudocode:

15/10/25

Bafna Gold
Date: Page:

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

function TT-Entails?(KB, α) return true or false

inputs: KB, the knowledge base, a sentence in propositional logic.
 α , the query, a sentence in propositional logic.

symbols \leftarrow a list of the propositional symbols in KB and α .

return TT-CHECK-ALL(KB, α , symbols, $\{ \}$)

function TT-CHECK-ALL(KB, α , symbols, model)

returns true or false.

if EMPTY?(symbols) then

if PL-TRUE?(KB, model) then return PL-TRUE?(α , model)

else return true.

else do

P \leftarrow FIRST(symbols)

rest \leftarrow REST(symbols)

return (TT-CHECK-ALL(KB, α , rest, model \cup {P = true})

and

TT-CHECK-ALL(KB, α , rest, model \cup {P = false}))

Code:

```
import itertools
import pandas as pd

# Define the propositional logic sentences
variables = ['P', 'Q', 'R']

def q_implies_p(p, q, r):
    return not q or p

def p_implies_not_q(p, q, r):
    return not p or not q

def q_or_r(p, q, r):
    return q or r

sentences = {
    'Q implies P': q_implies_p,
    'P implies not(Q)': p_implies_not_q,
    'Q or R': q_or_r
}

# Generate a truth table
truth_values = [True, False]
combinations = list(itertools.product(truth_values, repeat=len(variables)))

truth_table_data = []
for combination in combinations:
    p, q, r = combination
    row = {'P': p, 'Q': q, 'R': r}
    for sentence_name, sentence_func in sentences.items():
        row[sentence_name] = sentence_func(p, q, r)
    truth_table_data.append(row)

# Convert the list of dictionaries to a pandas DataFrame for better visualization
truth_table_df = pd.DataFrame(truth_table_data)
```

```

# Evaluate the knowledge base (KB)
sentence_columns = list(sentences.keys())
truth_table_df['KB is True'] = truth_table_df[sentence_columns].all(axis=1)

models = truth_table_df[truth_table_df['KB is True']]

# Check for entailment
kb_entails_r = models['R'].all()
kb_entails_r_implies_p = (models['R'].apply(lambda x: not x) | models['P']).all()
kb_entails_q_implies_r = (models['Q'].apply(lambda x: not x) | models['R']).all()

# Display the results
print("Truth Table:")
display(truth_table_df)

print("\nModels where KB is True:")
display(models)

print("\nEntailment Results:")
print(f'KB entails R: {kb_entails_r}')
print(f'KB entails R implies P: {kb_entails_r_implies_p}')
print(f'KB entails Q implies R: {kb_entails_q_implies_r}')

```

Output:



Truth Table:

	P	Q	R	Q implies P	P implies not(Q)	Q or R	KB is True
0	True	True	True	True	False	True	False
1	True	True	False	True	False	True	False
2	True	False	True	True	True	True	True
3	True	False	False	True	True	False	False
4	False	True	True	False	True	True	False
5	False	True	False	False	True	True	False
6	False	False	True	True	True	True	True
7	False	False	False	True	True	False	False



Models where KB is True:

	P	Q	R	Q implies P	P implies not(Q)	Q or R	KB is True
2	True	False	True	True	True	True	True
6	False	False	True	True	True	True	True



Entailment Results:

KB entails R: True

KB entails R implies P: False

KB entails Q implies R: True

Unification

Pseudocode:

Bafna Gold
Date: Page:

Implementing Unification in First order logic

Unify(ψ_1, ψ_2)

Step 1: If ψ_1 or ψ_2 is a variable or constant then:

- (a) If ψ_1, ψ_2 are identical, then return NIL
- (b) Else if ψ_1 is a variable,
 - (a) then if ψ_1 occurs in ψ_2 , then return Failure
 - (b) Else return $\{(\psi_2/\psi_1)\}$.
- (c) Else if ψ_2 is a variable,
 - (a) If ψ_2 occurs in ψ_1 then return failure
 - (b) Else return $\{(\psi_1/\psi_2)\}$
 - (c) Else return Failure

Step 2: If the initial Predicate symbol in ψ_1 and ψ_2 are not same, then return FAILURE

Step 3: IF ψ_1 and ψ_2 have a different number of arguments, then return FAILURE.

Step 4: Set Substitution set (SUBST) to NIL.

Step 5: For $i = 1$ to the number of elements in ψ_1 ,

- (a) call Unify function with the i th element of ψ_1 with i th element of ψ_2 and put the result into S.
- (b) If S = failure then return Failure.
- (c) If $S \neq \text{NIL}$ then do,
 - a) apply S to the remainder of both L_1 and L_2 .
 - b) SUBST = APPEND(S, SUBST)

Step 6: Return SUBST

Code:

```
import re
```

```
# Utility: parse the expression into function/operator and arguments
```

```
def parse(expr):
```

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

```
    if '(' not in expr:
```

```
        return expr, []
```

```
    func = expr[:expr.index('(')].strip()
```

```
    args = expr[expr.index('(')+1:-1]
```

```
    args = [a.strip() for a in split_args(args)]
```

```
    return func, args
```

```
# Split arguments correctly (handles nested brackets)
```

```
def split_args(args_str):
```

```
    args, level, start = [], 0, 0
```

```
    for i, ch in enumerate(args_str):
```

```
        if ch == ',' and level == 0:
```

```
            args.append(args_str[start:i].strip())
```

```
            start = i + 1
```

```
        elif ch == '(':
```

```
            level += 1
```

```
        elif ch == ')':
```

```
            level -= 1
```

```
    args.append(args_str[start:].strip())
```

```
    return args
```

```
# Apply substitution to an expression
```

```
def substitute(expr, subs):
```

```
    for var, val in subs.items():
```

```
        expr = re.sub(rf'\b{var}\b', val, expr)
```

```
    return expr
```

```
# Check if variable occurs inside term (Occurs check)
```

```
def occurs_check(var, term):
```

```
    if var == term:
```

```
        return True
```

```
    if '(' not in term:
```

```
        return False
```



```

_, args = parse(term)
return any(occurs_check(var, arg) for arg in args)

# Unification algorithm
def unify(e1, e2, subs=None):
    if subs is None:
        subs = {}

    e1 = substitute(e1, subs)
    e2 = substitute(e2, subs)

    if e1 == e2:
        return subs

    f1, args1 = parse(e1)
    f2, args2 = parse(e2)

    # Case 1: Both are compound terms
    if args1 and args2:
        if f1 != f2 or len(args1) != len(args2):
            print(f'Function symbols or arity mismatch: {f1} vs {f2}')
            return None
        for a1, a2 in zip(args1, args2):
            subs = unify(a1, a2, subs)
            if subs is None:
                return None
        return subs

    # Case 2: Variable binding
    elif e1.islower() and e1.isalpha(): # e1 is variable
        if occurs_check(e1, e2):
            print(f'Occurs check failed: {e1} occurs in {e2}')
            return None
        subs[e1] = e2
        return subs
    elif e2.islower() and e2.isalpha(): # e2 is variable
        if occurs_check(e2, e1):
            print(f'Occurs check failed: {e2} occurs in {e1}')
            return None
        subs[e2] = e1

```

```

        return subs

# Otherwise mismatch
else:
    print(f" Cannot unify {e1} with {e2}")
    return None

# --- MAIN PROGRAM ---
print("=== Unification Algorithm ===")
expr1 = input("Enter first expression: ").strip()
expr2 = input("Enter second expression: ").strip()

result = unify(expr1, expr2)

if result:
    print("\n Unification Successful!")
    print("Substitutions:")
    for k, v in result.items():
        print(f" {k} / {v}")
else:
    print("\n Unification Failed.")

```

Output:

Python 3.11.9 (tags/v3.11.9:de54cf5, Apr 2 2024, 10:12:12) [MSC v.1938 64 bit (AMD64)] on win32

Type "help", "copyright", "credits" or "license()" for more information.

= RESTART: D:\desktop data\AI Lab programs.py

=== Unification Algorithm ===

Enter first expression: $P(f(x), g(y), y)$

Enter second expression: $P(f(g(z)), g(f(a)), f(a))$

☒ Unification Successful!

Substitutions:

$x / g(z)$

$y / f(a)$

===== RESTART: D:\desktop data\AI Lab programs.py =====

=== Unification Algorithm ===

Enter first expression: $Q(x, f(x))$

Enter second expression: $Q(f(y), y)$

☒ Occurs check failed: y occurs in $f(f(y))$

☒ Unification Failed.

===== RESTART: D:\desktop data\AI Lab programs.py =====

=== Unification Algorithm ===

Enter first expression: $H(x, g(x))$

Enter second expression: $H(g(y), g(g(z)))$

☒ Unification Successful!

Substitutions:

Forward Reasoning

Pseudocode:

```
function FOL-FC-ASK (KB,  $\alpha$ ) return a
Substitution or false

inputs : KB,  $\alpha$ , the query, atomic sentences
local variables: new, the new sentences inferred
on each iteration.

repeat until new is empty
  new  $\leftarrow \{\}$ 
  for each rule in KB do
     $[P_1 \wedge \dots \wedge P_n \Rightarrow Q] \leftarrow \text{STANDARDIZE -}$ 
     $\text{VARIABLES}(\text{rule})$ 
    for each  $\theta$  such that  $\text{SUBST}(\theta,$ 
     $P_1 \wedge \dots \wedge P_n) = \text{SUBST}(\theta, P'_1 \wedge \dots \wedge P'_n)$  for
    some  $P'_1 \dots P'_n$  in KB
       $Q' \leftarrow \text{SUBST}(\theta, Q)$ 
      if  $Q'$  does not unify with some
      sentence already in KB or new then
        add  $Q'$  to new
         $\phi \leftarrow \text{UNIFY}(Q', \alpha)$ 
        if  $\phi$  is not fail then return  $\phi$ 

  add new to KB
return false.
```

Code:
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-z~]+\)(\[^\&]+\)'
    return re.findall(expr, string)

class Fact:
    def __init__(self, expression):
        self.expression = expression
        predicate, params = self.splitExpression(expression)
        self.predicate = predicate
        self.params = params
        self.result = any(self.getConstants())

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

    def getResult(self):
        return self.result

    def getConstants(self):
        return [None if isVariable(c) else c for c in self.params]

    def getVariables(self):
        return [v if isVariable(v) else None for v in self.params]

    def substitute(self, constants):
        constants_copy = constants.copy()
        expr = f'{self.predicate}({',''.join([constants_copy.pop(0) if isVariable(p) else p for p in self.params])})'
        return Fact(expr)

```

```

class Implication:
    def __init__(self, expression):
        self.expression = expression
        l = expression.split('=>')
        self.lhs = [Fact(f) for f in l[0].split('&')]
        self.rhs = Fact(l[1])

    def evaluate(self, facts):
        constants = {}
        new_lhs = []
        for fact in facts:
            for val in self.lhs:
                if val.predicate == fact.predicate:
                    for i, v in enumerate(val.getVariables()):
                        if v:
                            constants[v] = fact.getConstants()[i]
                    new_lhs.append(fact)

        predicate = getPredicates(self.rhs.expression)[0]
        attributes = str(getAttributes(self.rhs.expression)[0])

        for key in constants:
            if constants[key]:
                attributes = attributes.replace(key, constants[key])

        expr = f'{predicate} {attributes}'
        return Fact(expr) if len(new_lhs) and all([f.getResult() for f in new_lhs]) else None

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

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

```

```

        res = i.evaluate(self.facts)
        if res:
            self.facts.add(res)

def ask(self, e):
    facts = set([f.expression for f in self.facts])
    print(f'\nQuerying {e}:')
    i = 1
    found = False
    for f in facts:
        if Fact(f).predicate == Fact(e).predicate:
            print(f'\t{i}. {f}')
            i += 1
            found = True
    if not found:
        print("\tNo matching facts found.")

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

def main():
    kb = KB()
    print("Enter the number of FOL expressions present in KB:")
    n = int(input())
    print("Enter the expressions:")
    for i in range(n):
        fact = input().strip()
        kb.tell(fact)

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

if __name__ == "__main__":
    main()

```

Output:

Enter the number of FOL expressions present in KB:

4

Enter the expressions:

LivingThing(Deer)

LivingThing(Tiger)

Eats(Tiger, Deer)

$\text{Eats}(x, y) \wedge \text{LivingThing}(x) \wedge \text{LivingThing}(y) \Rightarrow \text{Predator}(x)$

Enter the query:

Predator(Tiger)

Querying Predator(Tiger):

1. redator(Tiger)

All facts:

1. LivingThing(Tiger)

2. LivingThing(Deer)

3. redator(Tiger)

4. Eats(Tiger, Deer)

|

Resolution

Pseudocode:

Bafna Gold
Date: Page:

Resolution in FOL

Steps for proving a conclusion S given premises

1. Convert all sentences to CNF
2. Negate conclusion S & convert result to CNF
3. Add negated conclusion S to the premise clauses.
4. Repeat until contradiction or no progress is made:
 - a. Select 2 clauses (call them parent clauses)
 - b. Resolve them together, performing all required unification.
 - c. If resolvent is the empty clause, a contradiction has been found (i.e. S follows from the premises)
 - d. If not add resolvent to the premises

If we succeeded in Step 4, we have proved the conclusion.

Code:

```
def parse_clause(clause_str):
    return set(clause_str.split('v'))

def get_complement(literal):
    return literal[1:] if literal.startswith('~') else '~' + literal

def resolve(ci, cj):
    resolvents = set()
    for literal in ci:
        complement = get_complement(literal)
        if complement in cj:
            new_clause = (ci - {literal}) | (cj - {complement})
            resolvents.add(frozenset(new_clause))
    return resolvents

def resolution(kb_clauses, query):
    negated_query = get_complement(query)
    kb = [parse_clause(clause) for clause in kb_clauses] + [parse_clause(negated_query)]

    print("\n-----")
    print("KnowledgeBase - Resolution")
    print("-----")
    print(f"\nKnowledge Base Clauses: {kb_clauses}")
    print(f"Query: {query}")
    print(f"Negated Query Added: {negated_query}")
    print("\nResolution Steps:\n")

    new = set()

    while True:
        pairs = [(kb[i], kb[j]) for i in range(len(kb)) for j in range(i + 1, len(kb))]
        for (ci, cj) in pairs:
            resolvents = resolve(ci, cj)
            for resolvent in resolvents:
                print(f'Resolving {set(ci)} and {set(cj)} => {set(resolvent)}')
                if not resolvent:
```

```

        print("\n Knowledge Base entails the query (empty clause derived).")
        return True
    new.add(resolvent)

if new.issubset(set(map(frozenset, kb))):
    print("\n Knowledge Base does NOT entail the query (no empty clause derived).")
    return False

for clause in new:
    if clause not in kb:
        kb.append(clause)

print("KnowledgeBase - Resolution")
print("-----")
print("Enter clauses for the Knowledge Base.")
print("Use 'v' for OR between literals (e.g., '~qv~pvr'), and separate each clause with a space.\n")

kb_input = input("Enter clauses: ").split()
query_input = input("Enter the query: ")

resolution(kb_input, query_input)

```

Output:

```

KnowledgeBase - Resolution
-----
Enter clauses for the Knowledge Base.
Use 'v' for OR between literals (e.g., '~qv~pvr'), and separate each clause with
a space.

Enter clauses: (~q v ~p v r) ^ (~q ^ p) ^ q
Enter the query: r

-----
KnowledgeBase - Resolution
-----

Knowledge Base Clauses: ['(~q', 'v', '~p', 'v', 'r)', '^', '(~q', '^', 'p)', '^',
, 'q']
Query: r
Negated Query Added: ~r

Resolution Steps:

Knowledge Base does NOT entail the query (no empty clause derived).
|

```

Alpha Beta Pruning

Pseudocode:

Alpha-Beta pruning

function Alpha-Beta-search (state) returns an action
 $v \leftarrow \text{MAX-VALUE}(\text{state}, -\infty, +\infty)$
 return the action in ACTIONS (state) with value v .

function MAX-VALUE (state, α , β) returns a utility value
 if TERMINAL-TEST (state) then return UTILITY (state)
 $v \leftarrow -\infty$
 for each a in ACTIONS (state) do
 $v \leftarrow \text{MAX}(v, \text{MIN-VALUE}(\text{Result}(s, a), \beta))$
 if $v \geq \beta$ then return v
 $\alpha \leftarrow \text{MAX}(\alpha, v)$
 return v

function MIN-VALUE (state, α , β) returns a utility value
 if TERMINAL-TEST (state) then return UTILITY (state)
 $v \leftarrow \infty$
 for each a in ACTIONS (state) do
 $v \leftarrow \text{MIN}(v, \text{MAX-VALUE}(\text{Result}(s, a), \alpha, \beta))$
 if $v \leq \alpha$ then return v
 $\beta \leftarrow \text{MIN}(\beta, v)$
 return v

Tic Tac Toe using Alpha Beta

Code:

```
import math
import random

# Use an external "real" board only for the main game loop; recursive functions use state
parameters.
board = [" " for _ in range(9)] # 3x3 board

def print_board(state):
    print("\n")
    for i in range(3):
        print(" " + " | ".join(state[i*3:(i+1)*3]))
        if i < 2:
            print("---+---+---")
    print("\n")

def is_winner(state, player):
    win_combinations = [
        [0, 1, 2], [3, 4, 5], [6, 7, 8],
        [0, 3, 6], [1, 4, 7], [2, 5, 8],
        [0, 4, 8], [2, 4, 6]
    ]
    return any(all(state[i] == player for i in combo) for combo in win_combinations)

def is_full(state):
    return " " not in state

def actions(state):
    return [i for i in range(9) if state[i] == " "]

def result(state, action, player):
    new_state = state.copy()
    new_state[action] = player
    return new_state

def utility(state):
    if is_winner(state, "O"):
        return +1
    elif is_winner(state, "X"):
```

```

        return -1
    else:
        return 0

def terminal_test(state):
    return is_winner(state, "X") or is_winner(state, "O") or is_full(state)

# --- Alpha-Beta Functions ---
def max_value(state, alpha, beta):
    if terminal_test(state):
        return utility(state)
    v = -math.inf
    for a in actions(state):
        v = max(v, min_value(result(state, a, "O"), alpha, beta))
        if v >= beta:
            return v
    alpha = max(alpha, v)
    return v

def min_value(state, alpha, beta):
    if terminal_test(state):
        return utility(state)
    v = math.inf
    for a in actions(state):
        v = min(v, max_value(result(state, a, "X"), alpha, beta))
        if v <= alpha:
            return v
    beta = min(beta, v)
    return v

def alpha_beta_search(state):
    best_score = -math.inf
    best_action = None
    if not actions(state):
        return None
    for a in actions(state):
        value = min_value(result(state, a, "O"), -math.inf, math.inf)
        if value > best_score:
            best_score = value
            best_action = a

```

```

# Fallback: if something goes wrong, return a random legal move
if best_action is None:
    legal = actions(state)
    return random.choice(legal) if legal else None
return best_action

# --- Game Loop ---
def human_move():
    while True:
        try:
            move = int(input("Enter your move (1-9): ")) - 1
        except ValueError:
            print("Please enter a number 1-9.")
            continue
        if move < 0 or move > 8:
            print("Move out of range. Choose 1-9.")
            continue
        if board[move] != " ":
            print("Cell already taken. Try another.")
            continue
        return move

def choose_first():
    while True:
        ans = input("Who goes first? (me/ai) [me]: ").strip().lower()
        if ans == "" or ans.startswith("m"):
            return "me"
        if ans.startswith("a"):
            return "ai"
        print("Type 'me' or 'ai' (or press Enter for me).")

def main():
    global board
    board = [" " for _ in range(9)]
    print("Welcome to Tic-Tac-Toe! You are X, AI is O.")
    first = choose_first()
    print_board(board)

    while True:
        if first == "me":

```

```

# Human turn
move = human_move()
board[move] = "X"
print_board(board)
if is_winner(board, "X"):
    print("You win!")
    break
if is_full(board):
    print("It's a draw!")
    break

# AI turn
print("AI is thinking...")
ai_move = alpha_beta_search(board)
if ai_move is None:
    print("AI could not find a move — it's a draw.")
    break
board[ai_move] = "O"
print_board(board)
if is_winner(board, "O"):
    print("AI wins!")
    break
if is_full(board):
    print("It's a draw!")
    break

else: # AI first
    print("AI is thinking...")
    ai_move = alpha_beta_search(board)
    if ai_move is None:
        print("AI could not find a move — it's a draw.")
        break
    board[ai_move] = "O"
    print_board(board)
    if is_winner(board, "O"):
        print("AI wins!")
        break
    if is_full(board):
        print("It's a draw!")
        break

```



```
# Human turn
move = human_move()
board[move] = "X"
print_board(board)
if is_winner(board, "X"):
    print("You win!")
    break
if is_full(board):
    print("It's a draw!")
    break

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

Output:

Welcome to Tic-Tac-Toe! You are X, AI is O.
Who goes first? (me/ai) [me]: me

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

Enter your move (1-9): 5

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

AI is thinking...

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

Enter your move (1-9): 7

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

AI is thinking...

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

Enter your move (1-9): 6

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

AI is thinking...

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

Enter your move (1-9): 9

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

It's a draw!

Mini Max Algorithm

Pseudocode:

Min-Max Tic-Tac-Toe

```
function minimax (board, depth, is Maximizing):  
    if current board state is terminal state:  
        return value of board.  
  
    if is Maximizing Player:  
        bestVal = -INFINITY  
        for each move in board:  
            value = minimax (board, depth-1, false)  
            max bestVal = max (value, bestVal)  
        return bestVal.  
  
    else:  
        minVal = +INFINITY  
        for each move in board:  
            value = minimax (board, depth-1, true)  
            bestVal minVal = min (minVal, value)  
        return minVal.
```

Code to implement X-O game using minimax algorithm:

```
import math

# ----- PRINT BOARD -----
def print_board(board):
    print()
    for i in range(3):
        print(" | ".join(board[i]))
        if i < 2:
            print("-----")
    print()

# ----- CHECK WINNER -----
def check_winner(board):
    # Rows
    for i in range(3):
        if board[i][0] == board[i][1] == board[i][2] != "_":
            return board[i][0]

    # Columns
    for i in range(3):
        if board[0][i] == board[1][i] == board[2][i] != "_":
            return board[0][i]

    # Diagonals
    if board[0][0] == board[1][1] == board[2][2] != "_":
        return board[0][0]

    if board[0][2] == board[1][1] == board[2][0] != "_":
        return board[0][2]

    return None

# ----- MOVES LEFT -----
def moves_left(board):
    for row in board:
        if "_" in row:
            return True
    return False
```

```

# ----- MINIMAX -----
def minimax(board, depth, is_max):
    winner = check_winner(board)

    if winner == "O":
        return 10 - depth
    if winner == "X":
        return depth - 10
    if not moves_left(board):
        return 0

    if is_max: # AI (O)
        best = -math.inf
        for i in range(3):
            for j in range(3):
                if board[i][j] == "_":
                    board[i][j] = "O"
                    best = max(best, minimax(board, depth + 1, False))
                    board[i][j] = "_"
            return best

    else: # Player (X)
        best = math.inf
        for i in range(3):
            for j in range(3):
                if board[i][j] == "_":
                    board[i][j] = "X"
                    best = min(best, minimax(board, depth + 1, True))
                    board[i][j] = "_"
            return best

# ----- BEST MOVE FOR AI -----
def best_move(board):
    best_val = -math.inf
    move = (-1, -1)

    for i in range(3):
        for j in range(3):
            if board[i][j] == "_":

```

```

        board[i][j] = "O"
        move_val = minimax(board, 0, False)
        board[i][j] = "_"

        if move_val > best_val:
            best_val = move_val
            move = (i, j)

    return move

# ----- CONVERT 1-9 POSITION TO ROW,COL -----
def pos_to_index(pos):
    pos -= 1      # convert 1-9 to 0-8
    return pos // 3, pos % 3

# ----- MAIN GAME LOOP -----
def play_game():
    board = [["_ ", "_ ", "_ "],
             ["_ ", "_ ", "_ "],
             ["_ ", "_ ", "_ "]]

    print("Welcome to Tic-Tac-Toe (Player vs Computer)")
    print("You are X. Computer is O.")
    print("Choose positions 1-9 as shown:")
    print("""
1 | 2 | 3
-----
4 | 5 | 6
-----
7 | 8 | 9
""")

    print_board(board)

    while True:

        # ----- PLAYER MOVE -----
        while True:
            try:

```

```

pos = int(input("Enter position (1-9): "))
if pos < 1 or pos > 9:
    print("Invalid! Enter 1-9 only.")
    continue

r, c = pos_to_index(pos)

if board[r][c] == "_":
    board[r][c] = "X"
    break
else:
    print("Position already taken, try again.")

except:
    print("Enter a valid number!")

print_board(board)

if check_winner(board) == "X":
    print(" You WIN!")
    break
if not moves_left(board):
    print("It's a DRAW!")
    break

# ----- AI MOVE -----
print("Computer is thinking...")
r, c = best_move(board)
board[r][c] = "O"

print_board(board)

if check_winner(board) == "O":
    print(" Computer WINS!")
    break
if not moves_left(board):
    print("It's a DRAW!")
    break

```



```

# ----- RUN GAME -----
play_game()

# Check if player wins
if check_winner(board) == "X":
    print("You WIN! ")
    break
if not moves_left(board):
    print("It's a DRAW!")
    break

# ----- AI MOVE -----
print("Computer is thinking...")
r, c = best_move(board)
board[r][c] = "O"

print_board(board)

# Check if AI wins
if check_winner(board) == "O":
    print("Computer WINS! ")
    break
if not moves_left(board):
    print("It's a DRAW!")
    break

play_game()

```

Output:

```
= RESTART: C:\Users\amith\OneDr
Welcome to Tic-Tac-Toe (Player
You are X. Computer is O.
Choose positions 1-9 as shown:

  1 | 2 | 3
  -----
  4 | 5 | 6
  -----
  7 | 8 | 9

  _ | _ | _
  -----
  _ | _ | _
  -----
  _ | _ | _

Enter position (1-9): 5

  _ | _ | _
  -----
  _ | X | _
  -----
  _ | _ | _

Computer is thinking...

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

Enter position (1-9): 3

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

Computer is thinking...

  O | _ | X
  -----
  _ | X | _
  -----
  O | _ | _
```

Enter position (1-9): 4

```
O | _ | X
-----
X | X | _
-----
O | _ | _
```

Computer is thinking...

```
O | _ | X
-----
X | X | O
-----
O | _ | _
```

Enter position (1-9): 2

```
O | X | X
-----
X | X | O
-----
O | _ | _
```

Computer is thinking...

```
O | X | X
-----
X | X | O
-----
O | O | _
```

Enter position (1-9): 9

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

It's a DRAW!