VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Aparna Sankar (1BM23CS047)

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 **Aparna Sankar (1BM23CS047),** 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.

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

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Github Link:

https://github.com/1BM23CS047/AI-lab

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<u>Program 1</u>
Implement Tic –Tac –Toe Game
Implement vacuum cleaner agent

Tic-Tac-Toe

Algorithm

Bafna Gold
Date: Page: 1

Tic - Tac - Toe Game
Week ~~Lab~~ - 1

~~Pseudocode~~: Algorithm:

→ start
→ initialize 3x3 board with spaces that are empty
→ Let computer play 'O'
→ Let user play 'X'
→ Let Users ~~Humans and Computer~~ Choose from row (1-3) and Column number (1-3)
→ When the chosen cell is free the user can enter 'X'
→ If the chosen cell is not free the system should display error and the User should ~~be~~ have to choose another cell that is free to ~~display~~ enter 'X'
→ After ~~that Dis~~ every move display the board
→ If the user wins the ~~displ~~ system should display 'you win'
→ If the rows and columns are full then the system should display 'draw'

For the Computer:-

Min Max Algorithm

→ call minmax (board, depth, ismaximizing = false)

→ undo move

→ If score > best score

let ~~sore~~ score be best score

→ minmax is recursively called to consider all moves to find the move of best score, that move is made by computer

→ return the best move

→ place 'O' in the best move cell.

→ if computer wins → print "computer win"

if board is full print 'draw'

↳ minmax (board, depth, ismaximizing)

If ~~O~~ "O" wins return +1

If "x" wins return -1

If board is full return 0

IF ismaximizing = "True"

Let bestscore = -∞

→ For each empty cell place "O"

recursively call minmax with ismaximizing = false

→ undo move

→ update best ~~cell~~ score = max (best_score, score)

→ return ~~the best~~ move best_score

else (user's turn)

~~place X on every possible empty space~~

initialize best_score = +∞

~~call minmax~~

is maximizing = true

call minmax (board, depth, ismaximizing)

- undo move

Bafna Gold
Date: Page:

if score > best_score
~~return~~ update best_score
- minimax is recursively called to consider all ~~moves~~ mov
- return the best move
- stop

Code

```
import math

def print_board(board):
    for row in board:
        print(" | ".join(row))
        print("-" * 5)

def check_winner(board, player):
    for row in board:
        if all(cell == player for cell in row):
            return True
    for col in range(3):
        if all(board[row][col] == player for row 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 minimax(board, depth, is_maximizing, ai, human):
    if check_winner(board, ai):
        return 1
    if check_winner(board, human):
        return -1
    if is_full(board):
        return 0
```

```
    if is_maximizing:
        best = -math.inf
        for r in range(3):
            for c in range(3):
                if board[r][c] == " ":
                    board[r][c] = ai
                    score = minimax(board, depth + 1, False, ai, human)
                    board[r][c] = " "
                    best = max(best, score)
        return best
    else:
        best = math.inf
        for r in range(3):
            for c in range(3):
                if board[r][c] == " ":
                    board[r][c] = human
                    score = minimax(board, depth + 1, True, ai, human)
                    board[r][c] = " "
                    best = min(best, score)
        return best

def best_move(board, ai, human):
    best_score = -math.inf
    move = None
    for r in range(3):
        for c in range(3):
            if board[r][c] == " ":
                board[r][c] = ai
                score = minimax(board, 0, False, ai, human)
                board[r][c] = " "
                if score > best_score:
                    best_score = score
                    move = (r, c)
    return move

def tic_tac_toe():
    board = [[" " for _ in range(3)] for _ in range(3)]
    human, ai = "X", "O"

    print("Welcome to Tic-Tac-Toe!")
    print("You are X, Computer is O (Unbeatable AI)")
    print_board(board)

    while True:
        # Human move
        try:
            row = int(input("Enter row (0-2): "))
```

```
            col = int(input("Enter col (0-2): "))
        except ValueError:
            print("Invalid input. Try again.")
            continue

        if row not in [0,1,2] or col not in [0,1,2] or board[row][col] != " ":
            print("Invalid move! Try again.")
            continue

        board[row][col] = human
        print_board(board)

        if check_winner(board, human):
            print("🎉 You win!")
            break
        if is_full(board):
            print("It's a draw!")
            break

        # Computer move
        print("Computer's turn...")
        row, col = best_move(board, ai, human)
        board[row][col] = ai
        print_board(board)

        if check_winner(board, ai):
            print("💻 Computer wins!")
            break
        if is_full(board):
            print("It's a draw!")
            break

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

Output

```
Welcome to Tic-Tac-Toe!
You are X, Computer is O (Unbeatable AI)
  |   |
-----
  |   |
-----
  |   |
-----
Enter row (0-2): 1
Enter col (0-2): 2
  |   |
-----
  |   | X
-----
  |   |
-----
Computer's turn...
  |   | O
-----
  |   | X
-----
  |   |
-----
```

```
Enter row (0-2): 1
Enter col (0-2): 0
  |   | O
-----
X |   | X
-----
  |   |
-----
Computer's turn...
  |   | O
-----
X | O | X
-----
  |   |
-----
```

```
Enter row (0-2): 0
Enter col (0-2): 0
X |   | O
-----
X | O | X
-----
  |   |
-----
Computer's turn...
X |   | O
-----
X | O | X
-----
O |   |
-----
💻 Computer wins!
```

Vacuum Cleaner

Algorithm

Vaccum Cleaner Algorithm

Function _ vaccum _ clener (room-array) :
for each room in room-array :
of room is duty:
print " Room [label] is cleaned"
else
print "Room [label] is already clean"
More to next room

```
def vaccum cleaner (room-array):
    for room in room array):
        label, status = room[0], room[1].lower()
~~print(f' Current room[2], room[3].lower')~~
        printf( Currently in room {label}")
        if status = = "dirty":
            print(f " Room {label} is cleaned")
        else:
            printf("Room {label} is already
                cleaned")

rooms = [('A', 'duty'), ('B', 'clean'), ('C', 'clean'),
         ('D', 'duty'), ('A', 'clean'))
vaccum_cleaner (rooms)
```

Code

```
def vacuum_cleaner(room_array):
    for room in room_array:
        label, status = room[0], room[1].lower()
        print(f"Currently in Room {label}")
        if status == "dirty":
            print(f"Room {label} is cleaned")
        else:
            print(f"Room {label} is already clean")
```

```
        print("Moving to next room...\n")

# Example input: list of rooms with their status
rooms = [('A', 'dirty'), ('B', 'clean'), ('A', 'clean'), ('B', 'dirty')]
vacuum_cleaner(rooms)
```

Output

```
Currently in Room A
Room A is cleaned
Moving to next room...

Currently in Room B
Room B is already clean
Moving to next room...

Currently in Room A
Room A is already clean
Moving to next room...

Currently in Room B
Room B is cleaned
Moving to next room...
```

<u>Program 2</u>

Implement 8 puzzle problems using Depth First Search (DFS)
Implement Iterative deepening search algorithm

8 Puzzle Problem

Algorithm

Date: Page:

Week Lab 2

Q) 8 puzzle problem using misplaced tiles and Manhattan distance and IDDFS

Initialize 8 puzzle problem using misplaced tiles and Manhattan distance

Goal State		
1	2	3
4	5	6
7	8	_

- Initialize by creating a priority queue
- $f(n) = \underbrace{g(n)}_{\text{total cost so far}} + h(n)$ - heuristic estimate
- Set g(start)=0
- Set f(start) = heuristic(start, goal)
- Store parent [start] = null
- Search loop
- insert start into openset
- Search loop while openset is not empty
- Remove the current with lowest f from openset

IF current = goal:

Return path by reconstructing from parent

Else expand current for each valid move of the blank tile:

- Generate neighbour with next move

tentative g = g(current) + 1

IF neighbour is not in gScore or tentative g < g(neighbour):

Update g(neighbour) = tentative_g

Compute f(neighbor) = g(neighbor) + heuristic (neighbor, goal)

Set parent [neighbor] = current

Add neighbor into openset

→ Failure occurs if openset becomes empty
so then theres no solution

Heuristic Functions
~~misplacedTiles (state, goal)~~

Code

```
import time

def find_possible_moves(state):
    index = state.index('_')
    moves = {
        0: [1, 3],
        1: [0, 2, 4],
        2: [1, 5],
        3: [0, 4, 6],
        4: [1, 3, 5, 7],
        5: [2, 4, 8],
        6: [3, 7],
        7: [6, 8, 4],
        8: [5, 7],
    }
    return moves.get(index, [])

def dfs(initial_state, goal_state, max_depth=50):
    stack = [(initial_state, [], 0)]
    visited = {tuple(initial_state)}
    states_explored = 0
    printed_depths = set()

    while stack:
```

```
        current_state, path, depth = stack.pop()

        if depth > max_depth:
            continue

        if depth not in printed_depths:
            print(f"\n--- Depth {depth} ---")
            printed_depths.add(depth)

        states_explored += 1
        print(f"State #{states_explored}: {current_state}")

        if current_state == goal_state:
            print(f"\n Goal reached at depth {depth} after exploring {states_explored} states.\n")
            return path, states_explored

        possible_moves_indices = find_possible_moves(current_state)

        for move_index in reversed(possible_moves_indices):  # Reverse for DFS order
            next_state = list(current_state)
            blank_index = next_state.index('_')
            next_state[blank_index], next_state[move_index] = next_state[move_index],
next_state[blank_index]

            if tuple(next_state) not in visited:
                visited.add(tuple(next_state))
                stack.append((next_state, path + [next_state], depth + 1))

    print(f"\n Goal state not reachable within depth {max_depth}. Explored {states_explored}
states.\n")
    return None, states_explored


# ----------------- TEST -----------------
initial_state = [1, 2, 3,
                 4, 8, '_',
                 7, 6, 5]

goal_state    = [1, 2, 3,
                 4, 5, 6,
                 7, 8, '_']

# Measure execution time
start_time = time.time()
solution_path, explored = dfs(initial_state, goal_state, max_depth=50)
end_time = time.time()
```

```
if solution_path is None:
    print("No solution found.")
else:
    print("Solution path:")
    for step, state in enumerate(solution_path, start=1):
        print(f"Step {step}: {state}")

print("\nExecution time: {:.6f} seconds".format(end_time - start_time))
print("Total states explored:", explored)
```

Output

```
--- Depth 0 ---
State #1: [1, 2, 3, 4, 8, '_', 7, 6, 5]

--- Depth 1 ---
State #2: [1, 2, '_', 4, 8, 3, 7, 6, 5]

--- Depth 2 ---
State #3: [1, '_', 2, 4, 8, 3, 7, 6, 5]

--- Depth 3 ---
State #4: ['_', 1, 2, 4, 8, 3, 7, 6, 5]

--- Depth 4 ---
State #5: [4, 1, 2, '_', 8, 3, 7, 6, 5]

--- Depth 5 ---
State #6: [4, 1, 2, 8, '_', 3, 7, 6, 5]

--- Depth 6 ---
State #7: [4, '_', 2, 8, 1, 3, 7, 6, 5]

--- Depth 7 ---
State #8: ['_', 4, 2, 8, 1, 3, 7, 6, 5]

--- Depth 8 ---
State #9: [8, 4, 2, '_', 1, 3, 7, 6, 5]
```

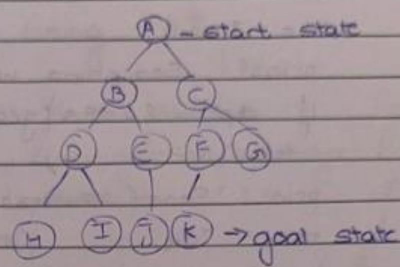
```
--- Depth 9 ---
State #10: [8, 4, 2, 1, '_', 3, 7, 6, 5]

--- Depth 10 ---
State #11: [8, '_', 2, 1, 4, 3, 7, 6, 5]

--- Depth 11 ---
State #12: ['_', 8, 2, 1, 4, 3, 7, 6, 5]

--- Depth 12 ---
State #13: [1, 8, 2, '_', 4, 3, 7, 6, 5]

--- Depth 13 ---
State #14: [1, 8, 2, 7, 4, 3, '_', 6, 5]

--- Depth 14 ---
State #15: [1, 8, 2, 7, 4, 3, 6, '_', 5]

--- Depth 15 ---
State #16: [1, 8, 2, 7, 4, 3, 6, 5, '_']

--- Depth 16 ---
State #17: [1, 8, 2, 7, 4, '_', 6, 5, 3]
```

IDDFS

Algorithm

IDDFS

graph




```
graph { 'A' : ['B', 'C'], 'B' : ['D', 'E'], 'C' : ['F', 'G'],
        'D' : ['H', 'I'], 'E' : ['J'], 'F' : ['K'],
        'G' : [], 'H' : [], 'I' : [] }  - graph struct

def depth_l_dfs(graph, current_node, goal_node,
                depth_limit):
    if current_node == goal_node:
    printf("Goal found at depth {depth_limit}")
    return 'True'

    if depth_limit == 0
        return false

    for i in graph.get(current_node, []):
        if depth_l_dfs(graph, i, goal_node,
                       depth_limit - 1):
            return True
    return False
```

Note Remaining Depth = Depth limit - Current Depth

Stopping condition IF Current Depth == Depth Limit cutd

```
def iddfs (graph, start_node, goal_node)
    depth=0
    while True:
        printf ("Searching with Depth limit
        if depth_l_dfs (graph, start_node, goal_node,
         depth)
        print ("Search successful!")
        return True
        depth += 1

start_node = 'A'
goal_node = 'F'
iddfs (graph, start_node, goal_node)
```

Output:

```
Searching with depth limit : 0
    "        "     "     "   : 1
    "        "     "     "   : 2
    "        "     "     "   : 3
Goal found at depth 0
search successful!
```

3/12

Code

import time

```
def find_possible_moves(state):
    index = state.index('_')

    if index == 0:
        return [1, 3]
    elif index == 1:
        return [0, 2, 4]
    elif index == 2:
        return [1, 5]
    elif index == 3:
        return [0, 4, 6]
    elif index == 4:
        return [1, 3, 5, 7]
    elif index == 5:
        return [2, 4, 8]
    elif index == 6:
        return [3, 7]
    elif index == 7:
        return [4, 6, 8]
    elif index == 8:
        return [5, 7]
    return []

def depth_limited_dfs(state, goal_state, limit, path, visited):
    if state == goal_state:
        return path

    if limit <= 0:
        return None

    visited.add(tuple(state))

    for move_index in find_possible_moves(state):
        next_state = list(state)
        blank_index = next_state.index('_')
        next_state[blank_index], next_state[move_index] = next_state[move_index],
next_state[blank_index]

        if tuple(next_state) not in visited:
            result = depth_limited_dfs(next_state, goal_state, limit - 1, path + [next_state], visited)
            if result is not None:
                return result
    return None

def iddfs(initial_state, goal_state, max_depth=30):
    for depth in range(max_depth):
        print(f"Searching at depth limit = {depth}")
```

```
        visited = set()
        result = depth_limited_dfs(initial_state, goal_state, depth, [initial_state], visited)
        if result is not None:
            return result, depth
    return None, max_depth

# ----------------- TEST -----------------
initial_state = [1, 2, 3,
                 4, 8, '_',
                 7, 6, 5]

goal_state    = [1, 2, 3,
                 4, 5, 6,
                 7, 8, '_']

# Measure execution time
start_time = time.time()
solution_path, depth_reached = iddfs(initial_state, goal_state, max_depth=30)
end_time = time.time()

if solution_path is None:
    print("Goal state is not reachable within given depth limit.")
else:
    print("\n\nSolution path found:")
    for step, state in enumerate(solution_path, start=0):
        print(f"Step {step}: {state}")

print("\nExecution time: {:.6f} seconds".format(end_time - start_time))
print("Depth reached:", depth_reached)
```

Output

```
Searching at depth limit = 0
Searching at depth limit = 1
Searching at depth limit = 2
Searching at depth limit = 3
Searching at depth limit = 4
Searching at depth limit = 5


Solution path found:
Step 0: [1, 2, 3, 4, 8, '_', 7, 6, 5]
Step 1: [1, 2, 3, 4, 8, 5, 7, 6, '_']
Step 2: [1, 2, 3, 4, 8, 5, 7, '_', 6]
Step 3: [1, 2, 3, 4, '_', 5, 7, 8, 6]
Step 4: [1, 2, 3, 4, 5, '_', 7, 8, 6]
Step 5: [1, 2, 3, 4, 5, 6, 7, 8, '_']

Execution time: 0.000194 seconds
Depth reached: 5

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

Program 3

Implement A* search algorithm

Algorithm

10/9/25

Week ~~Lab~~ 3

Q 8 puzzle using A*

```
- function a* aStarSearch(startState,
                 goalState, heuristicType)      Goal State =
                                                { {1,2,3}
  openlist = priority Queue()                     {4,5,6},
  closedlist = set()                              {7,8,0} }
  StartNode = CreateBoard(start state, Null,
                    0,0)
  openlist.enqueue(Start Node)
  while openlist is not empty:
      current Node = openlist.dequeue()
      if current node = openlist.dequeue()
         return reconstructPath(current Node)
         ~~currentNode~~
         closedlist.add(current Node)
         for each move in valid Moves :
             childstate = applyNone(Current Node, none)
         if  childstate in closed list:
             continue
         g = current Node.g + 1
         if heuristicType == 'Misplaced Tiles'
             h = misplaced_tiles(childState)
      else:
             h = manhattan_dist(childstate)
      f = g+h
      childNode = create Node(ChildState,
                          currentNode, g, f)
      openlist.push(childNode)
  return NULL
```

```
function reconstructPath(node):
    path = []
    while node is not NULL:
        path.append(node)
        node = node.parent
    return reverse(path)
```

```
1 2 3
- 4 6
7 5 8
```

$g=0$ $\boxed{h=3}$ $F=g+h=3$

$g=1, h=4, F=5$

```
- 2 3
1 4 6
7 5 8
```

$g=1, h=2, f=3$

```
1 2 3
4 - 6
7 5 8
```

$g=1, h=4, F=5$

```
1 2 3
7 4 6
- 5 8
```

```
1 2 3
4 5 6
7 - 8
```

```
1 2 3
4 6 -
7 5 8
```

```
1 - 3
4 2 6
7 5 8
```

$g=2, h=1, f=3$ $g=2, h=3, f=5$ $g=2, h=3, f=5$

```
1 2 3
4 5 6
- 7 8
```

```
1 2 3
4 5 6
7 8 -
```

goal state

$g=3$ $h=2$ $f=5$ $g=3$ $h=0$ $f=3$

Code

```
import heapq
import time

# Heuristic: Manhattan Distance
def heuristic(state, goal):
    distance = 0
    for i in range(1, 9):  # tile numbers 1 to 8
        x1, y1 = divmod(state.index(i), 3)
        x2, y2 = divmod(goal.index(i), 3)
distance += abs(x1 - x2) + abs(y1 - y2)
return distance

# Get neighbors by sliding blank (0) up/down/left/right
def get_neighbors(state):
    neighbors = []
    i = state.index(0)  # position of blank
    x, y = divmod(i, 3)
    moves = [(-1,0), (1,0), (0,-1), (0,1)]

    for dx, dy in moves:
new_x, new_y = x + dx, y + dy
if 0 <= new_x < 3 and 0 <= new_y < 3:
            j = new_x * 3 + new_y
            new_state = list(state)
            new_state[i], new_state[j] = new_state[j], new_state[i]
            neighbors.append(tuple(new_state))
    return neighbors

# A* Search for 8-puzzle
def astar(start, goal):
    open_set = []
    heapq.heappush(open_set, (heuristic(start, goal), 0, start))

    came_from = {}
    g_score = {start: 0}

    while open_set:
        _, cost, current = heapq.heappop(open_set)

        if current == goal:
            # Reconstruct path
            path = []
            while current in came_from:
                path.append(current)
```

```
            current = came_from[current]
        path.append(start)
        return path[::-1]

    for neighbor in get_neighbors(current):
        tentative_g = g_score[current] + 1
        if neighbor not in g_score or tentative_g < g_score[neighbor]:
            came_from[neighbor] = current
            g_score[neighbor] = tentative_g
            f_score = tentative_g + heuristic(neighbor, goal)
            heapq.heappush(open_set, (f_score, tentative_g, neighbor))

    return None  # no solution

# ----------------- TEST -----------------
start = (1, 2, 3,
         4, 8, 0,
         7, 6, 5)

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

# Measure execution time
start_time = time.time()
path = astar(start, goal)
end_time = time.time()

if path:
    print("Steps to solve ({} moves):".format(len(path)-1))
    for state in path:
        for i in range(0, 9, 3):
            print(state[i:i+3])
        print()
else:
    print("No solution found")

print("Execution time: {:.6f} seconds".format(end_time - start_time))
```

Output

```
Steps to solve (5 moves):
(1, 2, 3)
(4, 8, 0)
(7, 6, 5)

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

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

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

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

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

Execution time: 0.000111 seconds
```

Program 4

Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm

8/10/25

Week 4

Q N Queens problem Using Hill Climbing

function Hill-Climbing (Problem) returns local minima ~~maxima~~

    current ← Make Node (Problem.initalState)
    while True;
        next ← get_best_neighbor(curent)
        if cost (current) <= cost (~~next~~)
                    then break
        end if
        current ← next
    end while
    return current

Eg) Initial State =

	0	1	2	3
				Q
		Q		
			Q	
	Q			

$x_0 = 3$
$x_1 = 1$
$x_2 = 2$
$x_3 = 0$

Cost = 2

Possible children

1) Swap (x_0, x_1)

			Q
Q			
		Q	
	Q		

Choose this

$x_0 = 1$, $x_1 = 3$,

ii) Swap (x_0, x_2)

			Q
	Q		
Q			
		Q	

$x_0 = 2,\ x_1 = 1,\ x_2 = 3,\ x_3 = 0$

cost = 1

iii) Swap (x_0, x_3)

Q			
	Q		
		Q	
			Q

$x_0 = 0,\ x_1 = 1,\ x_2 = 2,\ x_3 = 3$

cost = 6

iv) Swap (x_1, x_2)

			Q
		Q	
	Q		
Q			

$x_0 = 3,\ x_1 = 2,\ x_2 = 1,\ x_3 = 0$

Cost = 6

v) Swap (x_1, x_3)

	Q		
			Q
		Q	
Q			

$x_0 = 3,\ x_1 = 0,\ x_2 = 2,\ x_3 = 1$

Cost = 1

vi) Swap (x_2, x_3)

		Q	
	Q		
			Q
Q			

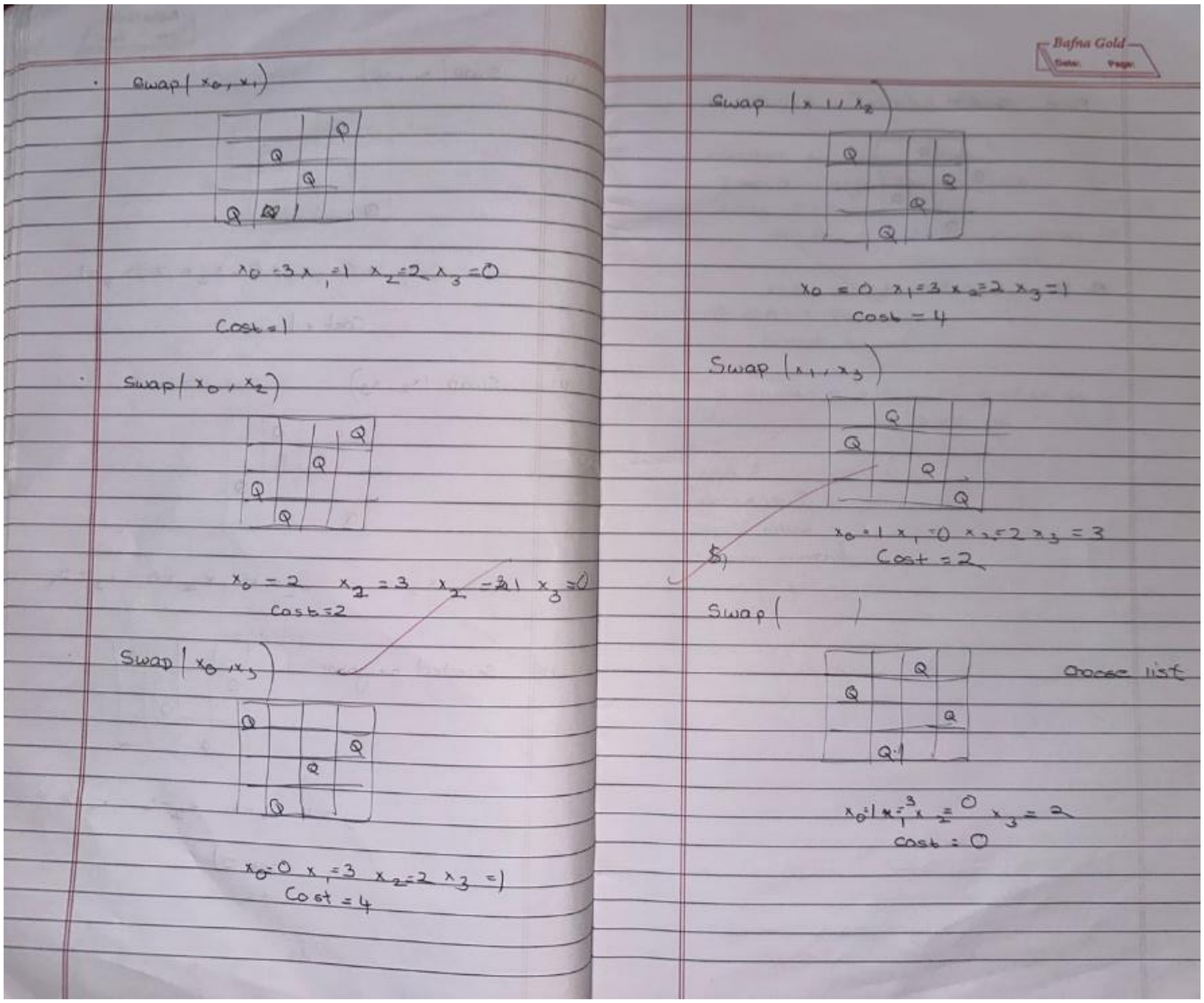
$x_0 = 3 \quad x_2 = 1 \quad x_2 = 0 \quad x_3 = 2$

vii) Selected neighbor =

			Q
Q			
		Q	
	Q		

$x_0 = 1 \quad x_2 = 3 \quad x_2 = 2 \quad x_3 = 0$

Cost = 1



Code

```
import random
import math

def compute_cost(state):
    """Count diagonal conflicts for a permutation-state (one queen per row & column)."""
    conflicts = 0
    n = len(state)
    for i in range(n):
        for j in range(i + 1, n):
            if abs(state[i] - state[j]) == abs(i - j):
                conflicts += 1
    return conflicts
```

```
def random_permutation(n):
    arr = list(range(n))
    random.shuffle(arr)
    return arr

def neighbors_by_swaps(state):
    """All neighbors obtained by swapping two columns (keeps permutation property)."""
    n = len(state)
    for i in range(n - 1):
        for j in range(i + 1, n):
            nb = state.copy()
            nb[i], nb[j] = nb[j], nb[i]
            yield nb

def hill_climb_with_restarts(n, max_restarts=None):
    """Hill climbing on permutations with random restart on plateau (no revisits)."""
    visited = set()
    total_states = math.factorial(n)
    restarts = 0

    while True:
        # pick a random unvisited start permutation
        if len(visited) >= total_states:
            raise RuntimeError("All states visited — giving up (no solution found).")

        state = random_permutation(n)
        while tuple(state) in visited:
            state = random_permutation(n)
        visited.add(tuple(state))

        # climb from this start
        while True:
            cost = compute_cost(state)
            if cost == 0:
                return state, restarts

            # find best neighbor (swap-based neighbors)
            best_neighbor = None
            best_cost = float("inf")
            for nb in neighbors_by_swaps(state):
                c = compute_cost(nb)
                if c < best_cost:
                    best_cost = c
                    best_neighbor = nb

            # if strictly better, move; otherwise it's a plateau/local optimum -> restart
```

```python
            if best_cost < cost:
                state = best_neighbor
                visited.add(tuple(state))
            else:
                # plateau or local optimum -> restart
                restarts += 1
                if max_restarts is not None and restarts >= max_restarts:
                    raise RuntimeError(f"Stopped after {restarts} restarts (no solution found).")
                break  # go pick a new unvisited start

def format_board(state):
    n = len(state)
    lines = []
    for r in range(n):
        lines.append(" ".join("Q" if state[c] == r else "-" for c in range(n)))
    return "\n".join(lines)

if __name__ == "__main__":
    n = 4
    solution, restarts = hill_climb_with_restarts(n)
    print("Found solution:", solution)
    print(format_board(solution))
```

Output

```
Found solution: [2, 0, 3, 1]
- Q - -
- - - Q
Q - - -
- - Q -
```

Program 5

Simulated Annealing to Solve 8-Queens problem

Algorithm

N Queens Simulated Annealing

```
current ← initial state
 T ← a large positive value
 while T > 0 do
      next ← a random neighbor of current
      ΔE ← current.cost − next.cost
 if ΔE > 0 then
      current ← next
 else
      current ← next with probability
                   p = e^(ΔE / T)
 end if
 decrease T
 end while
 return current
```

Code

```
import random
import math

def cost(state):

    attacks = 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):
                attacks += 1
    return attacks

def get_neighbor(state):

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

def simulated_annealing(n=8, max_iter=10000, temp=100.0, cooling=0.95):

    current = list(range(n))
    random.shuffle(current)
    current_cost = cost(current)

    temperature = temp
    cooling_rate = cooling

    best = current[:]
    best_cost = current_cost

    for _ in range(max_iter):
        if temperature <= 0 or best_cost == 0:
            break

        neighbor = get_neighbor(current)
        neighbor_cost = cost(neighbor)
        delta = current_cost - neighbor_cost

        if delta > 0 or random.random() < math.exp(delta / temperature):
            current, current_cost = neighbor, neighbor_cost
            if neighbor_cost < best_cost:
                best, best_cost = neighbor[:], neighbor_cost

        temperature *= cooling_rate

    return best, best_cost

def print_board(state):

    n = len(state)
    for row in range(n):
        line = " ".join("Q" if state[col] == row else "." for col in range(n))
```

```
        print(line)
    print()


n = 8
solution, cost_val = simulated_annealing(n, max_iter=20000)
print("Best position found:", solution)
print(f"Number of non-attacking pairs: {n*(n-1)//2 - cost_val}")
print("\nBoard:")
print_board(solution)
```

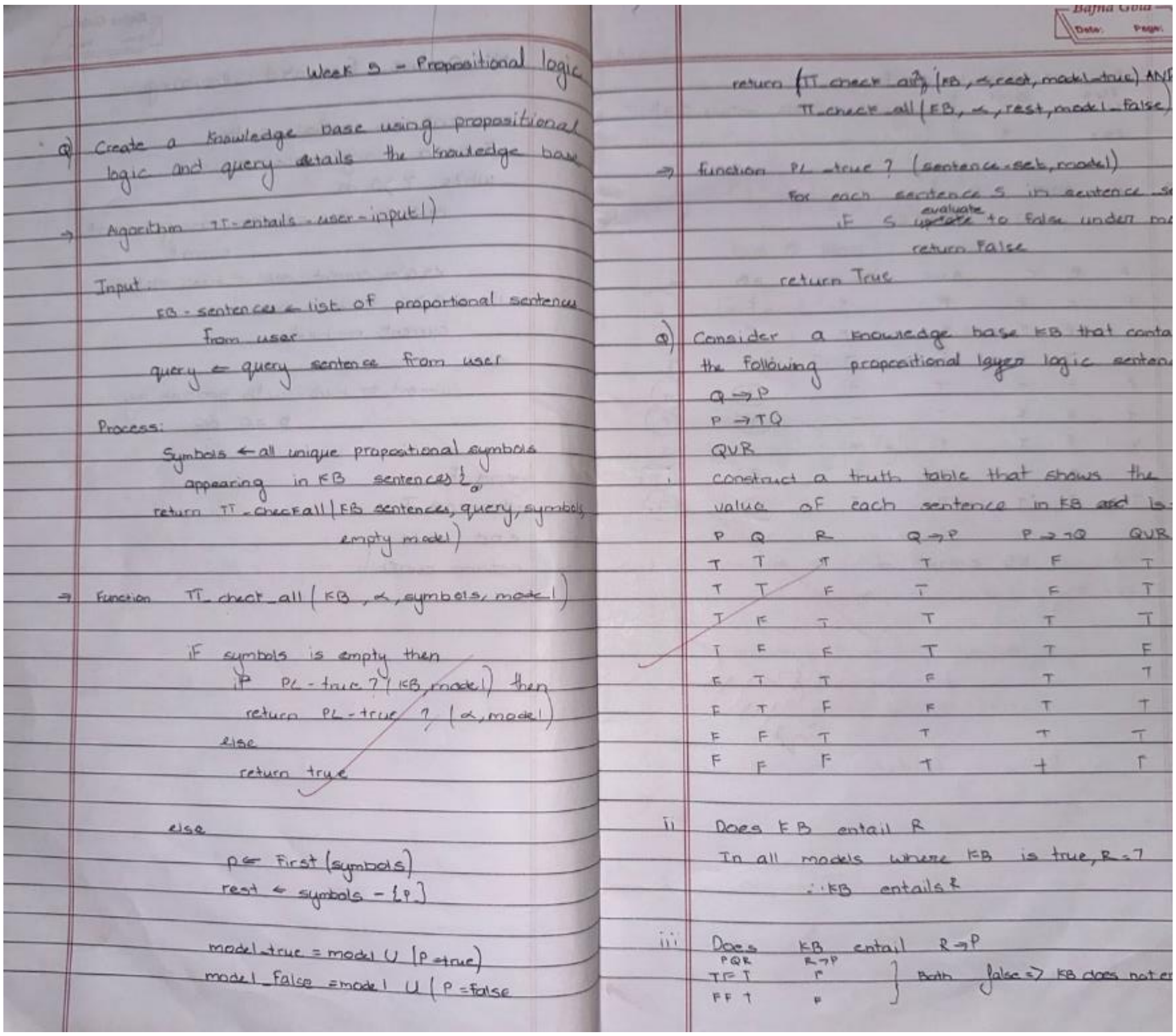
Output

```
Best position found: [6, 3, 1, 7, 5, 0, 2, 4]
Number of non-attacking pairs: 28

Board:
. . . . . Q . .
. . Q . . . . .
. . . . . . Q .
. Q . . . . . .
. . . . . . . Q
. . . . Q . . .
Q . . . . . . .
. . . Q . . . .


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

Program 6

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

Algorithm



Week 5 - Propositional logic

Q) Create a knowledge base using propositional logic and query details the knowledge base

→ Algorithm TT-entails-user-input()

Input:
  KB-sentences ← list of proportional sentences from user
  query ← query sentence from user

Process:
  Symbols ← all unique propositional symbols appearing in KB sentences ∪ α
  return TT-checkall(KB sentences, query, symbols, empty model)

→ Function TT_check_all(KB, α, symbols, model)

  if symbols is empty then
    if PL-true?(KB, model) then
      return PL-true?(α, model)
    else
      return true

  else
    p ← First(symbols)
    rest ← symbols - {P}

    model_true = model ∪ {P = true}
    model_false = model ∪ {P = false

    return (TT_check_all(KB, α, rest, model_true) AND
      TT_check_all(KB, α, rest, model_false)

→ function PL_true?(sentence_set, model)
    For each sentence S in sentence_set
      if S ~~update~~ evaluate to false under model
        return False
    return True

Q) Consider a knowledge base KB that contains the following propositional ~~layer~~ logic sentences
$Q \rightarrow P$
$P \rightarrow \neg Q$
$Q \vee R$

i. Construct a truth table that shows the value of each sentence in KB and is

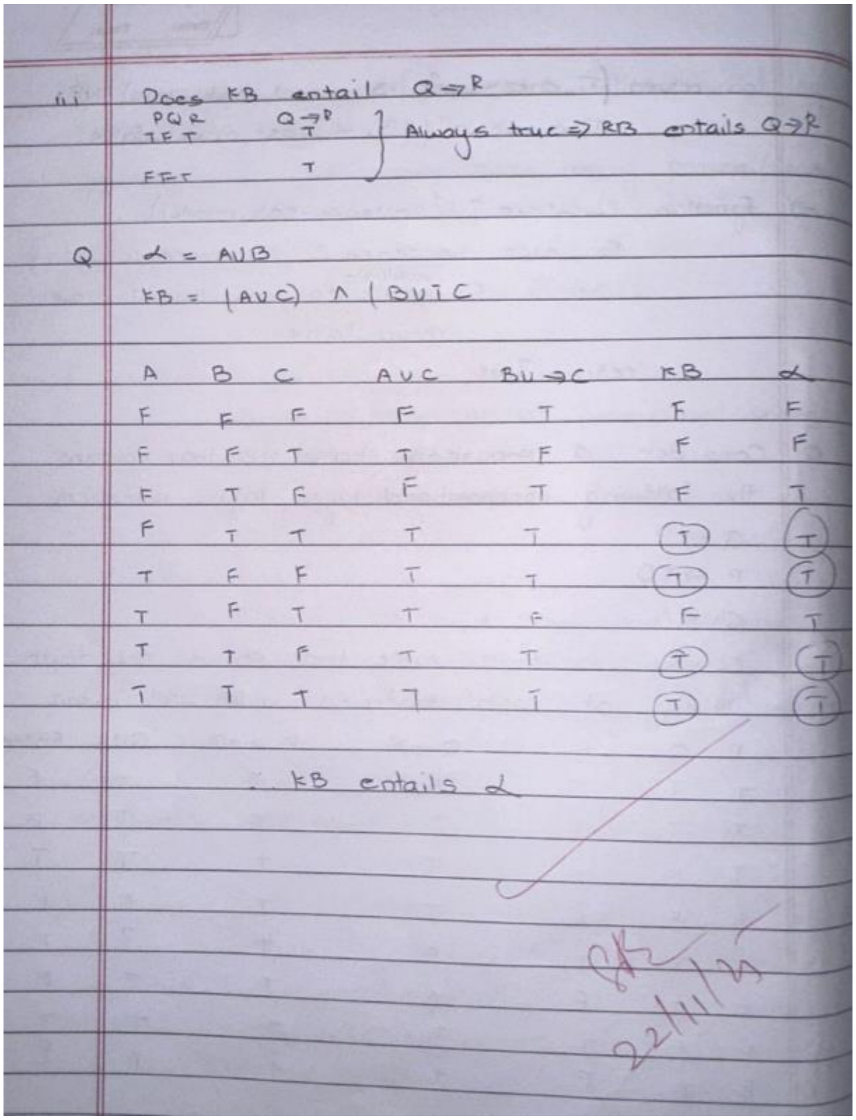
P	Q	R	$Q \rightarrow P$	$P \rightarrow \neg Q$	$Q \vee R$
T	T	T	T	F	T
T	T	F	T	F	T
T	F	T	T	T	T
T	F	F	T	T	F
F	T	T	F	T	T
F	T	F	F	T	T
F	F	T	T	T	T
F	F	F	T	T	T

ii. Does KB entail R
In all models where KB is true, R = T
∴ KB entails R

iii. Does KB entail $R \rightarrow P$

P Q R	$R \rightarrow P$
T F T	F
F F T	F

Both false ⇒ KB does not en



iii) Does KB entail $Q \Rightarrow R$

P	Q	R	$Q \Rightarrow R$
T	F	T	T
F	F	T	T

Always true $\Rightarrow$ KB entails $Q \Rightarrow R$

Q $\alpha = A \vee B$

$KB = (A \vee C) \wedge (B \vee \neg C)$

A	B	C	$A \vee C$	$B \vee \neg C$	KB	α
F	F	F	F	T	F	F
F	F	T	T	F	F	F
F	T	F	F	T	F	T
F	T	T	T	T	T	T
T	F	F	T	T	T	T
T	F	T	T	F	F	T
T	T	F	T	T	T	T
T	T	T	T	T	T	T

$\therefore$ KB entails α

22/11/24

Code

```
import itertools
def evaluate_formula(formula, truth_assignment):
    eval_formula = formula
    for symbol, value in truth_assignment.items():
        eval_formula = eval_formula.replace(symbol, str(value))
    return eval(eval_formula)

def generate_truth_table(variables):
    return list(itertools.product([False, True], repeat=len(variables)))

def is_entailed(KB_formula, alpha_formula, variables):
    truth_combinations = generate_truth_table(variables)
```

```
    print(f"{' '.join(variables)} | KB Result | Alpha Result")
    print("-" * (len(variables) * 2 + 15))
    for combination in truth_combinations:
        truth_assignment = dict(zip(variables, combination))
        KB_value = evaluate_formula(KB_formula, truth_assignment)
        alpha_value = evaluate_formula(alpha_formula, truth_assignment)
        result_str = " ".join(["T" if value else "F" for value in combination])
        print(f"{result_str} | {'T' if KB_value else 'F'}         | {'T' if alpha_value else 'F'}")
        if KB_value and not alpha_value:
            return False
    return True

KB = "(A or C) and (B or not C)"
alpha = "A or B"
variables = ['A', 'B', 'C']

if is_entailed(KB, alpha, variables):
    print("\nThe knowledge base entails alpha.")
else:
    print("\nThe knowledge base does not entail alpha.")
```

Output

```
A B C | KB Result | Alpha Result
---------------------
F F F | F         | F
F F T | F         | F
F T F | F         | T
F T T | T         | T
T F F | T         | T
T F T | F         | T
T T F | T         | T
T T T | T         | T

The knowledge base entails alpha.
```

Program 7

Implement unification in first order logic

Algorithm

29-10-25

Week 6 - Unification of FOL

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

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

Find θ (MGU)

(2) $Q(x, F(x))$

$Q(F(y), y)$

(3) $H(x, g(x))$

$H(g(y), g(g(z)))$

Answer

1 Compare x with $g(z)$, $\theta_1 = \{x/g(z)\}$

y with $F(a)$, $\theta_2 = \{y/F(a)\}$

Substituting θ in $P(F(x), g(y), y)$

=

$P(F(g(z)), g(F(a)), F(a))$

∴ both are identical ∴ unified

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

2 Comparing x with $F(y)$

Substituting θ in $Q(x, F(x))$

$= Q(F(y), F(F(y)))$

$F(F(y)) = y$

it is cyclic so not unifable

3) comparing x with $g(y)$

$x = g(y)$

comparing $g(x)$ & $g(g(z))$

$x = g(y)$

$\theta_1 = \{x/g(y)\}$

$g(x) = g(g(y))$

if $y = z$, $g(g(y)$ can be unifed but $g(g(z))$

$\theta_2 = \{y, z\}$

put θ_1 in $H(x, g(x))$

$\theta(MGU) = \{x, g(y), y, z\}$

$= H(g(y), g(g(y)))$

$= H(g(y), g(g(z)))$

$\therefore$ it is identical

$\therefore$ it is unifable

Execute

Without AB prung — 8 puzzle

Code

```
import re

def is_variable(x):
    return x[0].islower() and x.isalpha()

def parse(term):
    term = term.strip()
    if '(' not in term:
        return term
    name, args = term.split('(', 1)
    args = args[:-1]  # remove closing parenthesis
    return name.strip(), [parse(a.strip()) for a in args.split(',')]

def occurs_check(var, expr):
    if var == expr:
        return True
    if isinstance(expr, tuple):
        _, args = expr
        return any(occurs_check(var, a) for a in args)
    return False

def substitute(subs, expr):
    if isinstance(expr, str):
        if expr in subs:
            return substitute(subs, subs[expr])
        return expr
    else:
        func, args = expr
        return (func, [substitute(subs, a) for a in args])

def unify(x, y, subs=None):
    if subs is None:
        subs = {}

    x = substitute(subs, x)
    y = substitute(subs, y)

    if x == y:
```

```
        return subs

    if isinstance(x, str) and is_variable(x):
        if occurs_check(x, y):
            return None
        subs[x] = y
        return subs

    if isinstance(y, str) and is_variable(y):
        if occurs_check(y, x):
            return None
        subs[y] = x
        return subs

    if isinstance(x, tuple) and isinstance(y, tuple):
        if x[0] != y[0] or len(x[1]) != len(y[1]):
            return None
        for a, b in zip(x[1], y[1]):
            subs = unify(a, b, subs)
            if subs is None:
                return None
        return subs

    return None


def term_to_str(t):
    if isinstance(t, str):
        return t
    func, args = t
    return f"{func}({', '.join(term_to_str(a) for a in args)})"

def pretty_print(subs):
    return ', '.join(f"{v} : {term_to_str(t)}" for v, t in subs.items())


pairs = [
    ("P(f(x),g(y),y)", "P(f(g(z)),g(f(a)),f(a))"),
    ("Q(x,f(x))", "Q(f(y),y)"),
    ("H(x,g(x))", "H(g(y),g(g(z)))")
```

```
]

for s1, s2 in pairs:
    print(f"\nUnifying: {s1}  and  {s2}")
    result = unify(parse(s1), parse(s2))
    if result:
        print("=> Substitution:", pretty_print(result))
    else:
        print("=> Not unifiable.")
```

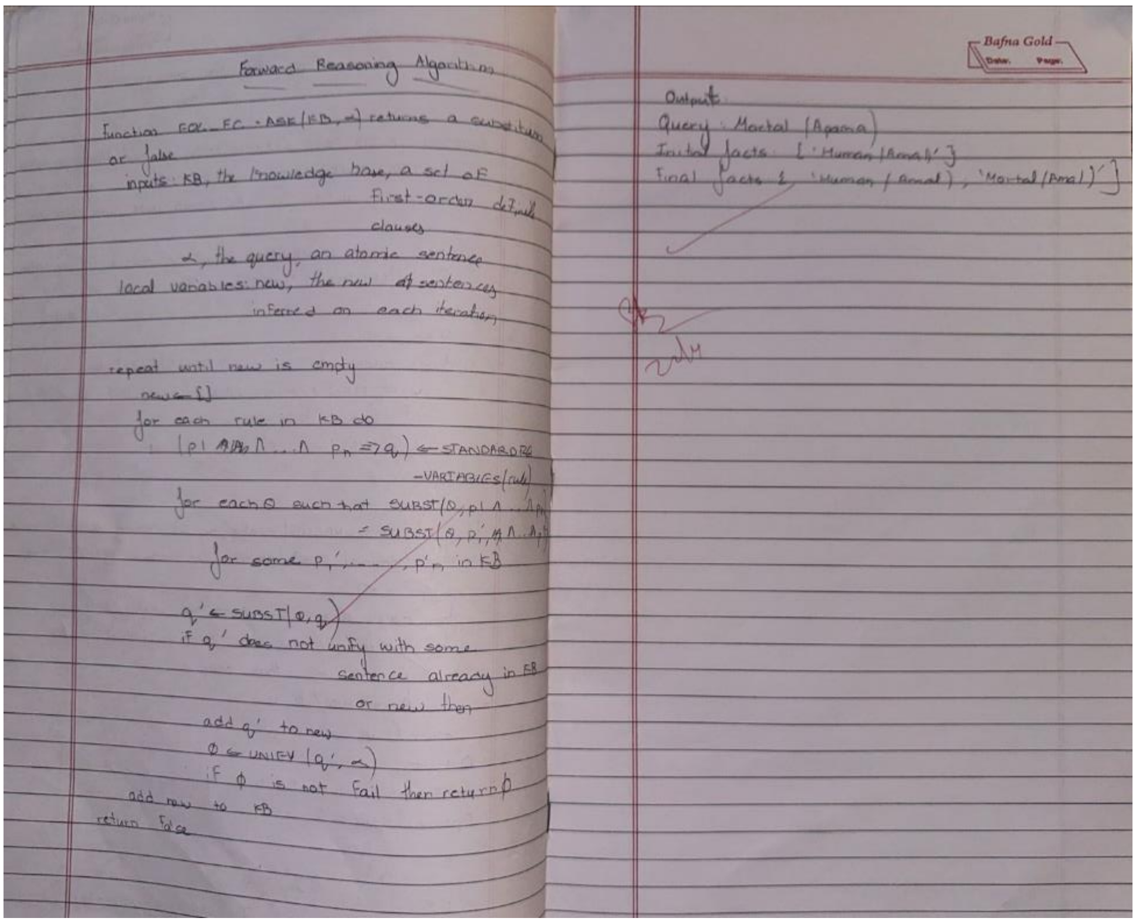
Output:

```
Unifying: P(f(x),g(y),y)  and  P(f(g(z)),g(f(a)),f(a))
=> Substitution: x : g(z), y : f(a)

Unifying: Q(x,f(x))  and  Q(f(y),y)
=> Not unifiable.

Unifying: H(x,g(x))  and  H(g(y),g(g(z)))
=> Substitution: x : g(y), y : 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
(p1 ∧ ... ∧ pn ⇒ q) ← STANDARDIZE-VARIABLES(rule)
for each θ such that SUBST(θ, p1 ∧ ... ∧ pn) = SUBST(θ, p1′ ∧ ... ∧ pn′)
for some p1′, ..., pn′ 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

Bafna Gold
Date. Page.

Output:
Query: Mortal (Apama)
Initial facts: {'Human (Amal)'}
Final facts: {'Human (Amal)', 'Mortal (Amal)'}

Code

```
import re

def match_pattern(pattern, fact):
    """
    Checks if a fact matches a rule pattern using regex-style variable substitution.
    Variables are lowercase words like p, q, x, r etc.
    Returns a dict of substitutions or None if not matched.
    """
    # Extract predicate name and arguments
    pattern_pred, pattern_args = re.match(r'(\w+)
', pattern).groups()
    fact_pred, fact_args = re.match(r'(\w+)
', fact).groups()

    if pattern_pred != fact_pred:
        return None  # predicate mismatch

    pattern_args = [a.strip() for a in pattern_args.split(",")]
    fact_args = [a.strip() for a in fact_args.split(",")]

    if len(pattern_args) != len(fact_args):
        return None

    subst = {}
    for p_arg, f_arg in zip(pattern_args, fact_args):
        if re.fullmatch(r'[a-z]\w*', p_arg):  # variable
            subst[p_arg] = f_arg
        elif p_arg != f_arg:  # constants mismatch
            return None
    return subst


def apply_substitution(expr, subst):
    """Replaces all variable names in expr using the given substitution dict."""
    for var, val in subst.items():
        expr = re.sub(rf'\b{var}\b', val, expr)
    return expr


# ---------- Knowledge Base ----------

rules = [
    (["American(p)", "Weapon(q)", "Sells(p,q,r)", "Hostile(r)"], "Criminal(p)"),
    (["Missile(x)"], "Weapon(x)"),
    (["Enemy(x, America)"], "Hostile(x)"),
    (["Missile(x)", "Owns(A, x)"], "Sells(Robert, x, A)")
]
```

```
facts = {
    "American(Robert)",
    "Enemy(A, America)",
"Owns(A, T1)",
    "Missile(T1)"
}

goal = "Criminal(Robert)"

def forward_chain(rules, facts, goal):
    added = True
    while added:
        added = False
        for premises, conclusion in rules:

            possible_substs = []
            for p in premises:
                for f in facts:
                    subst = match_pattern(p, f)
                    if subst:
                        possible_substs.append(subst)
                        break
                else:

                    break
            else:

                combined = {}
                for s in possible_substs:
                    combined.update(s)

                new_fact = apply_substitution(conclusion, combined)

                if new_fact not in facts:
                    facts.add(new_fact)
                    print(f"Inferred: {new_fact}")
                    added = True
                    if new_fact == goal:
                        return True
    return goal in facts


print("Goal achieved:", forward_chain(rules, facts, goal))
```

Output

```
Inferred: Weapon(T1)
Inferred: Hostile(A)
Inferred: Sells(Robert, T1, A)
Inferred: Criminal(Robert)
Goal achieved: True
```

Program 9

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

Algorithm

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12-11-23

Week 7

Convert a given First order logic statement into Conjuctive Normal Form (CNF)

procedure TO-CNF(F):

# Step1: Eliminate implications and biconditionals
for each subformula in F:
    if subformula is (A → B):
        replace with (¬A ∨ B)
    iF subformula is (A ⇔ B):
        replace with ((¬A ∨ B) ∧ (A ∨ ¬B))

# Step2 Move negations inward
while there exists a negation applied to a compound formula:
    apply De Morgan's laws:
        ¬(A ∧ B) → (¬A ∨ ¬B)
        ¬(A ∨ B) → (¬A ∧ ¬B)
    push ¬ through quantifiers:
        ¬∀x P(x) → ∃x ¬P(x)
        ¬Ex P(x) → ∀x ¬P(x)
    remove double negations:
        ¬(¬A) → A

# Step3 : Standardize variable
for each quantified variable x in F:
    iF variable name repeats:
        rename it to a unique variable

```
#step 4: Skolemize (remove existential quantifiers)
    For each ∃x in F:
        if ∃x is inside ∀y1, ∀y2, ... ∀yn:
            replace x with a new skolem
                                function F(y1, y2, ... yn)
        else:
            replace x with a new skolem constant
        remove ∃ quantifier

# Step 5: Drop universal quantifiers
remove all ∀ quantifiers (all variables now
                          implicitly universal)

# Step 6: Distribute ∨ over ∧
repeat until no distribution is possible
    apply rules:
        (A ∨ (B ∧ C)) → ((A ∨ B) ∧ (A ∨ C))
        ((A ∧ B) ∨ C) → ((A ∨ C) ∧ (B ∨ C))

# Step 7: Simplify
remove duplicate literals in clauses
remove tautological clauses (where A and ¬A appear
                             together)

return F
```

Output

Function: (A → (B ∨ C)) ∧ ¬(D → E)

Output: (¬A ∨ B ∨ C) ∧ D ∧ ¬E

Code

```
from copy import deepcopy

def print_step(title, content):
    print(f"\n{'='*45}\n{title}\n{'='*45}")
    if isinstance(content, list):
        for i, c in enumerate(content, 1):
            print(f"{i}. {c}")
```

```
    else:
        print(content)

KB = [
    ["¬Food(x)", "Likes(John,x)"],
    ["Food(Apple)"],
    ["Food(Vegetable)"],
    ["¬Eats(x,y)", "Killed(x)", "Food(y)"],
    ["Eats(Anil,Peanuts)"],
    ["Alive(Anil)"],
    ["¬Alive(x)", "¬Killed(x)"],
    ["Killed(x)", "Alive(x)"]
]

QUERY = ["Likes(John,Peanuts)"]

def negate(literal):
    if literal.startswith("¬"):
        return literal[1:]
    return "¬" + literal

def substitute(clause, subs):
    new_clause = []
    for lit in clause:
        for var, val in subs.items():
            lit = lit.replace(var, val)
        new_clause.append(lit)
    return new_clause

def unify(lit1, lit2):
    """Small unifier for patterns like Food(x) and Food(Apple)."""
    if "(" not in lit1 or "(" not in lit2:
        return None
    pred1, args1 = lit1.split("(")
    pred2, args2 = lit2.split("(")
    args1 = args1[:-1].split(",")
    args2 = args2[:-1].split(",")
    if pred1 != pred2 or len(args1) != len(args2):
        return None
    subs = {}
    for a, b in zip(args1, args2):
        if a == b:
            continue
        if a.islower():
            subs[a] = b
        elif b.islower():
            subs[b] = a
```

```
        else:
            return None
    return subs

def resolve(ci, cj):
    """Return list of (resolvent, substitution, pair)."""
    resolvents = []
    for li in ci:
        for lj in cj:
            if li == negate(lj):
                new_clause = [x for x in ci if x != li] + [x for x in cj if x != lj]
                resolvents.append((list(set(new_clause)), {}, (li, lj)))
            else:
                # same predicate, opposite sign
                if li.startswith("¬") and not lj.startswith("¬") and li[1:].split("(")[0] == lj.split("(")[0]:
                    subs = unify(li[1:], lj)
                    if subs:
                        new_clause = substitute([x for x in ci if x != li] + [x for x in cj if x != lj], subs)
                        resolvents.append((list(set(new_clause)), subs, (li, lj)))
                elif lj.startswith("¬") and not li.startswith("¬") and lj[1:].split("(")[0] == li.split("(")[0]:
                    subs = unify(lj[1:], li)
                    if subs:
                        new_clause = substitute([x for x in ci if x != li] + [x for x in cj if x != lj], subs)
                        resolvents.append((list(set(new_clause)), subs, (li, lj)))
    return resolvents

def resolution(kb, query):
    clauses = deepcopy(kb)
    negated_query = [negate(q) for q in query]
    clauses.append(negated_query)
    print_step("Initial Clauses", clauses)

    steps = []
    new = []
    while True:
        pairs = [(clauses[i], clauses[j]) for i in range(len(clauses))
                  for j in range(i + 1, len(clauses))]
        for (ci, cj) in pairs:
            for r, subs, pair in resolve(ci, cj):
                if not r:
                    steps.append({
                        "parents": (ci, cj),
                        "resolvent": r,
                        "subs": subs
                    })
                    print_tree(steps)
                    print("\n✅ Empty clause derived — query proven.")
```

```
                return True
            if r not in clauses and r not in new:
                new.append(r)
                steps.append({
                    "parents": (ci, cj),
                    "resolvent": r,
                    "subs": subs
                })
        if all(r in clauses for r in new):
            print_step("No New Clauses", "Query cannot be proven ❌")
            print_tree(steps)
            return False
        clauses.extend(new)

def print_tree(steps):
    print("\n" + "="*45)
    print("Resolution Proof Trace")
    print("="*45)
    for i, s in enumerate(steps, 1):
        p1, p2 = s["parents"]
        r = s["resolvent"]
        subs = s["subs"]
        subs_text = f"  Substitution: {subs}" if subs else ""

        print(f"  Resolve {p1} and {p2}")
        if subs_text:
            print(subs_text)
        if r:
            print(f"  ⇒ {r}")
        else:
            print("  ⇒ {} (empty clause)")
        print("-"*45)

def main():
    print_step("Knowledge Base in CNF", KB)
    print_step("Negated Query", [negate(q) for q in QUERY])
    proven = resolution(KB, QUERY)
    if proven:
        print("\n✅ Query Proven by Resolution: John likes peanuts.")
    else:
        print("\n❌ Query cannot be proven from KB.")

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

Output

```
Unifying: P(f(x),g(y),y)  and  P(f(g(z)),g(f(a)),f(a
    ))
=> Substitution: x : g(z), y : f(a)

Unifying: Q(x,f(x))  and  Q(f(y),y)
=> Not unifiable.

Unifying: H(x,g(x))  and  H(g(y),g(g(z)))
=> Substitution: x : g(y), y : z

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

Program 10

Implement Alpha-Beta Pruning

Algorithm

2-11-25

Date: Page:

Alpha beta Search
Algorithm

function ALPHA-BETA-SEARCH(state) ~~remove~~ returns an action
  v ← MAX-VALUE(state, −∞, +∞)
  return the action in ACTIONS(state) with value v

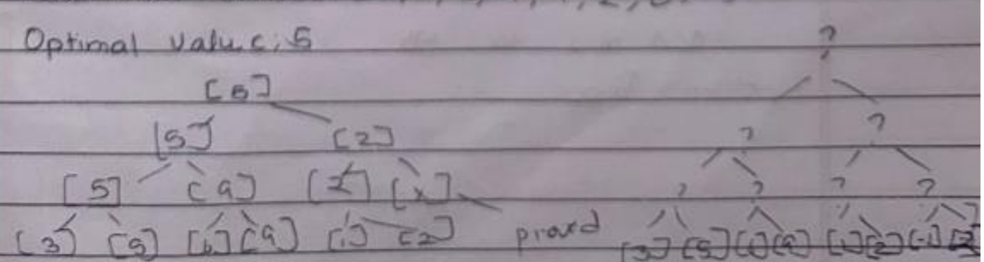
Function MAX-VALUE(state, α, β) returns a utility value
  if TERMINAL-TEST(state) then return UTILITY(state)
  v ← −∞
  for each a in ACTIONS(state) do
    v ← MAX(v, MIN-VALUE(RESULT(s,a), α, β))
    if v ≥ β then return v
    α ← MAX(α, v)
  return v

function MIN-VALUE(state, α, β) returns a utility value
  if terminal-TEST(state) then return UTILITY(state)
  v ← +∞
  for each a 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: 5



Code

```
def unify(a, b):
    """Very simple unification for small terms like ('line', [X,O,X])"""
    if a == b:
        return {}
    if isinstance(a, str) and a.islower():  # variable
        return {a: b}
    if isinstance(b, str) and b.islower():
        return {b: a}
    if isinstance(a, tuple) and isinstance(b, tuple):
        if a[0] != b[0] or len(a[1]) != len(b[1]):
            return None
        subs = {}
        for x, y in zip(a[1], b[1]):
            s = unify(x, y)
            if s is None:
                return None
            subs.update(s)
        return subs
    return None


# Winning triples (rows, cols, diagonals)
WIN_TRIPLES = [(0,1,2),(3,4,5),(6,7,8),(0,3,6),(1,4,7),(2,5,8),(0,4,8),(2,4,6)]

def winner(board):
    pattern = ('line', ['X','X','X'])
    for i,j,k in WIN_TRIPLES:
        term = ('line', [board[i], board[j], board[k]])
        if unify(term, pattern):
            return 'X'
        if unify(term, ('line',['O','O','O'])):
            return 'O'
    return None

def is_full(board): return all(c != '_' for c in board)

def evaluate(board):
    w = winner(board)
    if w == 'X': return 1
    if w == 'O': return -1
    if is_full(board): return 0
    return None
```

```
def alpha_beta(board, player, alpha=-float('inf'), beta=float('inf')):
    val = evaluate(board)
    if val is not None:
        return val, None

    moves = [i for i,c in enumerate(board) if c == '_']
    best_move = None
    if player == 'X':
        max_eval = -float('inf')
        for m in moves:
            new_board = board[:]
            new_board[m] = 'X'
            eval_, _ = alpha_beta(new_board, 'O', alpha, beta)
            if eval_ > max_eval:
                max_eval, best_move = eval_, m
            alpha = max(alpha, eval_)
            if beta <= alpha: break
        return max_eval, best_move
    else:
        min_eval = float('inf')
        for m in moves:
            new_board = board[:]
            new_board[m] = 'O'
            eval_, _ = alpha_beta(new_board, 'X', alpha, beta)
            if eval_ < min_eval:
                min_eval, best_move = eval_, m
            beta = min(beta, eval_)
            if beta <= alpha: break
        return min_eval, best_move

def print_board(b):
    for i in range(0,9,3):
        print(' '.join(b[i:i+3]))
    print()

# --- Example usage ---
board = ['_']*9
score, move = alpha_beta(board, 'X')
print("Best first move for X:", move)
board[move] = 'X'
print_board(board)
```

Output

```
You are X. AI is O.

   |   |
---+---+---
   |   |
---+---+---
   |   |

Enter your move (0-8): 2

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

AI is thinking...

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

Enter your move (0-8): 6

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

```
AI is thinking...

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

Enter your move (0-8): 7

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

AI is thinking...

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

Enter your move (0-8): 0

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

AI is thinking...

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

```
Enter your move (0-8): 5

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

Result: Draw
```