VISVESVARAYA TECHNOLOGICAL UNIVERSITY

“JnanaSangama”, Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (23CS5PCAIN)

Submitted by

ARCHITA V (1BM23CS050)

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

B.M.S. COLLEGE OF ENGINEERING
(Autonomous Institution under VTU)
BENGALURU-560019
Aug 2025 to Dec 2025

B.M.S. College of Engineering,

Bull Temple Road, Bangalore 560019

(Affiliated To Visvesvaraya Technological University, Belgaum)

Department of Computer Science and Engineering

CERTIFICATE

This is to certify that the Lab work entitled “Artificial Intelligence (23CS5PCAIN)” carried out by **ARCHITA V (1BM23CS050),** 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.

Sandhya A Kulkarni Assistant Professor Department of CSE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE

Index

Sl. No.	Experiment Title	Page No.
1	Implement Tic –Tac –Toe Game Implement vacuum cleaner agent	6-15
2	Solve 8 puzzle problems Implement Iterative deepening search algorithm	16-24
3	Implement A* search algorithm	25-33
4	Implement Hill Climbing search algorithm to solve N-Queens problem	34-36
5	Simulated Annealing to Solve 8-Queens problem	37-38
6	Create a knowledge base using propositional logic and show that the given query entails the knowledge base or not.	39-41
7	Implement unification in first order logic	42-44ss
8	Create a knowledge base consisting of first order logic statements and prove the given query using forward reasoning.	45-46
9	Create a knowledge base consisting of first order logic statements and prove the given query using Resolution	47-53
10	Implement Alpha-Beta Pruning.	54-55

Github Link:
https://github.com/1BM23CS050/AI-LAB

Artificial Intelligence Foundation Course Certificates:

Infosys®
Navigate your next

COURSE COMPLETION CERTIFICATE

The certificate is awarded to

ARCHITA V

for successfully completing the course

Introduction to Artificial Intelligence

on November 25, 2025

Infosys | Springboard

Congratulations! You make us proud!

Issued on: Tuesday, November 25, 2025
To verify, scan the QR code at https://verify.onwingspan.com

Satheesha B. Nanjappa
Senior Vice President and Head
Education, Training and Assessment
Infosys Limited

Infosys®
Navigate your next

COURSE COMPLETION CERTIFICATE

The certificate is awarded to

ARCHITA V

for successfully completing the course

Introduction to Deep Learning

on November 25, 2025

Infosys | Springboard

Congratulations! You make us proud!

Issued on: Tuesday, November 25, 2025
To verify, scan the QR code at https://verify.onwingspan.com

Satheesha B. Nanjappa
Senior Vice President and Head
Education, Training and Assessment
Infosys Limited

Infosys
Navigate your next

COURSE COMPLETION CERTIFICATE

The certificate is awarded to

ARCHITA V

for successfully completing the course

Introduction to Natural Language Processing

on November 25, 2025

Infosys | Springboard

Congratulations! You make us proud!

Issued on: Tuesday, November 25, 2025
To verify, scan the QR code at https://verify.onwingspan.com

Satheesha B.N.
Satheesha B. Nanjappa
Senior Vice President and Head
Education, Training and Assessment
Infosys Limited

Infosys
Navigate your next

CERTIFICATE OF ACHIEVEMENT

The certificate is awarded to

ARCHITA V

for successfully completing

Artificial Intelligence Foundation Certification

on November 25, 2025

Infosys | Springboard

Congratulations! You make us proud!

Issued on: Tuesday, November 25, 2025
To verify, scan the QR code at https://verify.onwingspan.com

Satheesha B.N.
Satheesha B. Nanjappa
Senior Vice President and Head
Education, Training and Assessment
Infosys Limited

Program 1
Implement Tic –Tac –Toe Game

Algorithm:

20 08 25
Week 1

1 Implement Tic - Tac - Toe game

Algorithm

1 Start

2 Initialize a 3 X 3 board

3 ~~Assigne Human1 value = x~~ for i from 0 to 3
~~Computer~~ Human 2 ~~value = 0~~ for j from 0 to 3
~~bored~~ board [i][j] = = '-1'

3 Assigning a value for the players
//Player 1 = X
//Player 2 = 0
print (Player 1 enter position (0 to 8) to place X).
print (Player 2 enter position (0 to 8) to place 0)
winner (board) // check for the winning condition.
check if empty.

// winning condition –
~~If other~~ Horizontally, Vertically & diagonally
check ~~for~~ if anyone player has placed same.
winner (board) checked.

Horizontal – if (board [0][i] ! = x || 0)
break.
Vertical – if (board [i][0] ! = x || 0)
break
Diagonal – if (board [i][j] ! = x || 0)
break.
if i = = j

if i + = 2
if (board [i][j] ! = x || 0)
break.

Code:

```
def print_board(board):
    print("\nCurrent Board:")
    for row in board:
        print(row)
    print()


def check_winner(board, player):
    for i in range(3):
        if all(cell == player for cell in board[i]):
            return True
        if all(board[j][i] == player for j in range(3)):
            return True


    if all(board[i][i] == player for i in range(3)):
        return True
    if all(board[i][2 - i] == player for i in range(3)):
        return True

    return False


def is_full(board):
    return all(cell != " " for row in board for cell in row)


def tic_tac_toe():
    board = [[" " for _ in range(3)] for _ in range(3)]
    current_player = "X"
    move_count = 0

    print("Tic-Tac-Toe Game (3x3 Matrix Format)\n")
    print_board(board)

    while True:
        try:
            row = int(input(f"Player {current_player}, enter row (0-2): "))
            col = int(input(f"Player {current_player}, enter col (0-2): "))
        except ValueError:
            print("Please enter integers between 0 and 2.")
            continue
```

```
        if not (0 <= row <= 2 and 0 <= col <= 2):
            print("Invalid position. Try again.")
            continue
        if board[row][col] != " ":
            print("Cell already filled. Choose another.")
            continue

        board[row][col] = current_player
        move_count += 1
        print_board(board)

        if check_winner(board, current_player):
            print(f"Player {current_player} wins!")
            break

        if is_full(board):
            print("Game is a draw.")
            break

        current_player = "O" if current_player == "X" else "X"

    print(f"Total moves (cost): {move_count}")

tic_tac_toe()
```

Output case1:

```
Tic-Tac-Toe Game (3x3 Matrix Format)


Current Board:
[' ', ' ', ' ']
[' ', ' ', ' ']
[' ', ' ', ' ']

Player X, enter row (0-2): 1
Player X, enter col (0-2): 1

Current Board:
[' ', ' ', ' ']
[' ', 'X', ' ']
[' ', ' ', ' ']

Player O, enter row (0-2): 0
Player O, enter col (0-2): 2

Current Board:
[' ', ' ', 'O']
[' ', 'X', ' ']
[' ', ' ', ' ']
```

```
Player X, enter row (0-2): 1
Player X, enter col (0-2): 0

Current Board:
[' ', ' ', 'O']
['X', 'X', ' ']
[' ', ' ', ' ']

Player O, enter row (0-2): 2
Player O, enter col (0-2): 1

Current Board:
[' ', ' ', 'O']
['X', 'X', ' ']
[' ', 'O', ' ']

Player X, enter row (0-2): 2
Player X, enter col (0-2): 2

Current Board:
[' ', ' ', 'O']
['X', 'X', ' ']
[' ', 'O', 'X']

Player O, enter row (0-2): 2
Player O, enter col (0-2): 0

Current Board:
[' ', ' ', 'O']
['X', 'X', ' ']
['O', 'O', 'X']

Player X, enter row (0-2): 0
Player X, enter col (0-2): 1

Current Board:
[' ', 'X', 'O']
['X', 'X', ' ']
['O', 'O', 'X']

Player O, enter row (0-2): 1
Player O, enter col (0-2): 2

Current Board:
[' ', 'X', 'O']
['X', 'X', 'O']
['O', 'O', 'X']

Player X, enter row (0-2): 0
Player X, enter col (0-2): 0

Current Board:
['X', 'X', 'O']
['X', 'X', 'O']
['O', 'O', 'X']

Player X wins!
Total moves (cost): 9
```

Output case2:

```
Tic-Tac-Toe Game (3x3 Matrix Format)


Current Board:
[' ', ' ', ' ']
[' ', ' ', ' ']
[' ', ' ', ' ']

Player X, enter row (0-2): 0
Player X, enter col (0-2): 2

Current Board:
[' ', ' ', 'X']
[' ', ' ', ' ']
[' ', ' ', ' ']

Player O, enter row (0-2): 2
Player O, enter col (0-2): 1

Current Board:
[' ', ' ', 'X']
[' ', ' ', ' ']
[' ', 'O', ' ']

Player X, enter row (0-2): 0
Player X, enter col (0-2): 0

Current Board:
['X', ' ', 'X']
[' ', ' ', ' ']
[' ', 'O', ' ']

Player O, enter row (0-2): 0
Player O, enter col (0-2): 1

Current Board:
['X', 'O', 'X']
[' ', ' ', ' ']
[' ', 'O', ' ']

Player X, enter row (0-2): 2
Player X, enter col (0-2): 0

Current Board:
['X', 'O', 'X']
[' ', ' ', ' ']
['X', 'O', ' ']

Player O, enter row (0-2): 1
Player O, enter col (0-2): 1

Current Board:
```

```
['X', 'O', 'X']
[' ', 'O', ' ']
['X', 'O', ' ']

Player O wins!
Total moves (cost): 6
```

Output case3:

```
Tic-Tac-Toe Game (3x3 Matrix Format):

Current Board:
[' ', ' ', ' ']
[' ', ' ', ' ']
[' ', ' ', ' ']


Player X, enter row (0-2): 1
Player X, enter col (0-2): 0
Current Board:
[' ', ' ', ' ']
['X', ' ', ' ']
[' ', ' ', ' ']

Player O, enter row (0-2): 0
Player O, enter col (0-2): 2

Current Board:
[' ', ' ', 'O']
['X', ' ', ' ']
[' ', ' ', ' ']

Player X, enter row (0-2): 2
Player X, enter col (0-2): 0

Current Board:
[' ', ' ', 'O']
['X', ' ', ' ']
['X', ' ', ' ']

Player O, enter row (0-2): 0
Player O, enter col (0-2): 0

Current Board:
['O', ' ', 'O']
['X', ' ', ' ']
['X', ' ', ' ']

Player X, enter row (0-2): 0
Player X, enter col (0-2): 1

Current Board:
['O', 'X', 'O']
['X', ' ', ' ']
['X', ' ', ' ']
```

```
Player O, enter row (0-2): 2
Player O, enter col (0-2): 1

Current Board:
['O', 'X', 'O']
['X', ' ', ' ']
['X', 'O', ' ']

Player X, enter row (0-2): 2
Player X, enter col (0-2): 2

Current Board:
['O', 'X', 'O']
['X', ' ', ' ']
['X', 'O', 'X']

Player O, enter row (0-2): 1
Player O, enter col (0-2): 1

Current Board:
['O', 'X', 'O']
['X', 'O', ' ']
['X', 'O', 'X']

Player X, enter row (0-2): 1
Player X, enter col (0-2): 2

Current Board:
['O', 'X', 'O']
['X', 'O', 'X']
['X', 'O', 'X']

Game is a draw.
Total moves (cost): 9
```

Implement vacuum cleaner agent

Algorithm:

2. Vaccum Cleaner

Algorithm -

1 Start

2 Initialize 4 rooms clean = 1 dirty = 0

3 count = 0

pos = 1

while (count < 4)

if (c[pos] == 0)

clean (room)

print ("Room [pos] cleaned")

else

print ("Room already cleaned")

count ++

move to next position

print ("All rooms cleaned")

~~room (){~~

~~clean = 0~~

~~dirty = 1~~

clean (room):{

c[pos] = 1

Code:

```
def vacuum_cleaner()
    A = int(input("Enter state of A (0 for clean, 1 for dirty): "))
    B = int(input("Enter state of B (0 for clean, 1 for dirty): "))
    location = input("Enter location (A or B): ").upper()

    cost = 0
    state = {'A': A, 'B': B}

    if location == 'A':
        if state['A'] == 1:  # If A is dirty
            print("Cleaned A.")
            state['A'] = 0
            cost += 1
        else:
            print("A is clean")

        if state['B'] == 1:  # If B is dirty
            print("Moving vacuum right")
            print("Cleaned B.")
            state['B'] = 0
            cost += 1
            print("Is B clean now? (0 if clean, 1 if dirty):", state['B'])
            print("Is A dirty? (0 if clean, 1 if dirty):", state['A'])
            print("B is clean")
            print("Moving vacuum left")
        else:
            print("Turning vacuum off")

    elif location == 'B':
        if state['B'] == 1:  # If B is dirty
            print("Cleaned B.")
            state['B'] = 0
            cost += 1
        else:
            print("B is clean")

        if state['A'] == 1:  # If A is dirty
            print("Moving vacuum left")
            print("Cleaned A.")
            state['A'] = 0
            cost += 1
            print("Is A clean now? (0 if clean, 1 if dirty):", state['A'])
            print("Is B dirty? (0 if clean, 1 if dirty):", state['B'])
            print("A is clean")
```

```
            print("Moving vacuum right")
        else:
            print("Turning vacuum off")

    print("Cost:", cost)
    print(state)


vacuum_cleaner()
```

OUTPUT Case1:

```
Enter state of A (0 for clean, 1 for dirty): 1
Enter state of B (0 for clean, 1 for dirty): 1
Enter location (A or B): A
Cleaned A.
Moving vacuum right
Cleaned B.
Is B clean now? (0 if clean, 1 if dirty): 0
Is A dirty? (0 if clean, 1 if dirty): 0
B is clean
Moving vacuum left
Cost: 2
{'A': 0, 'B': 0}
```

OUTPUT Case2:

```
Enter state of A (0 for clean, 1 for dirty): 0
Enter state of B (0 for clean, 1 for dirty): 1
Enter location (A or B): A
A is clean
Moving vacuum right
Cleaned B.
Is B clean now? (0 if clean, 1 if dirty): 0
Is A dirty? (0 if clean, 1 if dirty): 0
B is clean
Moving vacuum left
Cost: 1
{'A': 0, 'B': 0}
```

OUTPUT Case3:

```
Enter state of A (0 for clean, 1 for dirty): 0
Enter state of B (0 for clean, 1 for dirty): 0
Enter location (A or B): A
A is clean
Turning vacuum off
Cost: 0
{'A': 0, 'B': 0}
```

Program2

Solve 8 puzzle problems

Algorithm:

2-9-25
Week 2

8 Puzzle - misplaced tiles

```
function misplaced algo (start, goal)
    open = priority queue ordered by f = g + h
    close = empty set (states already visited)
    g (start) = 0
    h (start) = misplaced (start, goal)
    push (f, start, path = [start]) into open
    while open not empty
        (f, state, path) = pop lowest f from open
        if state == goal :
            return path
        add state to close
        for neighbor in expand (state) :
            if neighbor not in ~~expand~~ close :
                g (neighbor) = g (state) + 1
                h (neighbor) = misplaced (neighbor, goal)
                f (neighbor) = g(neighbor) + h (neighbor)
                push (f, neighbor, path + [neighbor])
                    into open.
    return "No solution"

function misplaced (state, goal):
    count = 0
    for i in 0 to 8 :
        if state [i] ! = 0 and state [i] ! = goal [i] :
            count ++
    return count.
```

$f(n) = g(n) + h(n)$

$g(n)$: cost from start to current state

$h(n)$: misplaced tiles count.

Code:

```
from collections import deque

def get_moves(state):
    idx = state.index("_")
    x, y = divmod(idx, 3)
    moves = []
    for dx, dy in [(-1,0),(1,0),(0,-1),(0,1)]:
        nx, ny = x+dx, y+dy
        if 0 <= nx < 3 and 0 <= ny < 3:
            nidx = nx*3 + ny
            lst = list(state)
            lst[idx], lst[nidx] = lst[nidx], lst[idx]
            moves.append("".join(lst))
    return moves

def bfs(start, goal):
    q = deque([(start, 0)])
    parent = {start: None}
    visited = {start}
    order = []
    while q:
        state, cost = q.popleft()
        order.append(state)
        if state == goal:   # stop immediately
            path = []
            while state:
                path.append(state)
                state = parent[state]
            path.reverse()
            return path, cost, order
        for move in get_moves(state):
            if move not in visited:
                visited.add(move)
                parent[move] = state
                q.append((move, cost+1))
    return None, -1, order   # if no solution

start = input("Enter initial state (e.g., 54_618732): ")
goal = input("Enter goal state (e.g., 12345678_): ")
path, cost, visited = bfs(start, goal)

print("Minimum cost:", cost)
print("\nSteps:")
for p in path:
    for i in range(0, 9, 3):
        print(p[i:i+3])
    print()

print("Visited states:")
for v in visited:
```

```
    for i in range(0, 9, 3):
        print(v[i:i+3])
    print()
```

Output:

```
Enter initial state (e.g., 54_618732): 2831647_5
Enter goal state (e.g., 12345678_): 1238_4765
Minimum cost: 5

Steps:
283
164
7_5

283
1_4
765

2_3
184
765

_23
184
765

123
_84
765

123
8_4
765
```

Solve 8 puzzle problems

Algorithm:

3. 8 Puzzle - Manhattan

```
function Manhattan Algo ( start , goal)
    open = priority queue ordered by f = g+h
    g (start) = 0
    h (start) = misplaced (start . goal)
    while ( open not empty)
        take state with smallest f
        if state = = goal
            return path
        for each neighbor state
            g = g (parent) + 1
            h = Manhattan (neighbor , goal)
            f = g + h
            Add neighbor to open
        return no solution

function Manhattan (state , goal) :
    dist = 0
    for each tile in state :
        find position in goal
        add row_diff + col_diff to distance
    return distance .
```

Output -

Solution found in 2 moves

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

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

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

Code:

```
def get_moves(state):
    idx = state.index("_")
    x, y = divmod(idx, 3)
    moves = []
    for dx, dy in [(-1,0),(1,0),(0,-1),(0,1)]:
        nx, ny = x+dx, y+dy
        if 0 <= nx < 3 and 0 <= ny < 3:
            nidx = nx*3 + ny
            lst = list(state)
            lst[idx], lst[nidx] = lst[nidx], lst[idx]
            moves.append("".join(lst))
    return moves

def dfs(start, goal):
    stack = [(start, 0)]
    parent = {start: None}
    visited = {start}
    order = []

    while stack:
        state, cost = stack.pop()
        order.append(state)
        if state == goal:
            path = []
            while state:
                path.append(state)
                state = parent[state]
            path.reverse()
            return path, cost, order, visited
        for move in reversed(get_moves(state)):
            if move not in visited:
                visited.add(move)
                parent[move] = state
                stack.append((move, cost+1))
    return None, -1, order, visited

start = input("Enter initial state (e.g., 54_618732): ")
goal = input("Enter goal state (e.g., 12345678_): ")
path, cost, visited_order, visited_set = dfs(start, goal)

print("Visited nodes (till goal found):")
for v in visited_order:
    for i in range(0, 9, 3):
        print(v[i:i+3])
    print()
    if v == goal:
        break

print("Steps (solution path):")
```

```
for p in path:
    for i in range(0, 9, 3):
        print(p[i:i+3])
    print()

print("Cost (depth to goal):", cost)
print("Number of nodes visited:", len(visited_set))
```

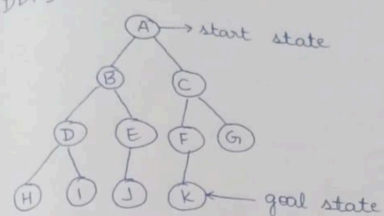
Output:

```
Steps (solution path):
283
164
7_5

283
1_4
765

2_3
184
765

_23
184
765

123
_84
765

123
8_4
765

Cost (depth to goal): 5
Number of nodes visited: 181440
```

Implement Iterative deepening search algorithm

Algorithm:

IDDFS



A
A B C
~~A B C D E F G~~
~~A B C D E F G~~
A B D E C F G
A B D H I E J C F K G

```
IDDFS (start , goal , max_depth) :
    for depth = 0 to max_depth
    visited = [ ]
    result = DFS (start , goal , depth , visited)
    if result = = found
        return true
    return false .
DFS (start , goal , depth , visited) :
    if node = = goal
        return found
result = DFS (node . left , goal , limit -1)
if ( result = = found
        return found .
result = DFS (node . right , goal , limit -1)
    if result = = found
        return found
    return not_found .
maxdepth (node) :
    if node is NULL :
        return 0
    left_depth = maxdepth (node . left)
    right_depth = maxdepth (node . left)
    return 1 + max (left_depth , right_depth)
```

Code:

```
def get_neighbors(state):
    neighbors = []
    idx = state.index("0")
    moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]
    x, y = divmod(idx, 3)

    for dx, dy in moves:
        nx, ny = x + dx, y + dy
        if 0 <= nx < 3 and 0 <= ny < 3:
            new_idx = nx * 3 + ny
            state_list = list(state)
            state_list[idx], state_list[new_idx] = state_list[new_idx], state_list[idx]
            neighbors.append("".join(state_list))
    return neighbors

def dfs_limit(start_state, goal_state, limit):
    stack = [(start_state, 0)]
    visited = set()
    parent = {start_state: None}
    path = []

    while stack:
        current_state, depth = stack.pop()

        if current_state == goal_state:
            while current_state:
                path.append(current_state)
                current_state = parent[current_state]
            return path[::-1]

        if depth < limit and current_state not in visited:
            visited.add(current_state)
            neighbors = get_neighbors(current_state)
            neighbors.reverse()  # Maintain consistent exploration order
            for neighbor in neighbors:
                if neighbor not in visited:
                    parent[neighbor] = current_state
                    stack.append((neighbor, depth + 1))
    return None

def iddfs(start_state, goal_state, max_depth):
    for limit in range(max_depth + 1):
        print(f"Searching with depth limit: {limit}")
        solution = dfs_limit(start_state, goal_state, limit)
        if solution:
            return solution
    return None

print("Enter the initial state (enter 3 digits per row, separated by spaces, 0 for empty):")
```

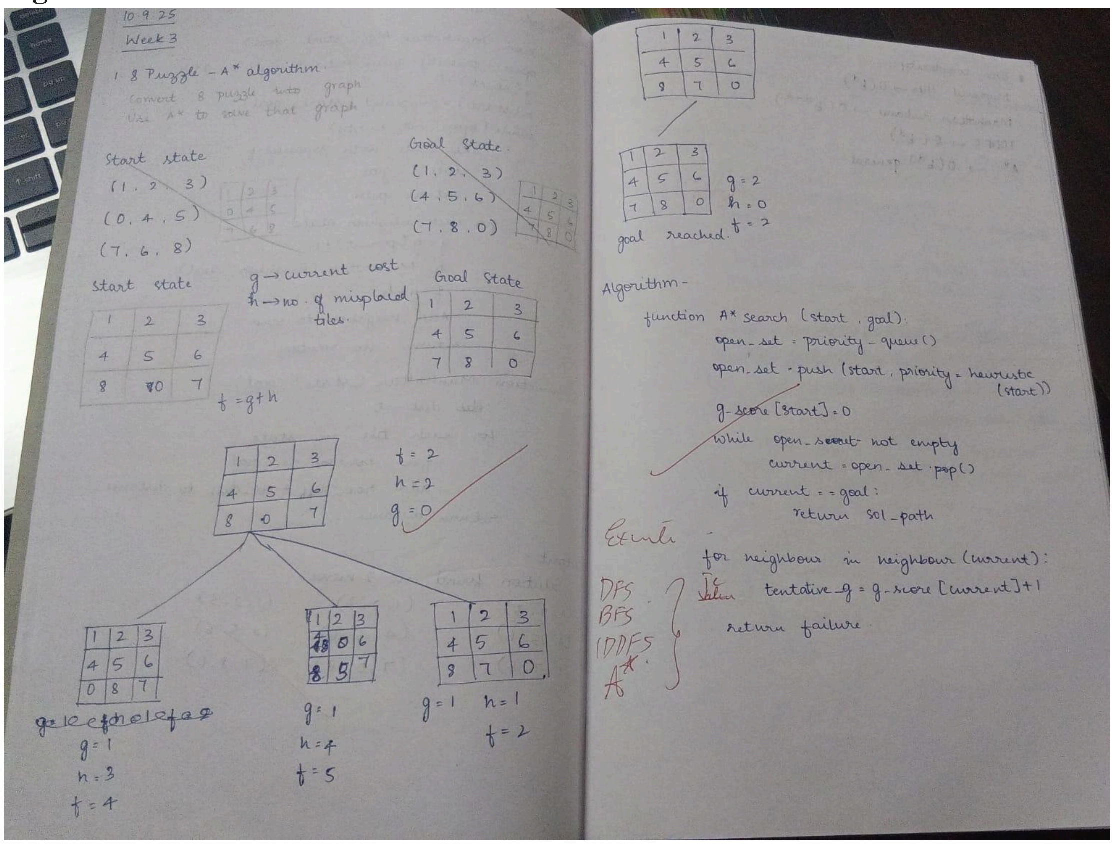
```
initial_state_rows = []
for i in range(3):
    row = input(f"Row {i+1}: ").split()
    initial_state_rows.extend(row)
initial_state = "".join(initial_state_rows)

print("\nEnter the goal state (enter 3 digits per row, separated by spaces, 0 for empty):")
goal_state_rows = []
for i in range(3):
    row = input(f"Row {i+1}: ").split()
    goal_state_rows.extend(row)
goal_state = "".join(goal_state_rows)

max_depth = 50

solution = iddfs(initial_state, goal_state, max_depth)

if solution:
    print("\nIDDFS solution path:")
    for s in solution:
        print(s[:3])
        print(s[3:6])
        print(s[6:])
        print()
else:
    print(f"\nNo solution found within the maximum depth of {max_depth}.")
```

Output:

```
Enter the initial state (enter 3 digits per row, separated by spaces, 0 for empty):
Row 1: 283
Row 2: 164
Row 3: 705

Enter the goal state (enter 3 digits per row, separated by spaces, 0 for empty):
Row 1: 123
Row 2: 804
Row 3: 765
Searching with depth limit: 0
Searching with depth limit: 1
Searching with depth limit: 2
Searching with depth limit: 3
Searching with depth limit: 4
Searching with depth limit: 5

IDDFS solution path:
283
164
705

283
104
765

203
184
765

023
184
765

123
084
765

123
804
765
```

Program3
Implement A* search algorithm

Algorithm:



Code:
```
#MISPLACED TILE
import heapq
from itertools import count

def misplaced_heuristic(board, goal):
    """h(n): number of tiles not in their goal position (excluding blank 0)."""
    n = len(board)
    misplaced = 0
    for i in range(n):
        for j in range(n):
            if board[i][j] != 0 and board[i][j] != goal[i][j]:
                misplaced += 1
    return misplaced

def find_blank(board):
    n = len(board)
    for i in range(n):
```

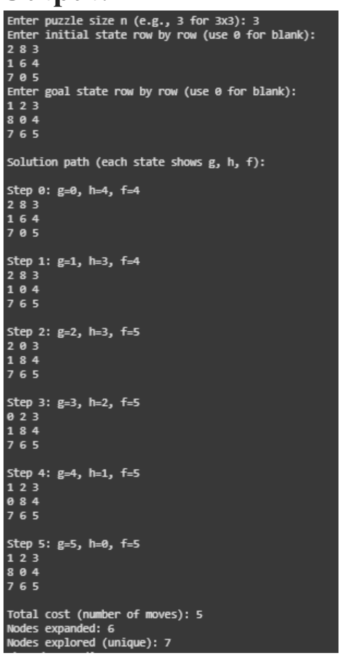
```
        for j in range(n):
            if board[i][j] == 0:
                return i, j
    raise ValueError("Board does not contain a blank tile (0)")

def neighbors(board):
    """Generate neighboring boards by sliding one tile into the blank."""
    n = len(board)
    x, y = find_blank(board)
    dirs = [(0,1),(0,-1),(1,0),(-1,0)]
    res = []
    for dx, dy in dirs:
        nx, ny = x + dx, y + dy
        if 0 <= nx < n and 0 <= ny < n:
            b = [list(row) for row in board]
            b[x][y], b[nx][ny] = b[nx][ny], b[x][y]
            res.append(tuple(tuple(row) for row in b))
    return res

def flatten(board):
    return [x for row in board for x in row]

def inversion_count(seq):
    arr = [x for x in seq if x != 0]
    inv = 0
    for i in range(len(arr)):
        for j in range(i+1, len(arr)):
            if arr[i] > arr[j]:
                inv += 1
    return inv

def blank_row_from_bottom(board):
    n = len(board)
    for i in range(n):
        for j in range(n):
            if board[i][j] == 0:
                return n - i
    raise ValueError("Board does not contain a blank tile (0)")

def is_solvable(start, goal):
    """General n-puzzle solvability test (odd/even width)."""
    n = len(start)
    start_flat = flatten(start)
    goal_flat = flatten(goal)

    pos = {val: idx for idx, val in enumerate(goal_flat)}
    start_perm = [pos[val] for val in start_flat]

    inv = inversion_count(start_perm)

    if n % 2 == 1:
        # odd grid: inversions parity must be even
```

```
        return inv % 2 == 0
    else:
        # even grid: blank row from bottom parity matters
        blank_row = blank_row_from_bottom(start)
        goal_blank_row = blank_row_from_bottom(goal)
        # When using relative permutation to goal, parity of blank rows must match
        return (inv + blank_row) % 2 == (0 + goal_blank_row) % 2

def reconstruct_path(came_from, current):
    path = [current]
    while current in came_from:
        current = came_from[current]
        path.append(current)
    path.reverse()
    return path

def a_star_misplaced(start, goal):
    start = tuple(tuple(row) for row in start)
    goal = tuple(tuple(row) for row in goal)

    if len(start) != len(start[0]) or len(goal) != len(goal[0]) or len(start) != len(goal):
        raise ValueError("Initial and goal must be square boards of the same size.")

    start_vals = sorted(flatten(start))
    goal_vals = sorted(flatten(goal))
    if start_vals != goal_vals:
        raise ValueError("Initial and goal must contain the same set of tiles.")

    if not is_solvable(start, goal):
        return None, None, 0, 0  # unsolvable

    counter = count()  # tie-breaker

    h0 = misplaced_heuristic(start, goal)
    g_score = {start: 0}
    f0 = h0

    open_heap = [(f0, next(counter), start)]
    open_set = {start: f0}
    closed = set()
    came_from = {}

    expansions = 0

    while open_heap:
        _, _, current = heapq.heappop(open_heap)
        if current in closed:
            continue
        closed.add(current)

        if current == goal:
            path = reconstruct_path(came_from, current)
```

```
            return path, g_score[current], expansions, len(closed)

        expansions += 1

        for nb in neighbors(current):
            tentative_g = g_score[current] + 1
            if nb in closed:
                continue
            if nb not in g_score or tentative_g < g_score[nb]:
                came_from[nb] = current
                g_score[nb] = tentative_g
                h = misplaced_heuristic(nb, goal)
                f = tentative_g + h
                if nb not in open_set or f < open_set[nb]:
                    heapq.heappush(open_heap, (f, next(counter), nb))
                    open_set[nb] = f

    return None, None, expansions, len(closed)

def read_board(n, prompt):
    print(prompt)
    board = []
    for i in range(n):
        row = list(map(int, input().split()))
        if len(row) != n:
            raise ValueError(f"Row {i+1} must contain exactly {n} integers.")
        board.append(row)
    return board

def print_board(board):
    for row in board:
        print(" ".join(f"{x}" for x in row))

def main():
    try:
        n = int(input("Enter puzzle size n (e.g., 3 for 3x3): ").strip())
        initial = read_board(n, "Enter initial state row by row (use 0 for blank):")
        goal = read_board(n, "Enter goal state row by row (use 0 for blank):")

        result = a_star_misplaced(initial, goal)
        path, cost, expansions, explored = result

        if path is None:
            print("No solution (unsolvable with given start/goal).")
            return

        print("\nSolution path (each state shows g, h, f):\n")
        for idx, state in enumerate(path):
            g = idx  # each step costs 1
            h = misplaced_heuristic(state, tuple(tuple(r) for r in goal))
            f = g + h
            print(f"Step {idx}: g={g}, h={h}, f={f}")
```

```
            print_board(state)
            print()

        print(f"Total cost (number of moves): {cost}")
        print(f"Nodes expanded: {expansions}")
        print(f"Nodes explored (unique): {explored}")
    except Exception as e:
        print("Error:", e)

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

Output:



```
Enter puzzle size n (e.g., 3 for 3x3): 3
Enter initial state row by row (use 0 for blank):
2 8 3
1 6 4
7 0 5
Enter goal state row by row (use 0 for blank):
1 2 3
8 0 4
7 6 5

Solution path (each state shows g, h, f):

Step 0: g=0, h=4, f=4
2 8 3
1 6 4
7 0 5

Step 1: g=1, h=3, f=4
2 8 3
1 0 4
7 6 5

Step 2: g=2, h=3, f=5
2 0 3
1 8 4
7 6 5

Step 3: g=3, h=2, f=5
0 2 3
1 8 4
7 6 5

Step 4: g=4, h=1, f=5
1 2 3
0 8 4
7 6 5

Step 5: g=5, h=0, f=5
1 2 3
8 0 4
7 6 5

Total cost (number of moves): 5
Nodes expanded: 6
Nodes explored (unique): 7
```

Code:

```
#MANHATTAN DISTANCE
import heapq
from itertools import count

def misplaced_heuristic(board, goal):
    misplaced = 0
    n = len(board)
    for i in range(n):
        for j in range(n):
            if board[i][j] != 0 and board[i][j] != goal[i][j]:
                misplaced += 1
    return misplaced

def manhattan_heuristic(board, goal):
    n = len(board)
    # Map goal positions for each tile
    goal_pos = {}
    for i in range(n):
```

```
        for j in range(n):
            goal_pos[goal[i][j]] = (i, j)

    dist = 0
    for i in range(n):
        for j in range(n):
            val = board[i][j]
            if val != 0:
                gi, gj = goal_pos[val]
                dist += abs(i - gi) + abs(j - gj)
    return dist

def find_blank(board):
    n = len(board)
    for i in range(n):
        for j in range(n):
            if board[i][j] == 0:
                return i, j
    raise ValueError("Board does not contain a blank tile (0)")

def neighbors(board):
    n = len(board)
    x, y = find_blank(board)
    dirs = [(0,1),(0,-1),(1,0),(-1,0)]
    res = []
    for dx, dy in dirs:
        nx, ny = x + dx, y + dy
        if 0 <= nx < n and 0 <= ny < n:
            b = [list(row) for row in board]
            b[x][y], b[nx][ny] = b[nx][ny], b[x][y]
            res.append(tuple(tuple(row) for row in b))
    return res

def flatten(board):
    return [x for row in board for x in row]

def inversion_count(seq):
    arr = [x for x in seq if x != 0]
    inv = 0
    for i in range(len(arr)):
        for j in range(i+1, len(arr)):
            if arr[i] > arr[j]:
                inv += 1
    return inv

def blank_row_from_bottom(board):
    n = len(board)
    for i in range(n):
        for j in range(n):
            if board[i][j] == 0:
                return n - i
    raise ValueError("Board does not contain a blank tile (0)")
```

```
def is_solvable(start, goal):
    n = len(start)
    start_flat = flatten(start)
    goal_flat = flatten(goal)

    pos = {val: idx for idx, val in enumerate(goal_flat)}
    start_perm = [pos[val] for val in start_flat]

    inv = inversion_count(start_perm)

    if n % 2 == 1:
        return inv % 2 == 0
    else:
        blank_row = blank_row_from_bottom(start)
        goal_blank_row = blank_row_from_bottom(goal)
        return (inv + blank_row) % 2 == (0 + goal_blank_row) % 2

def reconstruct_path(came_from, current):
    path = [current]
    while current in came_from:
        current = came_from[current]
        path.append(current)
    path.reverse()
    return path

def a_star_manhattan(start, goal):
    start = tuple(tuple(row) for row in start)
    goal = tuple(tuple(row) for row in goal)

    if len(start) != len(start[0]) or len(goal) != len(goal[0]) or len(start) != len(goal):
        raise ValueError("Initial and goal must be square boards of the same size.")

    start_vals = sorted(flatten(start))
    goal_vals = sorted(flatten(goal))
    if start_vals != goal_vals:
        raise ValueError("Initial and goal must contain the same set of tiles.")

    if not is_solvable(start, goal):
        return None, None, 0, 0

    counter = count()
    h0 = manhattan_heuristic(start, goal)
    g_score = {start: 0}
    f0 = h0

    open_heap = [(f0, next(counter), start)]
    open_set = {start: f0}
    closed = set()
    came_from = {}

    expansions = 0
```

```
    while open_heap:
        _, _, current = heapq.heappop(open_heap)
        if current in closed:
            continue
        closed.add(current)

        if current == goal:
            path = reconstruct_path(came_from, current)
            return path, g_score[current], expansions, len(closed)

        expansions += 1

        for nb in neighbors(current):
            tentative_g = g_score[current] + 1
            if nb in closed:
                continue
            if nb not in g_score or tentative_g < g_score[nb]:
                came_from[nb] = current
                g_score[nb] = tentative_g
                h = manhattan_heuristic(nb, goal)
                f = tentative_g + h
                if nb not in open_set or f < open_set[nb]:
                    heapq.heappush(open_heap, (f, next(counter), nb))
                    open_set[nb] = f

    return None, None, expansions, len(closed)

def read_board(n, prompt):
    print(prompt)
    board = []
    for i in range(n):
        row = list(map(int, input().split()))
        if len(row) != n:
            raise ValueError(f"Row {i+1} must contain exactly {n} integers.")
        board.append(row)
    return board

def print_board(board):
    for row in board:
        print(" ".join(f"{x}" for x in row))

def main():
    try:
        n = int(input("Enter puzzle size n (e.g., 3 for 3x3): ").strip())
        initial = read_board(n, "Enter initial state row by row (use 0 for blank):")
        goal = read_board(n, "Enter goal state row by row (use 0 for blank):")

        result = a_star_manhattan(initial, goal)
        path, cost, expansions, explored = result

        if path is None:
```

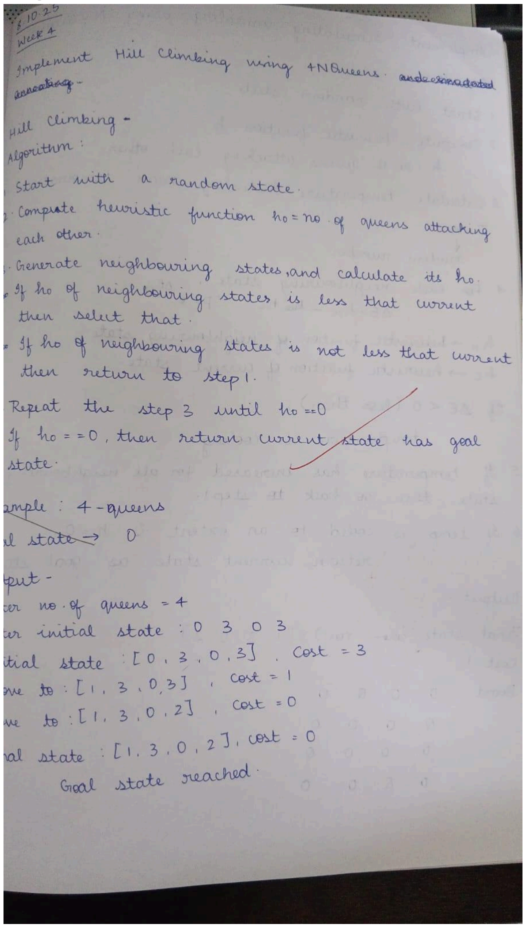
```
            print("No solution (unsolvable with given start/goal).")
            return

        print("\nSolution path (each state shows g, h, f):\n")
        for idx, state in enumerate(path):
            g = idx
            h = manhattan_heuristic(state, tuple(tuple(r) for r in goal))
            f = g + h
            print(f"Step {idx}: g={g}, h={h}, f={f}")
            print_board(state)
            print()

        print(f"Total cost (number of moves): {cost}")
        print(f"Nodes expanded: {expansions}")
        print(f"Nodes explored (unique): {explored}")


    except Exception as e:
        print("Error:", e)

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

```
Enter puzzle size n (e.g., 3 for 3x3): 3
Enter initial state row by row (use 0 for blank):
2 8 3
1 6 4
7 0 5
Enter goal state row by row (use 0 for blank):
1 2 3
8 0 4
7 6 5

Solution path (each state shows g, h, f):

Step 0: g=0, h=5, f=5
2 8 3
1 6 4
7 0 5

Step 1: g=1, h=4, f=5
2 8 3
1 0 4
7 6 5

Step 2: g=2, h=3, f=5
2 0 3
1 8 4
7 6 5

Step 3: g=3, h=2, f=5
0 2 3
1 8 4
7 6 5

Step 4: g=4, h=1, f=5
1 2 3
0 8 4
7 6 5

Step 5: g=5, h=0, f=5
1 2 3
8 0 4
7 6 5

Total cost (number of moves): 5
Nodes expanded: 5
Nodes explored (unique): 6
```

Program4

Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm:

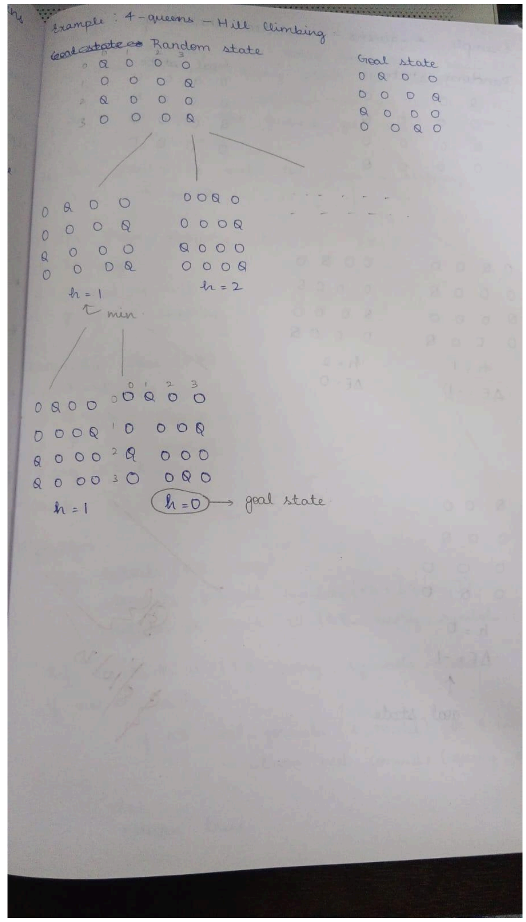


5.10.25
Week 4
Implement Hill Climbing using 4NQueens ~~and simulated annealing~~ -

Hill Climbing -
Algorithm :
1. Start with a random state.
2. Compute heuristic function h0 = no of queens attacking each other.
3. Generate neighbouring states and calculate its h0.
4. If h0 of neighbouring states is less that current then select that.
5. If h0 of neighbouring states is not less that current then return to step 1.

Repeat the step 3 until h0 ==0
If h0 = = 0, then return current state has goal state.

ample : 4 - queens
l state → 0
put -
er no. of queens = 4
er initial state : 0 3 0 3
itial state : [0, 3, 0, 3] . Cost = 3
ve to : [1, 3, 0, 3] , cost = 1
ve to : [1, 3, 0, 2] , cost = 0
al state : [1, 3, 0, 2], cost = 0
Goal state reached.



Code:

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

def generate_neighbors(state):
    neighbors = []
    n = len(state)
    for col in range(n):
        for row in range(n):
            if state[col] != row:  # move queen
                new_state = list(state)
```

```
            new_state[col] = row
            neighbors.append(new_state)
    return neighbors

def hill_climbing(initial_state):
    current = initial_state
    current_cost = calculate_cost(current)
    step = 0

    print(f"Step {step}: State = {current}, Cost = {current_cost}")

    while True:
        neighbors = generate_neighbors(current)
        neighbor_costs = [(n, calculate_cost(n)) for n in neighbors]

        # Print state space for this step
        print("\nNeighbors and their costs:")
        for n, c in neighbor_costs:
            print(f"   {n} -> Cost = {c}")

        # Pick the best neighbor (lowest cost)
        best_neighbor, best_cost = min(neighbor_costs, key=lambda x: x[1])

        if best_cost >= current_cost:
            break

        step += 1
        current, current_cost = best_neighbor, best_cost
        print(f"\nStep {step}: Move to {current}, Cost = {current_cost}")

        if current_cost == 0:
            print("\nGoal reached! Solution found.")
            break

initial_state = [3, 1, 2, 0]

hill_climbing(initial_state)
```

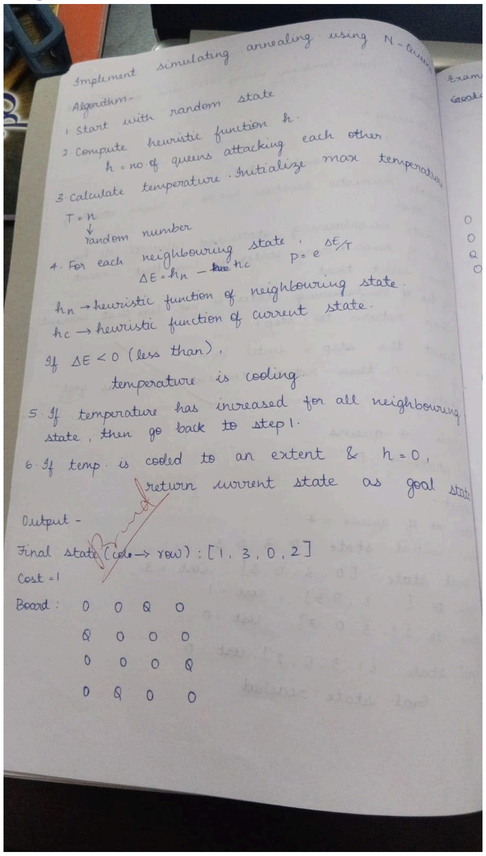
Output:

```
Week 7
Step 0: State = [3, 1, 2, 0], Cost = 2

Neighbors and their costs:
   [0, 1, 2, 0] -> Cost = 4
   [1, 1, 2, 0] -> Cost = 2
   [2, 1, 2, 0] -> Cost = 3
   [3, 0, 2, 0] -> Cost = 2
   [3, 2, 2, 0] -> Cost = 4
   [3, 3, 2, 0] -> Cost = 3
   [3, 1, 0, 0] -> Cost = 3
   [3, 1, 1, 0] -> Cost = 4
   [3, 1, 3, 0] -> Cost = 2
   [3, 1, 2, 1] -> Cost = 3
   [3, 1, 2, 2] -> Cost = 2
   [3, 1, 2, 3] -> Cost = 4
```

Program 5

Simulated Annealing to Solve 8-Queens problem

Algorithm:



Implement simulating annealing using N-Queens

Algorithm-

1. Start with random state
2. Compute heuristic function h.
   h = no. of queens attacking each other.
3. Calculate temperature. Initialize max temperature
   T = n → random number
4. For each neighbouring state, $\Delta E = h_n - h_c$ $\quad P = e^{\Delta E / T}$
   h_n → heuristic function of neighbouring state.
   h_c → heuristic function of current state.
   If $\Delta E < 0$ (less than),
   temperature is cooling.
5. If temperature has increased for all neighbouring state, then go back to step 1.
6. If temp. is coded to an extent & h = 0,
   return current state as goal state

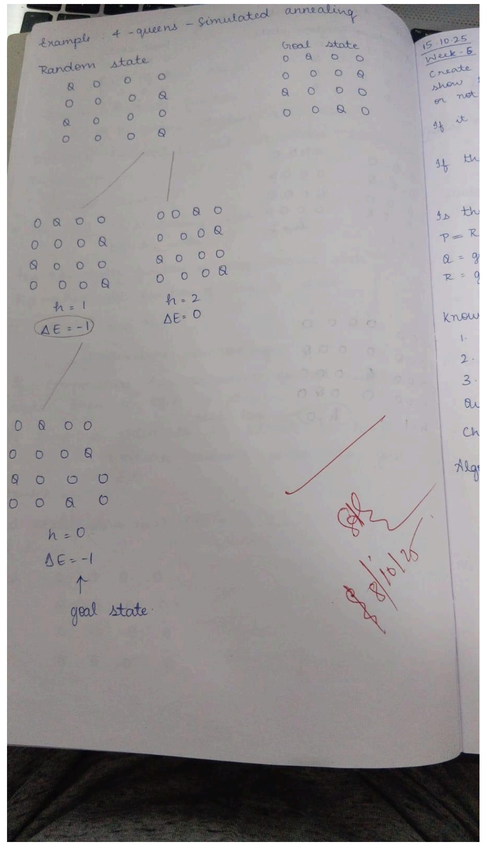
Output -

Final state (col → row) : [1, 3, 0, 2]

Cost = 1

Board :

0 0 Q 0
Q 0 0 0
0 0 0 Q
0 Q 0 0



Code:

```
import random
import math

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_random_neighbor(state):
    n = len(state)
    new_state = list(state)
    col = random.randint(0, n - 1)
    row = random.randint(0, n - 1)
    new_state[col] = row
    return new_state
```

```
def simulated_annealing(n=8, max_iterations=10000, initial_temp=100.0, cooling_rate=0.99):

    current = [random.randint(0, n - 1) for _ in range(n)]
    current_cost = calculate_cost(current)
    best = current
    best_cost = current_cost
    temperature = initial_temp

    for _ in range(max_iterations):
        if current_cost == 0:
            break

        neighbor = get_random_neighbor(current)
        neighbor_cost = calculate_cost(neighbor)
        delta = neighbor_cost - current_cost

        if delta < 0 or random.random() < math.exp(-delta / temperature):
            current, current_cost = neighbor, neighbor_cost

            if current_cost < best_cost:
                best, best_cost = current, current_cost

        temperature *= cooling_rate
        if temperature < 1e-6:
            break

    return best, best_cost

best_state, best_cost = simulated_annealing()

print("The best position found:", best_state)
print("cost =", best_cost)
```

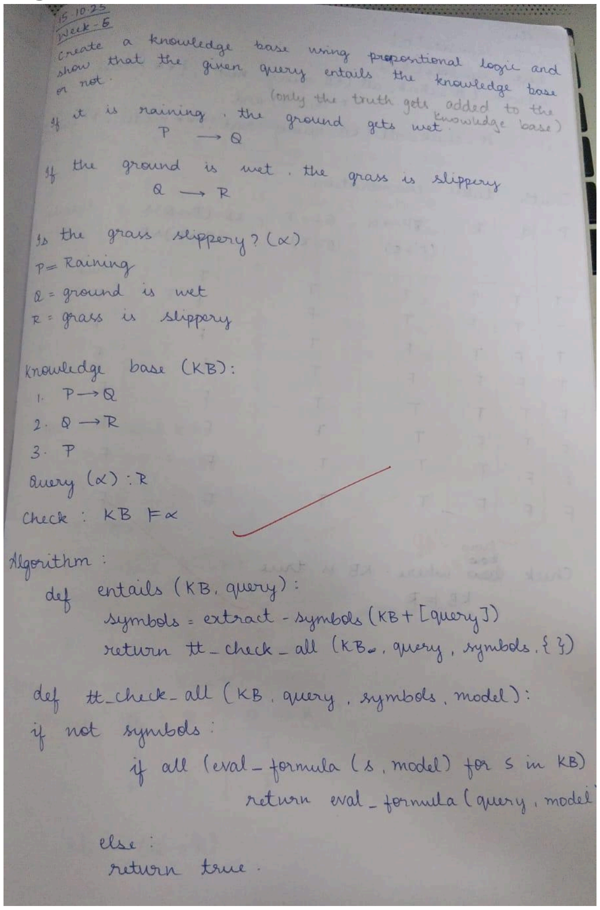
Output:

```
The best position found: [5, 2, 6, 1, 7, 4, 0, 3]
cost = 0
```

Program 6

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

Algorithm:



15.10.25
Week - 6

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

(only the truth gets added to the knowledge base)

If it is raining, the ground gets wet.
P → Q

If the ground is wet, the grass is slippery
Q → R

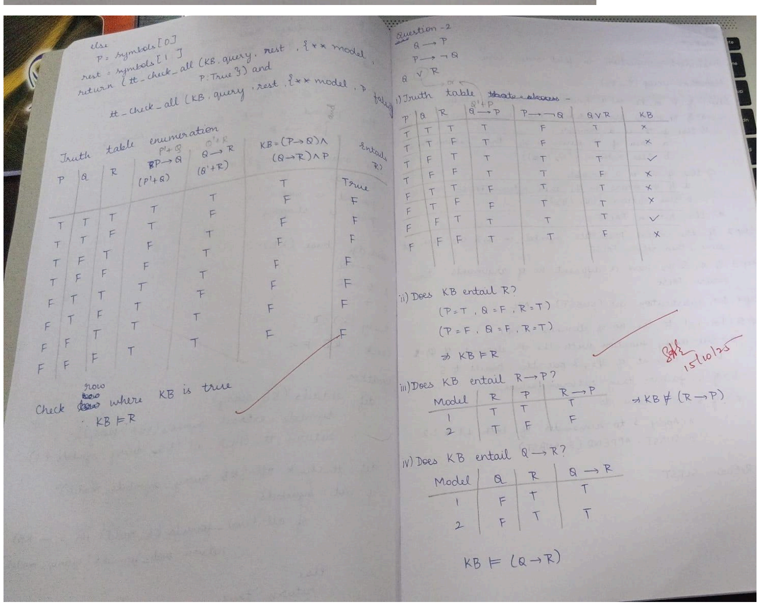
Is the grass slippery? (α)
P = Raining
Q = ground is wet
R = grass is slippery

Knowledge base (KB):
1. P → Q
2. Q → R
3. P

Query (α) : R
Check : KB ⊨ α

Algorithm :

```
def entails (KB, query):
    symbols = extract - symbols (KB + [query])
    return tt_check_all (KB, query, symbols, { })

def tt_check_all (KB, query, symbols, model):
if not symbols:
        if all (eval_formula (s, model) for s in KB)
                return eval_formula (query, model)
    else:
    return true.
```



```
else
   P = symbols [0]
rest = symbols [1 ]
return (tt_check_all (KB, query, rest, {** model, P: True}) and
        tt_check_all (KB, query, rest, {** model, P: false})
```

Truth table enumeration

P	Q	R	P → Q (P' + Q)	Q → R (Q' + R)	KB = (P → Q) ∧ (Q → R) ∧ P	Entails R?
T	T	T	T	T	T	True
T	T	F	T	F	F	F
T	F	T	F	T	F	F
T	F	F	F	T	F	F
F	T	T	T	T	F	F
F	T	F	T	F	F	F
F	F	T	T	T	F	F
F	F	F	T	T	F	F

Check row where KB is true
∴ KB ⊨ R

Question - 2
Q → P
P → ¬Q
Q ∨ R

i) Truth table -

P	Q	R	Q → P (Q' + P)	P → ¬Q	Q ∨ R	KB
T	T	T	T	F	T	×
T	T	F	T	F	T	×
T	F	T	T	T	T	✓
T	F	F	T	T	F	×
F	T	T	F	T	T	×
F	T	F	F	T	T	×
F	F	T	T	T	T	✓
F	F	F	T	T	F	×

ii) Does KB entail R?
(P = T, Q = F, R = T)
(P = F, Q = F, R = T)
⇒ KB ⊨ R

iii) Does KB entail R → P?

Model	R	P	R → P
1	T	T	T
2	T	F	F

⇒ KB ⊭ (R → P)

iv) Does KB entail Q → R?

Model	Q	R	Q → R
1	F	T	T
2	F	T	T

KB ⊨ (Q → R)

15/10/25

Code:

```
import itertools

def eval_expr(expr, model):
    try:
        return eval(expr, {}, model)
    except:
        return False

def tt_entails(KB, query):
    symbols = sorted(set([ch for ch in KB + query if ch.isalpha()]))

    print("\nTruth Table:")
    print(" | ".join(symbols) + " | KB | Query")
    print("-" * (6 * len(symbols) + 20))

    entails = True
    for values in itertools.product([False, True], repeat=len(symbols)):
        model = dict(zip(symbols, values))
        kb_val = eval_expr(KB, model)
        query_val = eval_expr(query, model)

        row = " | ".join(["T" if model[s] else "F" for s in symbols])
        print(f"{row} |  {kb_val}  |  {query_val}")

        if kb_val and not query_val:
            entails = False

    return entails

KB = input("Enter Knowledge Base (use &, |, ~ for AND, OR, NOT): ")
query = input("Enter Query: ")

result = tt_entails(KB, query)

print("\nResult:")
if result:
    print("KB entails Query (True in all cases).")
else:
    print("KB does NOT entail Query.")
```

Output:

```
Enter Knowledge Base (use &, |, ~ for AND, OR, NOT): (A|C)&(B|~C)
Enter Query:  A|B

Truth Table:
A | B | C | KB | Query
--------------------------------------
F | F | F |  0  |  False
F | F | T |  0  |  False
F | T | F |  0  |  True
F | T | T |  1  |  True
T | F | F |  1  |  True
T | F | T |  0  |  True
T | T | F |  1  |  True
T | T | T |  1  |  True

Result:
KB entails Query (True in all cases).
```

Program 7

Implement unification in first order logic

Algorithm:

29.10.25
Week - 7

Implement unification in first order logic.

Algorithm Unify (Ψ_1, Ψ_2)

Step 1: If Ψ_1 or Ψ_2 is a variable or constant, then:

a> If Ψ_1 or Ψ_2 are identical, then return NULL

b> Else if Ψ_1 is a variable,

a. then if Ψ_1 occurs in Ψ_2, then return FALSE

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 FALSE

b. Else return $\{(\Psi_1 / \Psi_2)\}$

d> Else return FALSE

Step 2: If the initial predicate symbol in Ψ_1 & Ψ_2 are not same, then return FALSE

Step 3: If Ψ_1 & Ψ_2 have a different no. of arguments, then return FALSE

Step 4: Set substitution set (SUBST) to NIL

Step 5: For i=1 to the no. of elements in Ψ_1

a> call unify function with the ith element of Ψ_1 & ith element of Ψ_2, & put the result to S.

b> If S = failure then returns failure

c> If S ≠ NIL then do,

a. Apply S to remainder of both L1 & L2

b. SUBST = APPEND (S, SUBST)

Step 6: Return SUBST

Question: Find θ (MGU)

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

Find θ (MGU) → most general unification

* Predicate symbols shd be same
* no. of terms shd be same
* no 2 terms shd be substituted to same term

2. Q(x, f(x))
Q(f(y), y)

3. H(x, g(x))
H(g(y), g(g(z)))

1. P(f(x), g(y), y)
P[f(g(z)), g(f(a)), f(a)]

y / f(a)
x / g(z)

P(f(g(z)), g(f(a)), f(a))
P(f(g(z)), g(f(a)), f(a))

∴ Unified

2. Q(x, f(x))
Q(f(y), y)

x / f(y)
y / f(x)

x appears in both
y appears in both

⇒ Not unifiable.

3. H(x, g(x))
H(g(y), g(g(z)))

x / g(y)
H(g(y), g(g(y)))
H(g(y), g(g(z)))

⇒ y / z

∴ Unifiable

Code:

```
def occurs_check(var, term, subst):
    if var == term:
        return True
    elif isinstance(term, tuple):
        return any(occurs_check(var, t, subst) for t in term)
    elif term in subst:
        return occurs_check(var, subst[term], subst)
    return False

def unify(x, y, subst):
    if subst is None:
        return None
    elif x == y:
        return subst
    elif isinstance(x, str) and x.isupper():
        return unify_var(x, y, subst)
    elif isinstance(y, str) and y.isupper():
        return unify_var(y, x, subst)
    elif isinstance(x, tuple) and isinstance(y, tuple):
        if x[0] != y[0] or len(x) != len(y):
            return None
        for a, b in zip(x[1:], y[1:]):
            subst = unify(a, b, subst)
            if subst is None:
                return None
        return subst
    else:
        return None

def unify_var(var, x, subst):
    if var in subst:
        return unify(subst[var], x, subst)
    elif x in subst:
        return unify(var, subst[x], subst)
    elif occurs_check(var, x, subst):
        return None
    else:
        subst[var] = x
        return subst

def parse_expr(s):
    s = s.replace(" ", "")
    if '(' not in s:
        return s
    name_end = s.index('(')
    name = s[:name_end]
    args = []
    depth = 0
    current = ""
    for c in s[name_end+1:-1]:
        if c == ',' and depth == 0:
```

```
            args.append(parse_expr(current))
            current = ""
        else:
            if c == '(':
                depth += 1
            elif c == ')':
                depth -= 1
            current += c
    if current:
        args.append(parse_expr(current))
    return tuple([name] + args)

def expr_to_str(expr):
    if isinstance(expr, tuple):
        return expr[0] + "(" + ",".join(expr_to_str(e) for e in expr[1:]) + ")"
    else:
        return expr

expr1_input = input("Enter first expression: ")
expr2_input = input("Enter second expression: ")

expr1 = parse_expr(expr1_input)
expr2 = parse_expr(expr2_input)

subst = unify(expr1, expr2, {})

if subst:
    formatted_subst = {var: expr_to_str(val) for var, val in subst.items()}
else:
    formatted_subst = None

print("Most General Unifier (MGU):", formatted_subst)
```

Output:

```
Enter first expression: p(b,X,f(g(Z)))
Enter second expression: p(Z,f(Y),f(Y))
Most General Unifier (MGU): {'Z': 'b', 'X': 'f(Y)', 'Y': 'g(Z)'}
```

Program 8

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

Algorithm:

Forward reasoning algorithm

function FOL-FC-ASK (KB, α) returns a substitution or false

inputs: KB, the knowledge base, a set of first order definite clauses α, the query, an atomic sentence

local variables: new, the new sentences inferred on each iteration

repeat until new is empty

new ← { }

for each rule in KB do

($p_1 \wedge \dots \wedge p_n \Rightarrow q$) ← STANDARDIZE-VARIABLES (rule)

for each θ such that SUBST (θ, $p_1 \wedge \dots \wedge p_n$) = SUBST($\theta$, $p'_1 \wedge \dots \wedge p'_n$)

for some $p'_1, \dots, p'_n$ in KB

q' ← SUBST(θ, q)

if q' does not unify with some sentence already in KB or new then add q' to new ϕ ← UNIFY (q', α)

if ϕ is not fail then return ϕ

add new to KB

return false.

Code:

```
facts = {
    'American(Robert)': True,
    'Hostile(A)': True,
    'Sells_Weapons(Robert, A)': True
}

If American(X) and Hostile(Y) and Sells_Weapons(X, Y), then Crime(X)
def forward_reasoning(facts):

 If American(X) and Hostile(Y) and Sells_Weapons(X, Y), then Crime(X)
    if facts.get('American(Robert)', False) and facts.get('Hostile(A)', False) and facts.get('Sells_Weapons(Robert, A)', False):
        facts['Crime(Robert)'] = True

forward_reasoning(facts)

if facts.get('Crime(Robert)', False):
    print("Robert is a criminal.")
else:
    print("Robert is not a criminal.")
```

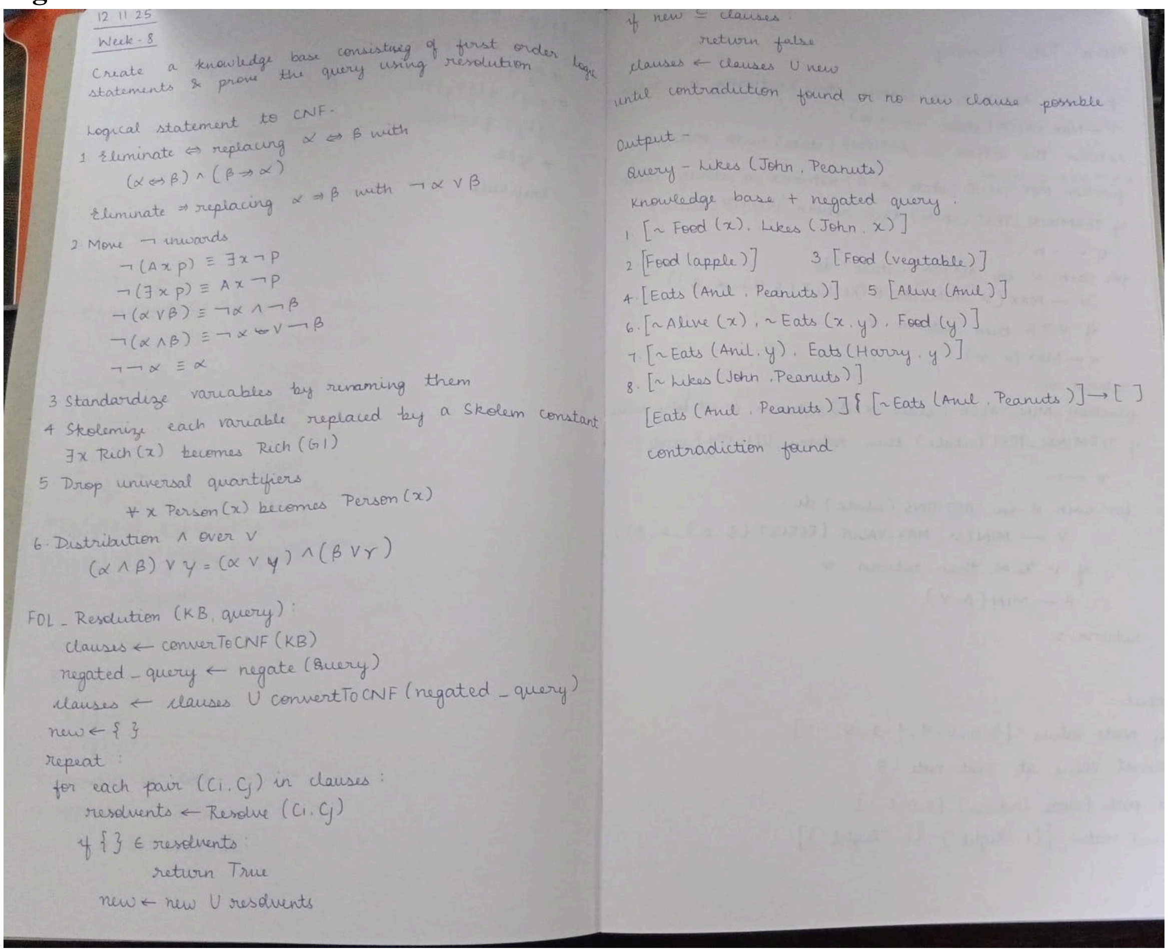
Output:

Robert is a criminal.

Program 9

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

Algorithm:



12 11 25
Week - 8

Create a knowledge base consisting of first order logic statements & prove the query using resolution logic

Logical statement to CNF.

1 Eliminate ⇔ replacing $\alpha \Leftrightarrow \beta$ with $(\alpha \Rightarrow \beta) \wedge (\beta \Rightarrow \alpha)$

Eliminate ⇒ replacing $\alpha \Rightarrow \beta$ with $\neg\alpha \vee \beta$

2 Move ¬ inwards

$\neg(\forall x\, p) \equiv \exists x \neg p$

$\neg(\exists x\, p) \equiv \forall x \neg p$

$\neg(\alpha \vee \beta) \equiv \neg\alpha \wedge \neg\beta$

$\neg(\alpha \wedge \beta) \equiv \neg\alpha \vee \neg\beta$

$\neg\neg\alpha \equiv \alpha$

3 Standardize variables by renaming them

4 Skolemize each variable replaced by a Skolem constant

$\exists x$ Rich(x) becomes Rich(G1)

5 Drop universal quantifiers

$\forall x$ Person(x) becomes Person(x)

6 Distribution ∧ over ∨

$(\alpha \wedge \beta) \vee \gamma = (\alpha \vee \gamma) \wedge (\beta \vee \gamma)$

```
FOL_Resolution(KB, query):
  clauses ← convertToCNF(KB)
  negated_query ← negate(query)
  clauses ← clauses ∪ convertToCNF(negated_query)
  new ← { }
  repeat:
    for each pair (Ci, Cj) in clauses:
      resolvents ← Resolve(Ci, Cj)
      if { } ∈ resolvents:
          return True
      new ← new ∪ resolvents
    if new ⊆ clauses:
        return false
    clauses ← clauses ∪ new
  until contradiction found or no new clause possible
```

Output -

Query - Likes(John, Peanuts)

Knowledge base + negated query:

1 [~Food(x), Likes(John, x)]

2 [Food(apple)] 3 [Food(vegetable)]

4 [Eats(Anil, Peanuts)] 5 [Alive(Anil)]

6 [~Alive(x), ~Eats(x, y), Food(y)]

7 [~Eats(Anil, y), Eats(Harry, y)]

8 [~Likes(John, Peanuts)]

[Eats(Anil, Peanuts)] [~Eats(Anil, Peanuts)] → [ ]

contradiction found

Code:

```
import copy

# ------------------------------
# Predicate Structure
# ------------------------------
class Predicate:
    def __init__(self, name, args, negated=False):
        self.name = name
        self.args = args if isinstance(args, tuple) else tuple(args)
        self.negated = negated

    def __eq__(self, other):
        return (self.name == other.name and
                self.args == other.args and
                self.negated == other.negated)
```

```python
    def __hash__(self):
        return hash((self.name, self.args, self.negated))

    def __repr__(self):
        neg = "~" if self.negated else ""
        args_str = ",".join(str(a) for a in self.args)
        return f"{neg}{self.name}({args_str})"

    def negate(self):
        return Predicate(self.name, self.args, not self.negated)

    def substitute(self, theta):
        """Apply substitution theta to this predicate"""
        new_args = tuple(substitute_term(arg, theta) for arg in self.args)
        return Predicate(self.name, new_args, self.negated)

def substitute_term(term, theta):
    """Apply substitution to a term"""
    if isinstance(term, str) and term.islower():  # variable
        if term in theta:
            return substitute_term(theta[term], theta)
        return term
    elif isinstance(term, tuple):
        return tuple(substitute_term(t, theta) for t in term)
    return term

# ------------------------------
# Unification Algorithm
# ------------------------------
def unify(x, y, theta=None):
    if theta is None:
        theta = {}
    if theta == "FAIL":
        return "FAIL"
    elif x == y:
        return theta
    elif isinstance(x, str) and x.islower():  # variable
        return unify_var(x, y, theta)
    elif isinstance(y, str) and y.islower():  # variable
        return unify_var(y, x, theta)
    elif isinstance(x, tuple) and isinstance(y, tuple):
        if len(x) != len(y):
            return "FAIL"
        theta = unify(x[0], y[0], theta)
        if theta == "FAIL":
            return "FAIL"
```

```
        return unify(x[1:], y[1:], theta)
    else:
        return "FAIL"

def unify_var(var, x, theta):
    if var in theta:
        return unify(theta[var], x, theta)
    elif isinstance(x, str) and x.islower() and x in theta:
        return unify(var, theta[x], theta)
    elif occurs_check(var, x, theta):
        return "FAIL"
    else:
        new_theta = copy.deepcopy(theta)
        new_theta[var] = x
        return new_theta

def occurs_check(var, x, theta):
    if var == x:
        return True
    elif isinstance(x, str) and x.islower() and x in theta:
        return occurs_check(var, theta[x], theta)
    elif isinstance(x, tuple):
        return any(occurs_check(var, xi, theta) for xi in x)
    return False

# ------------------------------
# Variable Standardization
# ------------------------------
var_counter = 0

def standardize_variables(clause):
    """Rename all variables in a clause to unique names"""
    global var_counter
    mapping = {}
    new_clause = []

    for pred in clause:
        new_args = []
        for arg in pred.args:
            if isinstance(arg, str) and arg.islower():  # variable
                if arg not in mapping:
                    mapping[arg] = f"{arg}{var_counter}"
                    var_counter += 1
                new_args.append(mapping[arg])
            else:
                new_args.append(arg)
        new_clause.append(Predicate(pred.name, new_args, pred.negated))
```

```
    return new_clause

# ------------------------------
# Resolution Algorithm
# ------------------------------
def resolve(ci, cj):
    """Resolve two clauses using FOL resolution"""
    ci = standardize_variables(ci)
    cj = standardize_variables(cj)

    resolvents = []

    for i, pi in enumerate(ci):
        for j, pj in enumerate(cj):
            # Check if predicates can be resolved (opposite signs, same name)
            if pi.negated != pj.negated and pi.name == pj.name:
                # Try to unify the arguments
                theta = unify(pi.args, pj.args)

                if theta != "FAIL":
                    # Create resolvent by removing resolved predicates and applying substitution
                    new_clause = []

                    # Add literals from ci except pi
                    for k, pred in enumerate(ci):
                        if k != i:
                            new_clause.append(pred.substitute(theta))

                    # Add literals from cj except pj
                    for k, pred in enumerate(cj):
                        if k != j:
                            new_clause.append(pred.substitute(theta))

                    # Remove duplicates
                    new_clause = list(set(new_clause))
                    resolvents.append(new_clause)

    return resolvents

def fol_resolution(kb, query):
    """FOL resolution algorithm"""
    # Negate query and add to KB
    clauses = [clause[:] for clause in kb]  # deep copy
    clauses.append([query.negate()])

    print(f"\nKnowledge Base + Negated Query:")
```

```
    for i, clause in enumerate(clauses):
        print(f"  {i+1}. {clause}")
    print()

    iteration = 0
    while True:
        iteration += 1
        n = len(clauses)
        pairs = [(clauses[i], clauses[j]) for i in range(n) for j in range(i + 1, n)]

        new_clauses = []
        for (ci, cj) in pairs:
            resolvents = resolve(ci, cj)

            for resolvent in resolvents:
                if len(resolvent) == 0:
                    print(f"Iteration {iteration}: Derived empty clause from:")
                    print(f"  {ci}")
                    print(f"  {cj}")
                    print("  → [] (Contradiction found!)")
                    return True

                # Check if this is a new clause
                if resolvent not in clauses and resolvent not in new_clauses:
                    new_clauses.append(resolvent)

        if not new_clauses:
            print(f"Iteration {iteration}: No new clauses derived. Query cannot be proved.")
            return False

        print(f"Iteration {iteration}: Generated {len(new_clauses)} new clause(s)")
        for clause in new_clauses:
            clauses.append(clause)

# ------------------------------
# Example Usage
# ------------------------------
if __name__ == "__main__":
    # Define knowledge base
    kb = [
        # John likes all food: Food(x) => Likes(John, x)
        [Predicate("Food", ("x",), negated=True), Predicate("Likes", ("John", "x"))],

        # Food(Apple)
        [Predicate("Food", ("Apple",))],

        # Food(Vegetables)
```

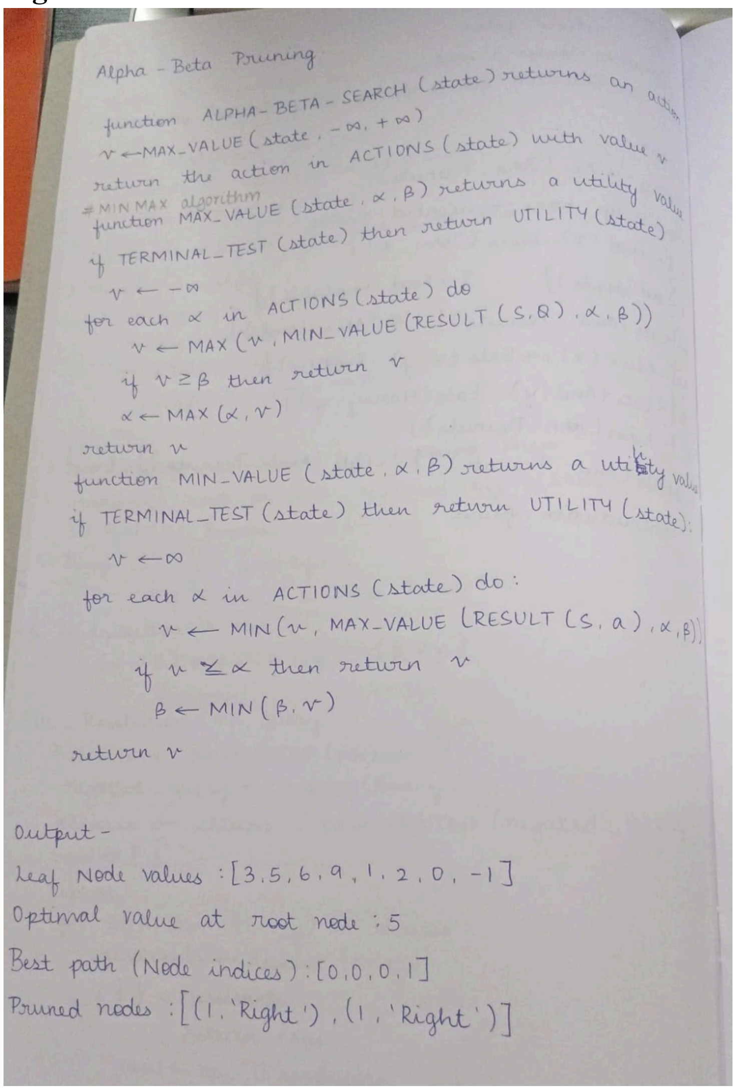
```
    [Predicate("Food", ("Vegetables",))],

    # Eats(Anil, Peanuts)
    [Predicate("Eats", ("Anil", "Peanuts"))],

    # Alive(Anil)
    [Predicate("Alive", ("Anil",))],

    # If alive and eats something, that thing is food: Alive(x) ∧ Eats(x,y) => Food(y)
    [Predicate("Alive", ("x",), negated=True),
     Predicate("Eats", ("x", "y"), negated=True),
     Predicate("Food", ("y",))],

    # Harry eats everything Anil eats: Eats(Anil,y) => Eats(Harry,y)
    [Predicate("Eats", ("Anil", "y"), negated=True),
     Predicate("Eats", ("Harry", "y"))]
]

# Query: Does John like Peanuts?
query = Predicate("Likes", ("John", "Peanuts"))

print("=" * 60)
print("FIRST-ORDER LOGIC RESOLUTION THEOREM PROVER")
print("=" * 60)
print(f"\nQuery: {query}")
print("-" * 60)

result = fol_resolution(kb, query)

print("\n" + "=" * 60)
if result:
    print("Query is PROVED using resolution!")
else:
    print("Query CANNOT be proved.")
print("=" * 60)
```

Output:

```
Query: Likes(John,Peanuts)
------------------------------------------------------------

Knowledge Base + Negated Query:
  1. [~Food(x), Likes(John,x)]
  2. [Food(Apple)]
  3. [Food(Vegetables)]
  4. [Eats(Anil,Peanuts)]
  5. [Alive(Anil)]
  6. [~Alive(x), ~Eats(x,y), Food(y)]
  7. [~Eats(Anil,y), Eats(Harry,y)]
  8. [~Likes(John,Peanuts)]

Iteration 1: Generated 8 new clause(s)
Iteration 2: Generated 16 new clause(s)
Iteration 3: Derived empty clause from:
  [Eats(Anil,Peanuts)]
  [~Eats(Anil,Peanuts)]
  → [] (Contradiction found!)

------------------------------------------------------------
```

Program 10
Implement Alpha-Beta Pruning.

Algorithm:



Alpha - Beta Pruning

function ALPHA-BETA-SEARCH (state) returns an action
v ← MAX_VALUE (state, −∞, +∞)
return the action in ACTIONS (state) with value v
MIN MAX algorithm
function MAX_VALUE (state, α, β) returns a utility value
if TERMINAL_TEST (state) then return UTILITY (state)
v ← −∞
for each α in ACTIONS (state) do
v ← MAX (v, MIN_VALUE (RESULT (S, a), α, β))
if v ≥ β then return v
α ← MAX (α, v)
return v
function MIN_VALUE (state, α, β) returns a utility value
if TERMINAL_TEST (state) then return UTILITY (state):
v ← ∞
for each α in ACTIONS (state) do :
v ← MIN (v, MAX_VALUE (RESULT (S, a), α, β))
if v ≤ α then return v
β ← MIN (β, v)
return v

Output -
Leaf Node values : [3, 5, 6, 9, 1, 2, 0, -1]
Optimal value at root node : 5
Best path (Node indices) : [0, 0, 0, 1]
Pruned nodes : [(1, 'Right'), (1, 'Right')]

Code:

```
import math

# Alpha-Beta Pruning Algorithm
def alpha_beta(depth, node_index, maximizing_player, values, alpha, beta, max_depth, path, pruned):
    # Base case: leaf node
    if depth == max_depth:
        return values[node_index], [node_index]

    if maximizing_player:
        best = -math.inf
        best_path = []
        for i in range(2):  # two children per node
            val, child_path = alpha_beta(depth + 1, node_index * 2 + i, False, values, alpha, beta, max_depth, path, pruned)
            if val > best:
                best = val
```

```
                best_path = [node_index] + child_path
            alpha = max(alpha, best)
            if beta <= alpha:
                pruned.append((node_index, "Right" if i == 0 else "Left"))
                break
        return best, best_path
    else:
        best = math.inf
        best_path = []
        for i in range(2):
            val, child_path = alpha_beta(depth + 1, node_index * 2 + i, True, values, alpha, beta, max_depth, path, pruned)
            if val < best:
                best = val
                best_path = [node_index] + child_path
            beta = min(beta, best)
            if beta <= alpha:
                pruned.append((node_index, "Right" if i == 0 else "Left"))
                break
        return best, best_path


# Example usage
if __name__ == "__main__":
    # Example game tree (leaf node values)
    values = [3, 5, 6, 9, 1, 2, 0, -1]

    print("Leaf Node Values:", values)
    path = []
    pruned = []

    max_depth = 3
    result, best_path = alpha_beta(0, 0, True, values, -math.inf, math.inf, max_depth, path, pruned)

    print("\nOptimal Value at Root Node:", result)
    print("Best Path (Node Indices):", best_path)
    print("Pruned Nodes:", pruned)
```

Output:

```
••• Leaf Node Values: [3, 5, 6, 9, 1, 2, 0, -1]

    Optimal Value at Root Node: 5
    Best Path (Node Indices): [0, 0, 0, 1]
    Pruned Nodes: [(1, 'Right'), (1, 'Right')]
```