VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT

on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Chethan K S(1BM23CS074)

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 **Chethan K S (1BM23CS074),** 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.

Swathi Sridharan Assistant Professor Department of CSE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE

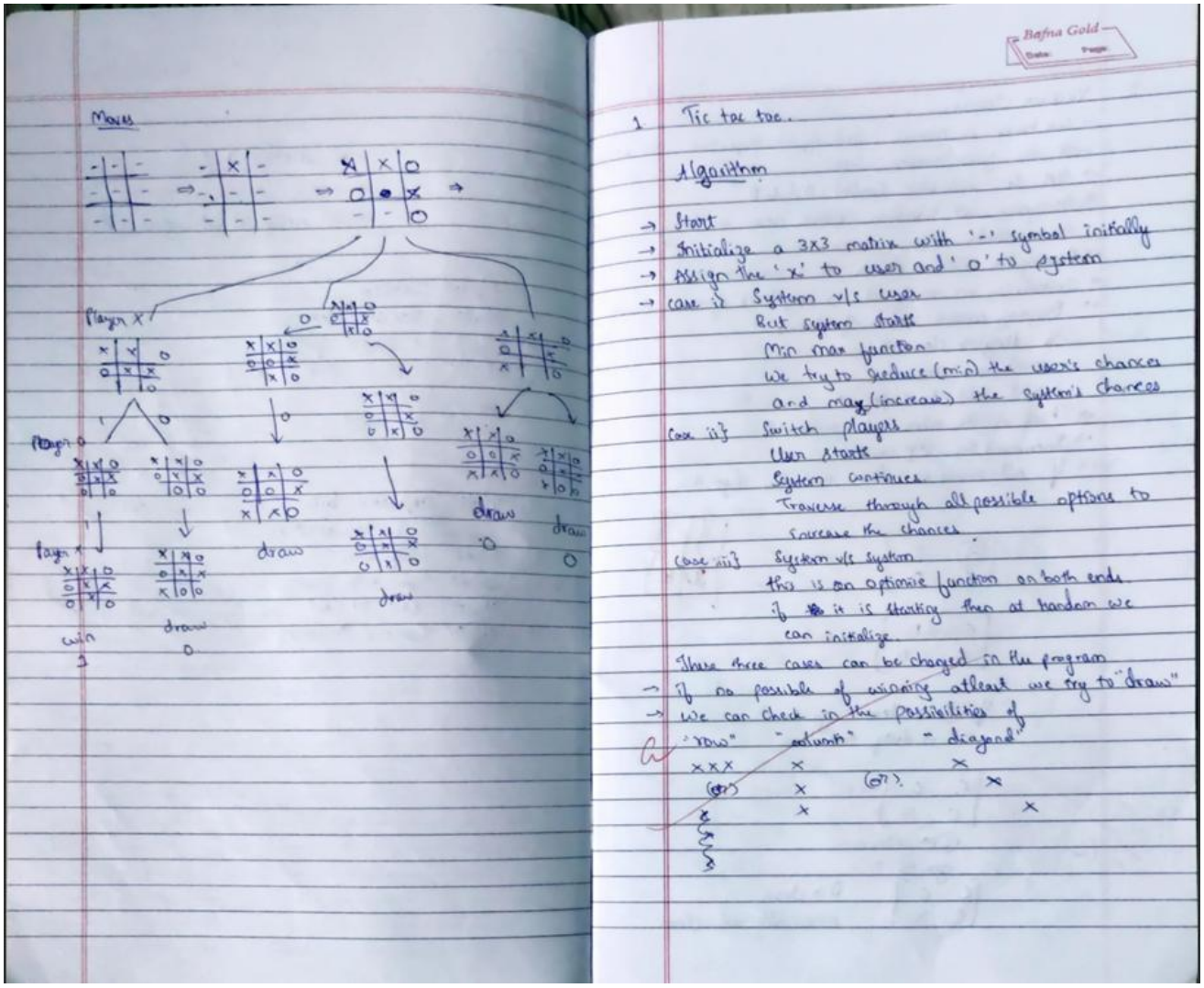
Index

Github Link:
https://github.com/Chethan-K-S/1BM23CS074-AI-LAB

Program 1

Implement Tic –Tac –Toe Game

Algorithm:



Code:

```
import random

# Constants
PLAYER = 'X'  # Human
AI = 'O'      # System
EMPTY = '-'

# Initialize board
def create_board():
```

```
    return [[EMPTY for _ in range(3)] for _ in range(3)]

# Display board
def print_board(board):
    for row in board:
        print(' '.join(row))
    print()

# Check for winner
def check_winner(board):
    lines = []

    # Rows, Columns
    lines.extend(board)
    lines.extend([[board[r][c] for r in range(3)] for c in range(3)])

    # Diagonals
    lines.append([board[i][i] for i in range(3)])
    lines.append([board[i][2 - i] for i in range(3)])

    for line in lines:
        if line.count(line[0]) == 3 and line[0] != EMPTY:
            return line[0]
    return None

# Check if board is full
def is_full(board):
    return all(cell != EMPTY for row in board for cell in row)

# Minimax algorithm
def minimax(board, depth, is_maximizing):
    winner = check_winner(board)
    if winner == AI:
        return 10 - depth
    elif winner == PLAYER:
        return depth - 10
    elif is_full(board):
        return 0

    if is_maximizing:
        best_score = float('-inf')
```

```
        for r in range(3):
            for c in range(3):
                if board[r][c] == EMPTY:
                    board[r][c] = AI
                    score = minimax(board, depth + 1, False)
                    board[r][c] = EMPTY
                    best_score = max(score, best_score)
        return best_score
    else:
        best_score = float('inf')
        for r in range(3):
            for c in range(3):
                if board[r][c] == EMPTY:
                    board[r][c] = PLAYER
                    score = minimax(board, depth + 1, True)
                    board[r][c] = EMPTY
                    best_score = min(score, best_score)
        return best_score

# Best move for AI
def best_move(board):
    best_score = float('-inf')
    move = None
    for r in range(3):
        for c in range(3):
            if board[r][c] == EMPTY:
                board[r][c] = AI
                score = minimax(board, 0, False)
                board[r][c] = EMPTY
                if score > best_score:
                    best_score = score
                    move = (r, c)
    return move

# User move
def user_move(board):
    while True:
        try:
            r, c = map(int, input("Enter row and column (0-2): ").split())
            if board[r][c] == EMPTY:
                return r, c
```

```
            else:
                print("Cell already taken.")
        except:
            print("Invalid input.")

# System random move (for system vs system)
def random_move(board, symbol):
    empty_cells = [(r, c) for r in range(3) for c in range(3) if board[r][c] == EMPTY]
    return random.choice(empty_cells)

# Game loop
def play_game(mode):
    board = create_board()
    print_board(board)

    current = PLAYER if mode == 'user_vs_system' else AI

    while True:
        if mode == 'user_vs_user':
            print(f"{current}'s turn")
            r, c = user_move(board)

        elif mode == 'user_vs_system':
            if current == PLAYER:
                print("Your turn")
                r, c = user_move(board)
            else:
                print("System's turn")
                r, c = best_move(board)

        elif mode == 'system_vs_system':
            print(f"{current}'s turn")
            r, c = best_move(board) if current == AI else random_move(board, PLAYER)

        board[r][c] = current
        print_board(board)

        winner = check_winner(board)
        if winner:
            print(f"{winner} wins!")
            break
```

```
        elif is_full(board):
            print("It's a draw!")
            break

        current = AI if current == PLAYER else PLAYER

# Choose mode
def main():
    print("Choose mode:")
    print("1. User vs System")
    print("2. System vs System")
    print("3. User vs User")
    choice = input("Enter choice (1-3): ")

    if choice == '1':
        play_game('user_vs_system')
    elif choice == '2':
        play_game('system_vs_system')
    elif choice == '3':
        play_game('user_vs_user')
    else:
        print("Invalid choice.")

main()
```

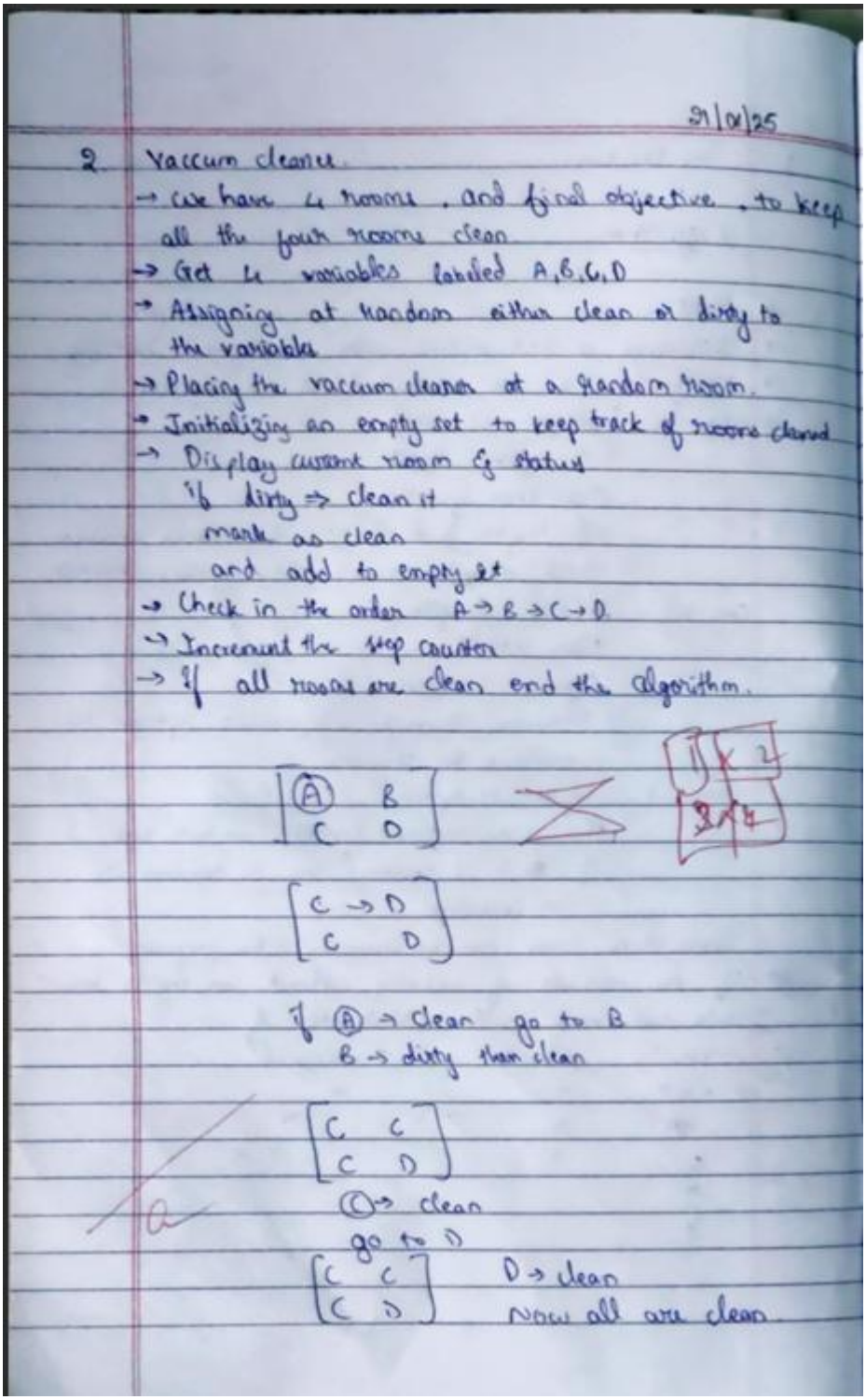
Output:

```
X's turn
Enter row and column (0-2): 1 0
X X O
X O -
- - -

O's turn
X X O
X O -
O - -

O wins!

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

Program 2

Implement vacuum cleaner agent

Algorithm:



Code:

```
import random

# Define environment
rooms = {
    'A': random.choice(['Clean', 'Dirty']),
    'B': random.choice(['Clean', 'Dirty']),
    'C': random.choice(['Clean', 'Dirty']),
    'D': random.choice(['Clean', 'Dirty'])
}

# Initial position of the agent
agent_position = random.choice(['A', 'B', 'C', 'D'])

# Display current state
def display_state():
    print(f"Agent is in Room {agent_position}")
    for room, status in rooms.items():
        print(f"Room {room}: {status}")
    print()

# Rule-based agent logic with smart movement
def vacuum_agent():
    global agent_position
    steps = 0

    # Keep track of cleaned rooms
    cleaned_rooms = set()

    while len(cleaned_rooms) < 4:
        display_state()

        # Clean current room if dirty
        if rooms[agent_position] == 'Dirty':
            print(f" 🧹 Cleaning Room {agent_position}")
            rooms[agent_position] = 'Clean'
            cleaned_rooms.add(agent_position)
        else:
            print(f"☑ Room {agent_position} is already clean.")
            cleaned_rooms.add(agent_position)
```

```
        # Decide next move only if not all rooms are clean
        if len(cleaned_rooms) < 4:
            # Move to the next room that is still dirty
            for next_room in ['A', 'B', 'C', 'D']:
                if next_room not in cleaned_rooms:
                    agent_position = next_room
                    break

        steps += 1
        print(f"Step {steps} complete.\n")

    print("🎉 All rooms are clean!")
    display_state()

vacuum_agent()
```

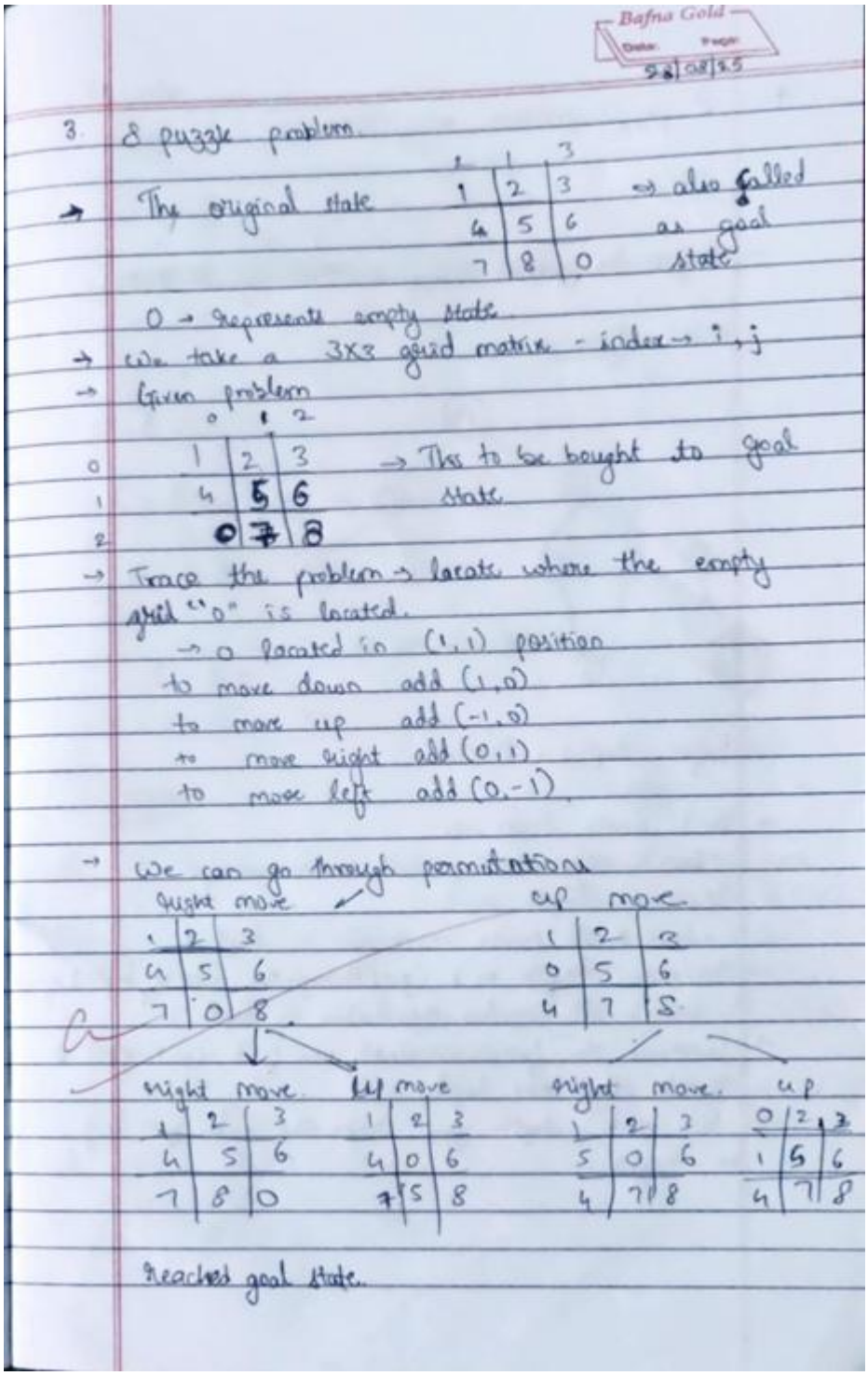
Output:

```
Agent is in Room D
Room A: Dirty
Room B: Clean
Room C: Dirty
Room D: Clean

✅ Room D is already clean.
Step 1 complete.

Agent is in Room A
Room A: Dirty
Room B: Clean
Room C: Dirty
Room D: Clean

🧹 Cleaning Room A
Step 2 complete.

Agent is in Room B
Room A: Clean
Room B: Clean
Room C: Dirty
Room D: Clean

✅ Room B is already clean.
Step 3 complete.

Agent is in Room C
Room A: Clean
Room B: Clean
Room C: Dirty
Room D: Clean

🧹 Cleaning Room C
Step 4 complete.
```

Program 3

Solve 8 puzzle problems.

Algorithm:



Code:

```
from collections import deque

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

moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]

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

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

def state_to_tuple(state):
    return tuple(tuple(row) for row in state)

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

    while queue:
        current_state, path = queue.popleft()
        if current_state == goal_state:
            return path + [current_state]

        visited.add(state_to_tuple(current_state))
        x, y = find_blank(current_state)

        for dx, dy in moves:
            nx, ny = x + dx, y + dy
            if is_valid(nx, ny):
                new_state = [row[:] for row in current_state]
                new_state[x][y], new_state[nx][ny] = new_state[nx][ny], new_state[x][y]
```

```
                if state_to_tuple(new_state) not in visited:
                    queue.append((new_state, path + [current_state]))

    return None

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

solution_path = bfs(start_state)

if solution_path:
    print("Solution found in", len(solution_path) - 1, "moves:")
    for step in solution_path:
        for row in step:
            print(row)
        print("-----")
else:
    print("No solution found.")
```

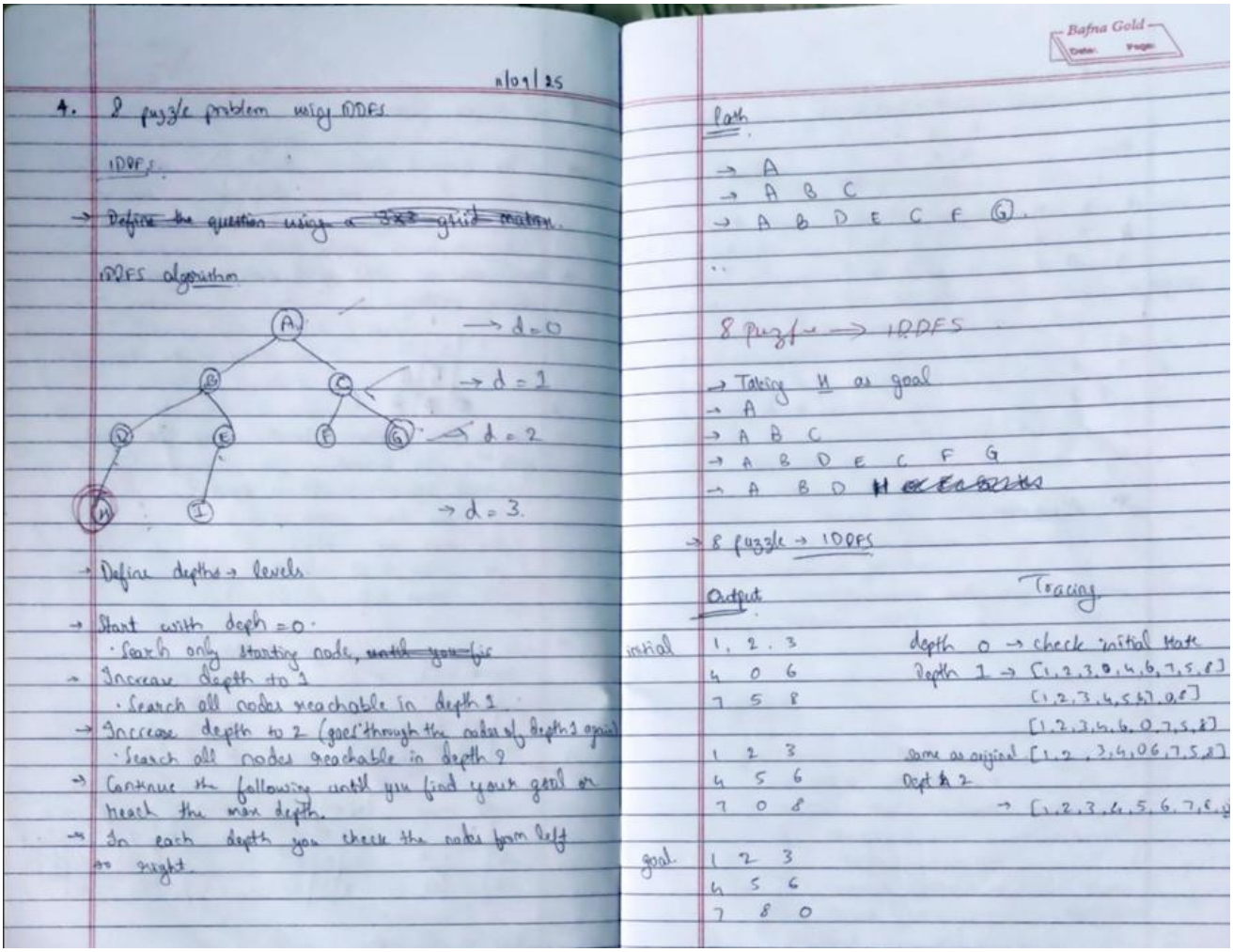
Output:

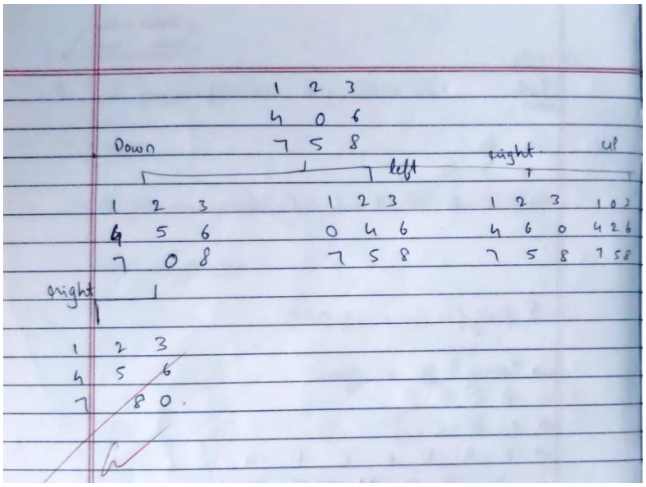
```
PS C:\Users\BMSCECSE\Desktop\Puzzle> & C:/Users/BMSCECSE/AppData/Local/Programs/Python/Python313/python.exe c:/Users/BMSCECSE/Desktop/Puzzle/puzzle.py
Solution found in 3 moves:
[1, 2, 3]
[0, 4, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 0, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 8, 0]
-----
PS C:\Users\BMSCECSE\Desktop\Puzzle>
```

Program 4

Implement Iterative deepening search algorithm.

Algorithm:





Code:

```
from copy import deepcopy

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

# Generate all valid neighbor states by moving the blank tile
def get_neighbors(state):
    neighbors = []
    index = state.index(0)
    row, col = divmod(index, 3)
    directions = [(-1, 0), (1, 0), (0, -1), (0, 1)]  # up, down, left, right

    for dr, dc in directions:
        new_row, new_col = row + dr, col + dc
        if 0 <= new_row < 3 and 0 <= new_col < 3:
            new_index = new_row * 3 + new_col
            new_state = state[:]
            new_state[index], new_state[new_index] = new_state[new_index], new_state[index]
            neighbors.append(new_state)

    return neighbors

# Depth-Limited Search
def dls(state, depth, visited):
    if state == GOAL_STATE:
        return [state]
    if depth == 0:
        return None
    visited.add(tuple(state))
    for neighbor in get_neighbors(state):
        if tuple(neighbor) not in visited:
            path = dls(neighbor, depth - 1, visited)
            if path:
                return [state] + path
    return None

# Iterative Deepening DFS
def iddfs(start_state, max_depth=20):
    for depth in range(max_depth):
```

```
        visited = set()
        path = dls(start_state, depth, visited)
        if path:
            return path
    return None

# Example start state
start = [1, 2, 3, 4, 0, 6, 7, 5, 8]
solution = iddfs(start)

# Print the solution path
if solution:
    print("Solution found in", len(solution) - 1, "moves:")
    for step in solution:
        print(step[:3])
        print(step[3:6])
        print(step[6:])
        print("-----")
else:
    print("No solution found within depth limit.")
```

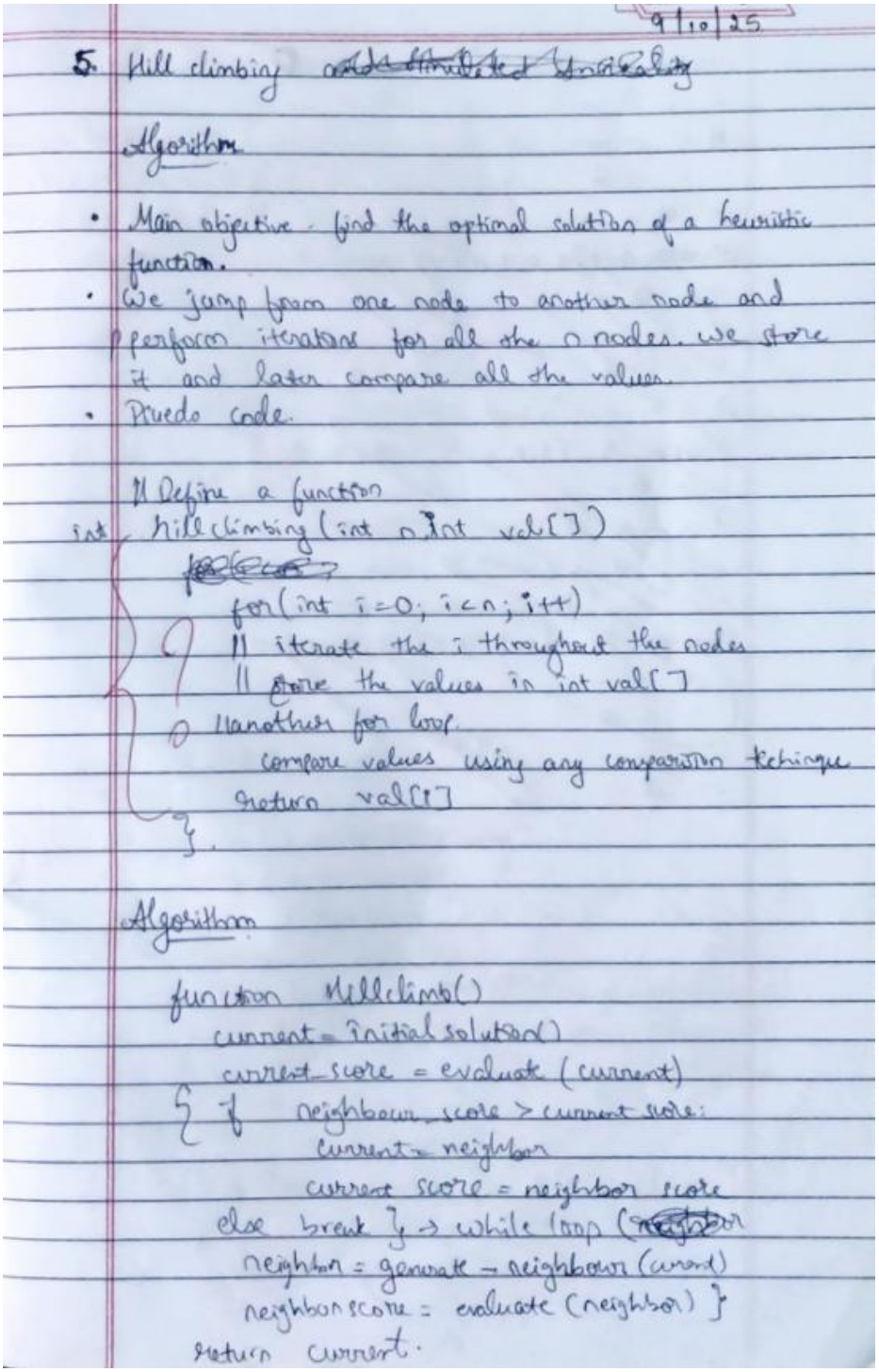
Output:

```
PS C:\Users\student\Desktop\Puzzle -  iddfs> & "C:\Program Files\Py
Solution found in 2 moves:
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 0, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 8, 0]
-----
```

Program 5

Implement Hill Climbing Algorithm.

Algorithm:



9/10/25

5. Hill climbing

Algorithm

- Main objective - find the optimal solution of a heuristic function.
- We jump from one node to another node and perform iterations for all the n nodes. we store it and later compare all the values.
- Pseudo code.

```
// Define a function
int hillclimbing(int n,int val[])
    for(int i=0; i<n; i++)
    // iterate the i throughout the nodes
    // store the values in int val[]
    // another for loop
        compare values using any comparision technique
    return val[i]
}
```

Algorithm

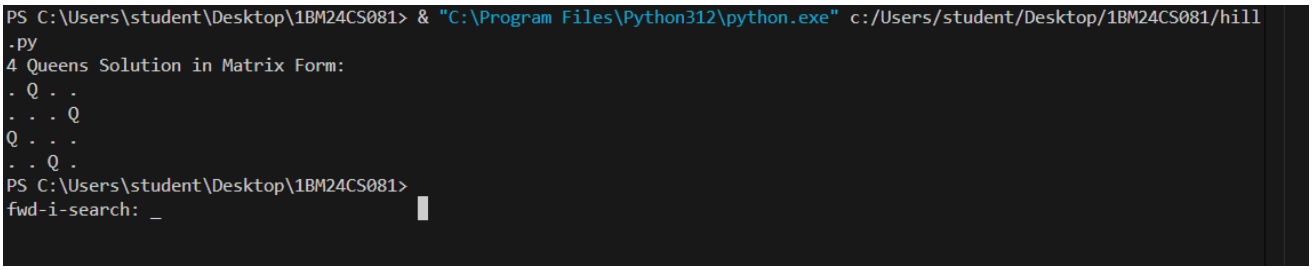
```
function Hillclimb()
  current = initial solution()
  current_score = evaluate(current)
{ if neighbour_score > current_score:
      current = neighbor
      current_score = neighbor_score
  else break } -> while loop (
  neighbor = generate_neighbours(current)
  neighbor_score = evaluate(neighbor) }
return current.
```

Code:

```
import random

# Count number of attacking pairs
def compute_attacks(state):
    attacks = 0
    for i in range(len(state)):
        for j in range(i + 1, len(state)):
            if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                attacks += 1
    return attacks

# Generate neighbors by moving one queen in its column
def get_neighbors(state):
    neighbors = []
    for col in range(len(state)):
        for row in range(len(state)):
            if state[col] != row:
                neighbor = state.copy()
                neighbor[col] = row
                neighbors.append(neighbor)
    return neighbors

# Hill climbing algorithm
def hill_climb():
    current = [random.randint(0, 3) for _ in range(4)]
    current_score = compute_attacks(current)

    while True:
        neighbors = get_neighbors(current)
        next_state = current
        next_score = current_score

        for neighbor in neighbors:
            score = compute_attacks(neighbor)
            if score < next_score:
                next_state = neighbor
                next_score = score

        if next_score == current_score:
```

```
            break  # No better neighbor found

        current = next_state
        current_score = next_score

    return current

# Convert solution to matrix
def print_board(state):
    size = len(state)
    board = [['.' for _ in range(size)] for _ in range(size)]
    for col, row in enumerate(state):
        board[row][col] = 'Q'
    for row in board:
        print(' '.join(row))

# Run the algorithm
solution = hill_climb()
print("4 Queens Solution in Matrix Form:")
print_board(solution)
```

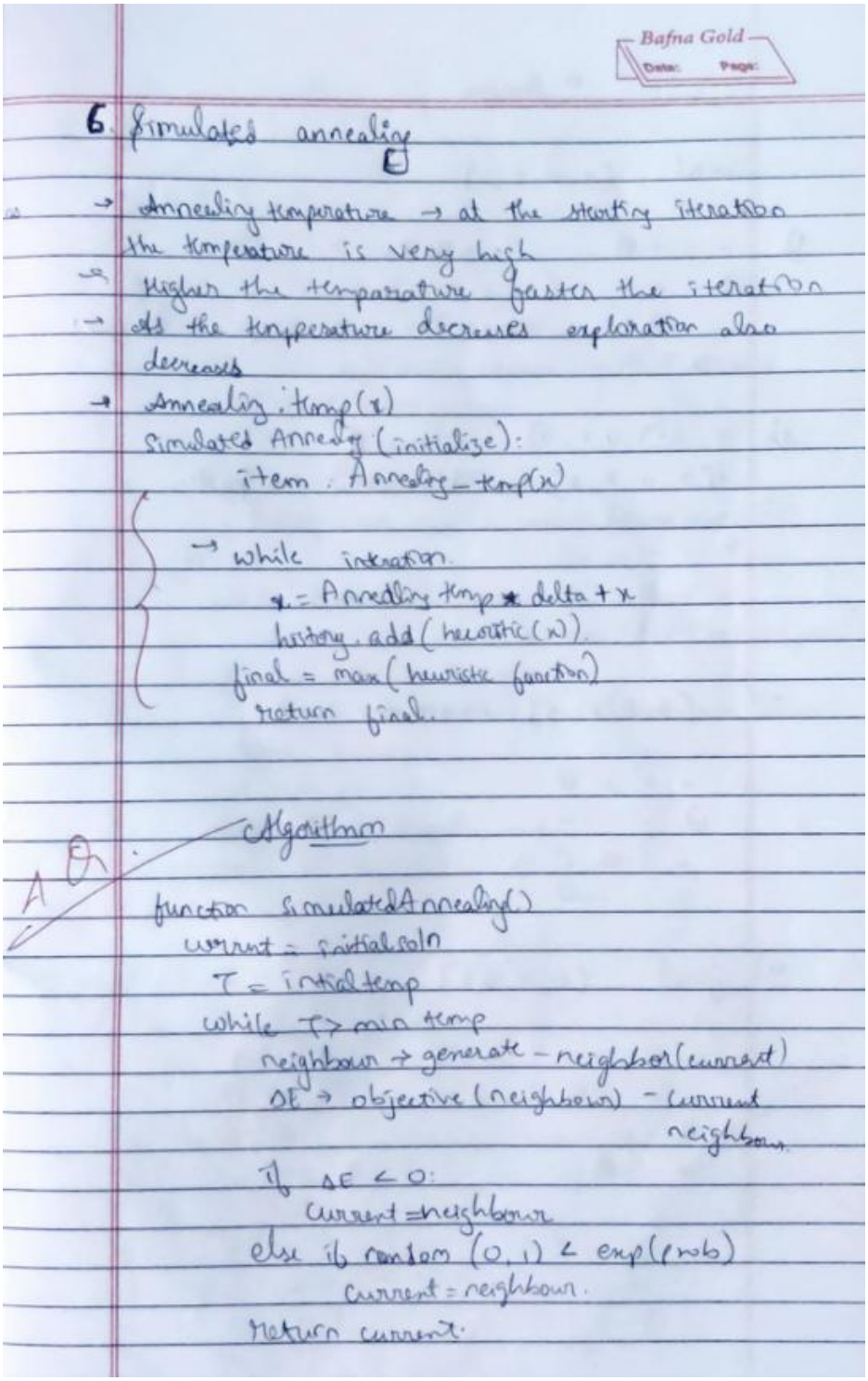
Output:



Program 6

Write a program to implement Simulated Annealing Algorithm

Algorithm:



Code:

```
import random
import math

# Count attacking pairs
def compute_attacks(state):
    attacks = 0
    for i in range(len(state)):
        for j in range(i + 1, len(state)):
            if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                attacks += 1
    return attacks

# Generate a neighbor by moving one queen
def get_neighbor(state):
    neighbor = state.copy()
    col = random.randint(0, 3)
    new_row = random.randint(0, 3)
    while neighbor[col] == new_row:
        new_row = random.randint(0, 3)
    neighbor[col] = new_row
    return neighbor

# Simulated Annealing algorithm
def simulated_annealing():
    current = [random.randint(0, 3) for _ in range(4)]
    current_score = compute_attacks(current)
    temperature = 100.0
    cooling_rate = 0.95
    min_temp = 0.01

    while temperature > min_temp and current_score > 0:
        neighbor = get_neighbor(current)
        neighbor_score = compute_attacks(neighbor)
        delta = neighbor_score - current_score

        if delta < 0 or random.random() < math.exp(-delta / temperature):
            current = neighbor
            current_score = neighbor_score
```

```
        temperature *= cooling_rate

    return current

# Print board matrix
def print_board(state):
    board = [['.' for _ in range(4)] for _ in range(4)]
    for col, row in enumerate(state):
        board[row][col] = 'Q'
    for row in board:
        print(' '.join(row))

# Run the algorithm
solution = simulated_annealing()
print("4 Queens Solution (Simulated Annealing):")
print_board(solution)
```

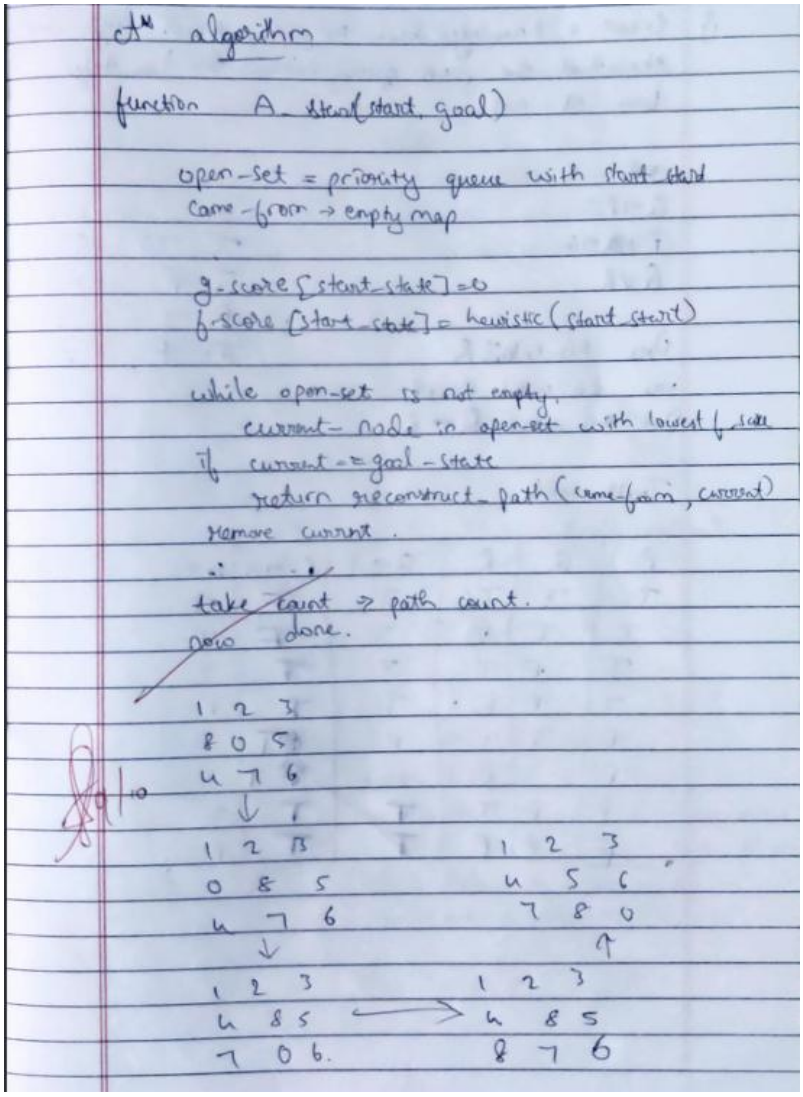
Output:

```
4 Queens Solution (Simulated Annealing):
. . Q .
Q . . .
. . . Q
. Q . .
```

Program 7

Implement A* search algorithm.

Algorithm:



Code:

```
import heapq
```

```
class PuzzleState:
    def __init__(self, board, moves=0, previous=None):
        self.board = board
        self.moves = moves
        self.previous = previous
        self.size = 3

    def __eq__(self, other):
        return self.board == other.board

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

    def get_neighbors(self):
        neighbors = []
        zero_index = self.board.index(0)
        x, y = divmod(zero_index, self.size)
        directions = [(-1, 0), (1, 0), (0, -1), (0, 1)]
        for dx, dy in directions:
            new_x, new_y = x + dx, y + dy
            if 0 <= new_x < self.size and 0 <= new_y < self.size:
                new_zero_index = new_x * self.size + new_y
                new_board = list(self.board)
                new_board[zero_index], new_board[new_zero_index] = new_board[new_zero_index],
new_board[zero_index]
                neighbors.append(PuzzleState(tuple(new_board), self.moves + 1, self))
        return neighbors

    def misplaced_tiles(self, goal):
        count = 0
        for i in range(len(self.board)):
            if self.board[i] != 0 and self.board[i] != goal.board[i]:
                count += 1
        return count

    def __lt__(self, other):
        return False


def a_star(start, goal):
    open_set = []
```

```
    heapq.heappush(open_set, (start.misplaced_tiles(goal), start))
    g_score = {start: 0}
    f_score = {start: start.misplaced_tiles(goal)}
    closed_set = set()
    while open_set:
        current_f, current = heapq.heappop(open_set)
        if current == goal:
            path = []
            while current:
                path.append(current)
                current = current.previous
            path.reverse()
            return path
        closed_set.add(current)
        for neighbor in current.get_neighbors():
            if neighbor in closed_set:
                continue
            tentative_g = g_score[current] + 1
            if neighbor not in g_score or tentative_g < g_score[neighbor]:
                neighbor.previous = current
                g_score[neighbor] = tentative_g
                f = tentative_g + neighbor.misplaced_tiles(goal)
                f_score[neighbor] = f
                heapq.heappush(open_set, (f, neighbor))
    return None


def print_path(path):
    for state in path:
        for i in range(3):
            print(state.board[i*3:(i+1)*3])
        print()


def get_input_state(prompt):
    print(prompt)
    while True:
        try:
            values = list(map(int, input("Enter 9 numbers (0 for blank) separated by spaces:
").strip().split()))
            if len(values) != 9 or sorted(values) != list(range(9)):
```

```
            raise ValueError
        return tuple(values)
    except ValueError:
        print("Invalid input. Please enter numbers 0 to 8 without duplicates.")


start_board = get_input_state("Enter initial state:")
goal_board = get_input_state("Enter goal state:")

start_state = PuzzleState(start_board)
goal_state = PuzzleState(goal_board)

solution_path = a_star(start_state, goal_state)

if solution_path:
    print(f"Solution found in {len(solution_path)-1} moves:")
    print_path(solution_path)
else:
    print("No solution found.")
```

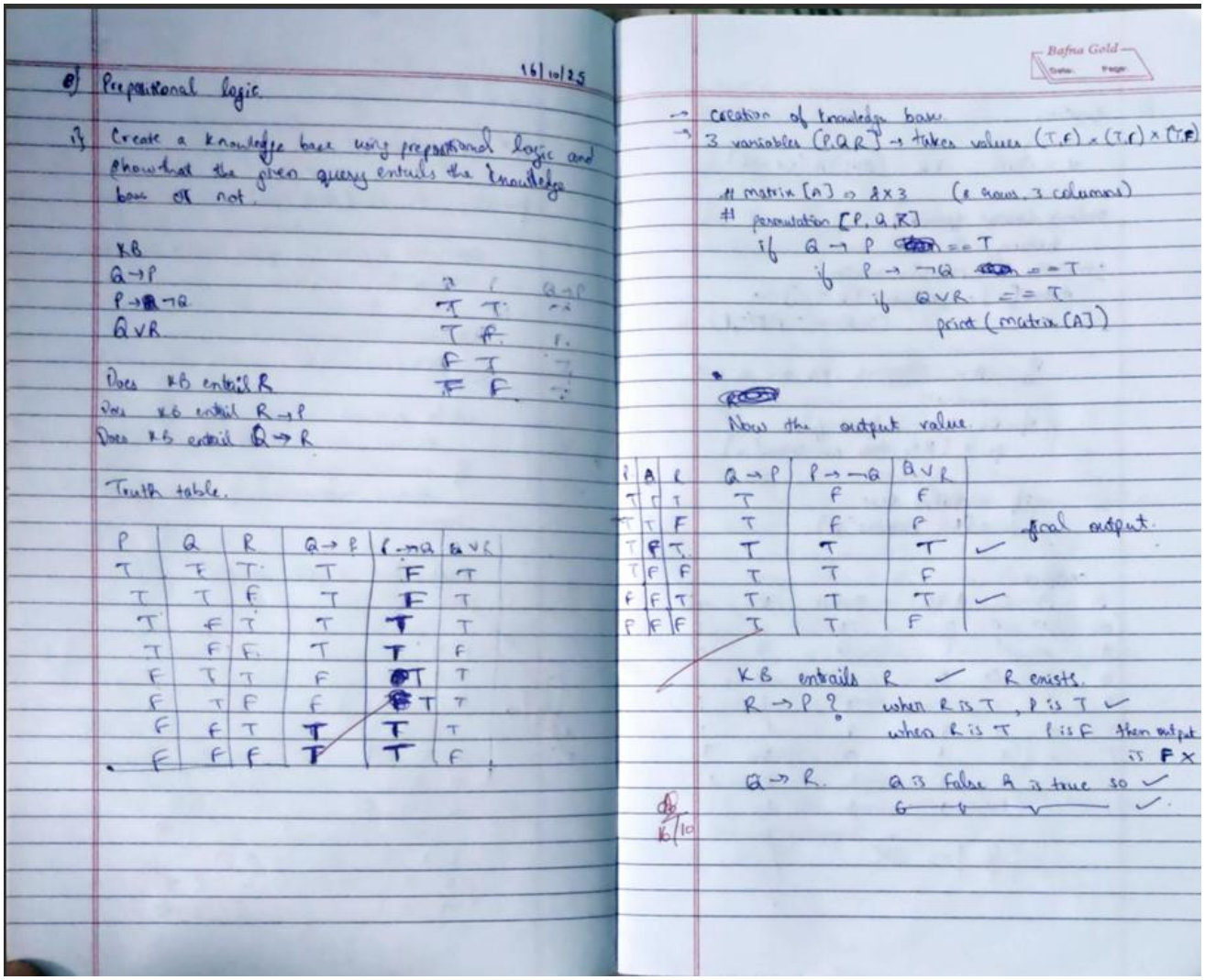
Output:

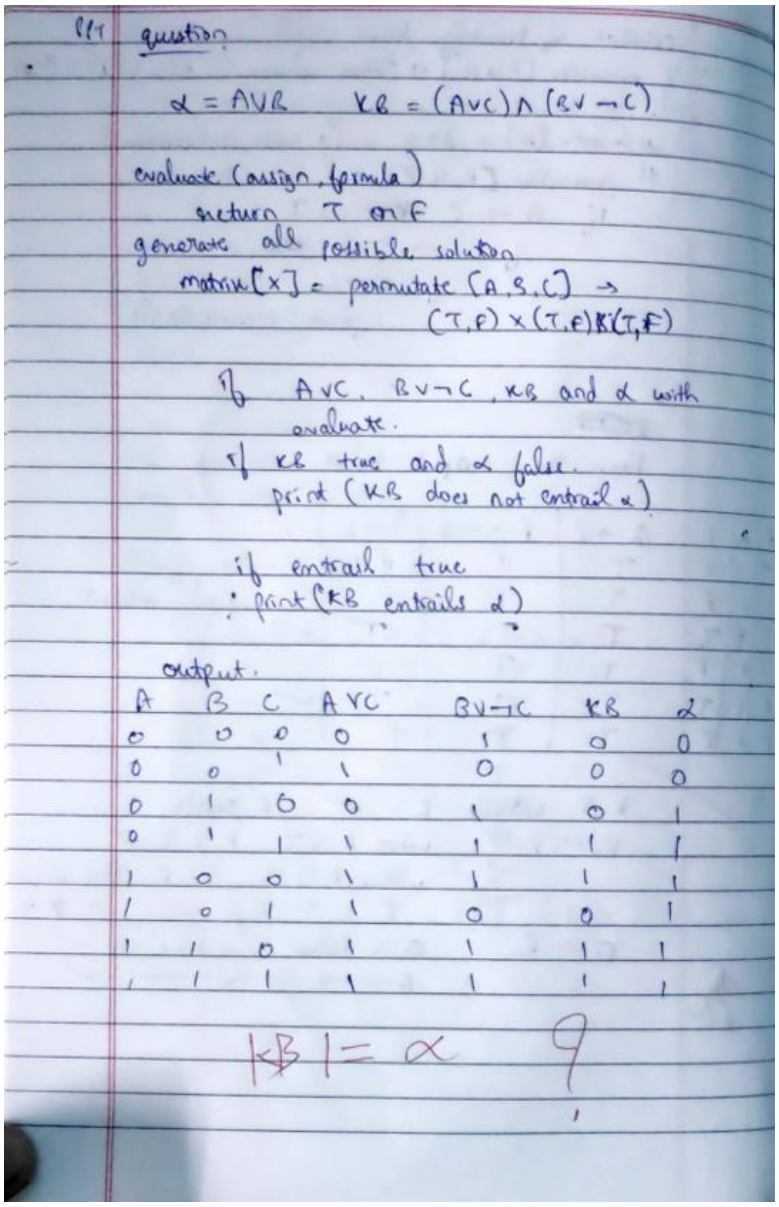
```
Enter initial state:
Enter 9 numbers (0 for blank) separated by spaces: 2 8 3 1 6 4 7 0 5
Enter goal state:
Enter 9 numbers (0 for blank) separated by spaces: 1 2 3 8 0 4 7 6 5
Solution found in 5 moves:
(2, 8, 3)
(1, 6, 4)
(7, 0, 5)

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

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

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

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

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

Program 8

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

Algorithm:





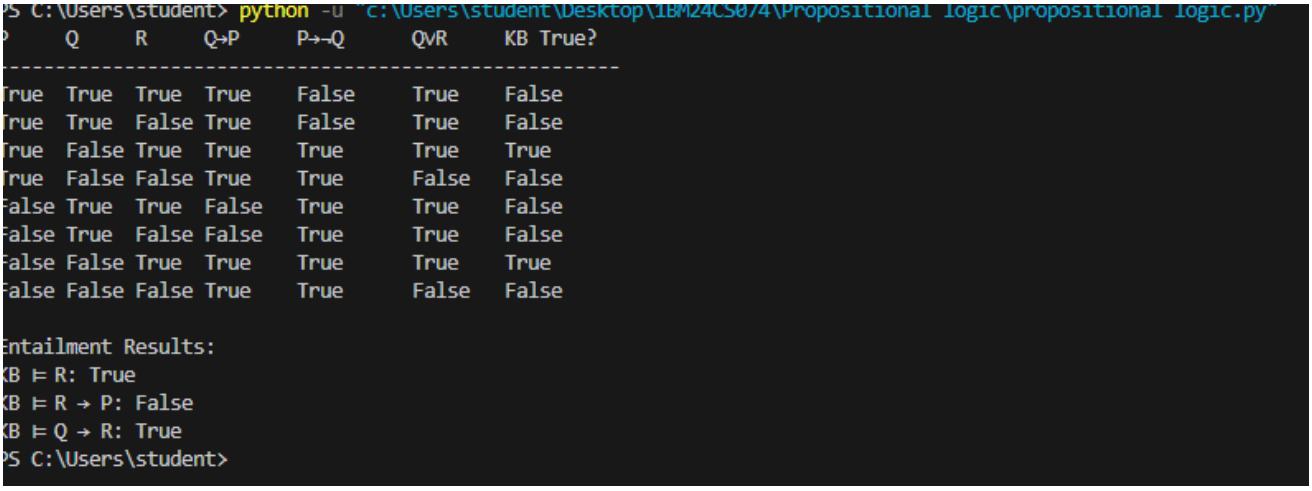
Code:

```
import itertools

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

# Logical operations
def implies(a, b):
    return (not a) or b

def not_(a):
```

```
    return not a

def or_(a, b):
    return a or b

# Evaluate KB sentences
def evaluate_kb_sentences(P, Q, R):
    s1 = implies(Q, P)       # Q → P
    s2 = implies(P, not_(Q)) # P → ¬Q
    s3 = or_(Q, R)           # Q ∨ R
    kb_true = s1 and s2 and s3
    return s1, s2, s3, kb_true

# Generate all models and print truth table
print(f"{'P':<6}{'Q':<6}{'R':<6}{'Q→P':<8}{'P→¬Q':<10}{'Q∨R':<8}{'KB True?':<10}")
print("-" * 54)

kb_true_models = []

for vals in itertools.product([True, False], repeat=3):
    P, Q, R = vals
    s1, s2, s3, kb_true = evaluate_kb_sentences(P, Q, R)
    if kb_true:
        kb_true_models.append({'P': P, 'Q': Q, 'R': R})

print(f"{str(P):<6}{str(Q):<6}{str(R):<6}{str(s1):<8}{str(s2):<10}{str(s3):<8}{str(kb_true):<10}")

# Entailment checks
def entails(models, formula_fn):
    return all(formula_fn(model) for model in models)

# Define entailment formulas
def formula_R(model):
    return model['R']

def formula_R_implies_P(model):
    return implies(model['R'], model['P'])

def formula_Q_implies_R(model):
    return implies(model['Q'], model['R'])
```

```
# Print entailment results
print("\nEntailment Results:")
print("KB ⊨ R:", entails(kb_true_models, formula_R))
print("KB ⊨ R → P:", entails(kb_true_models, formula_R_implies_P))
print("KB ⊨ Q → R:", entails(kb_true_models, formula_Q_implies_R))
```

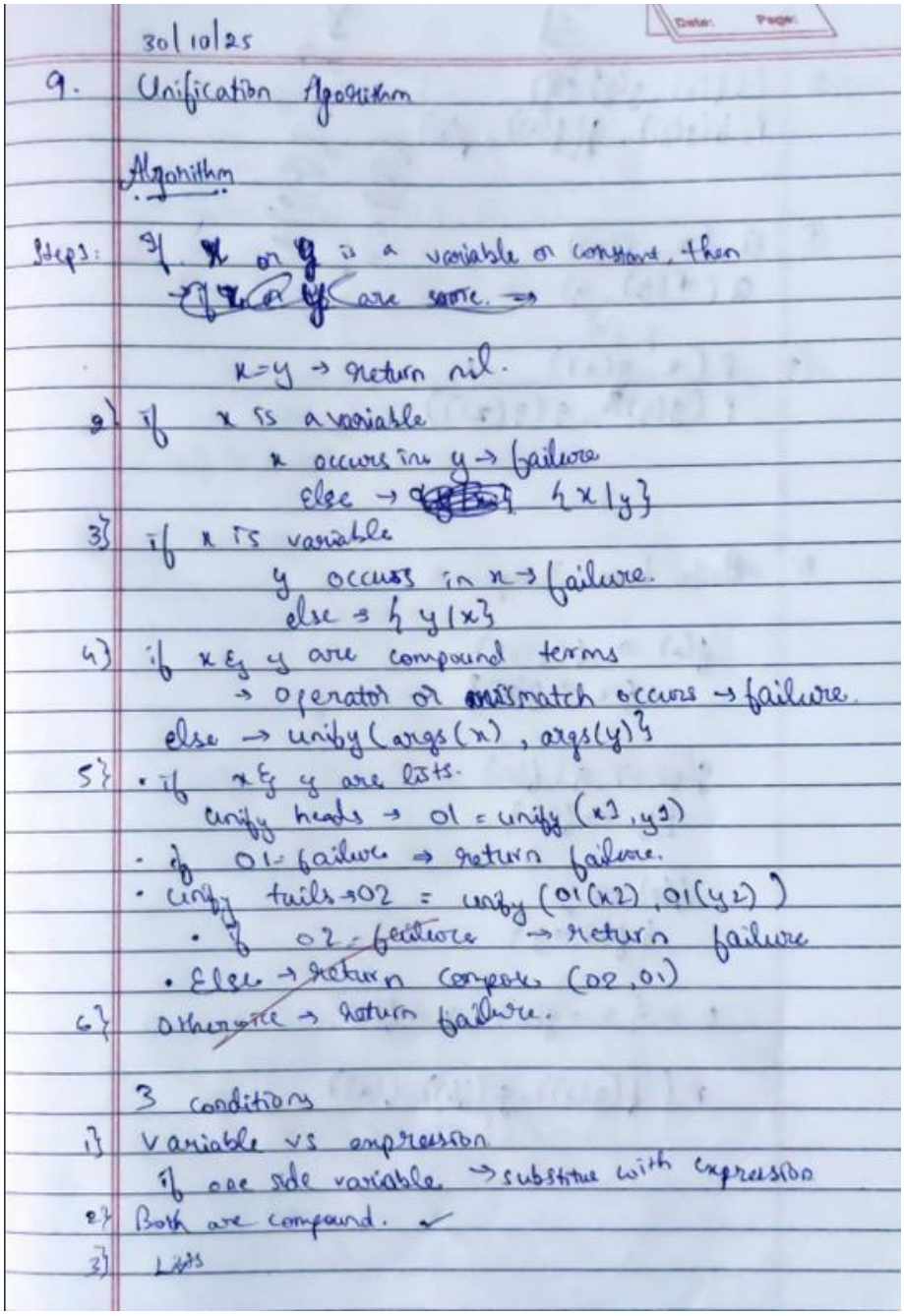
Output:



Program 9

Implement unification in first order logic.

Algorithm:



30/10/25

9. Unification Algorithm

Algorithm

Steps:

1) If x or y is a variable or constant, then
   if x or y are same. ⇒
   x=y → return nil.

2) if x is a variable
   x occurs in y → failure
   else → {x/y}

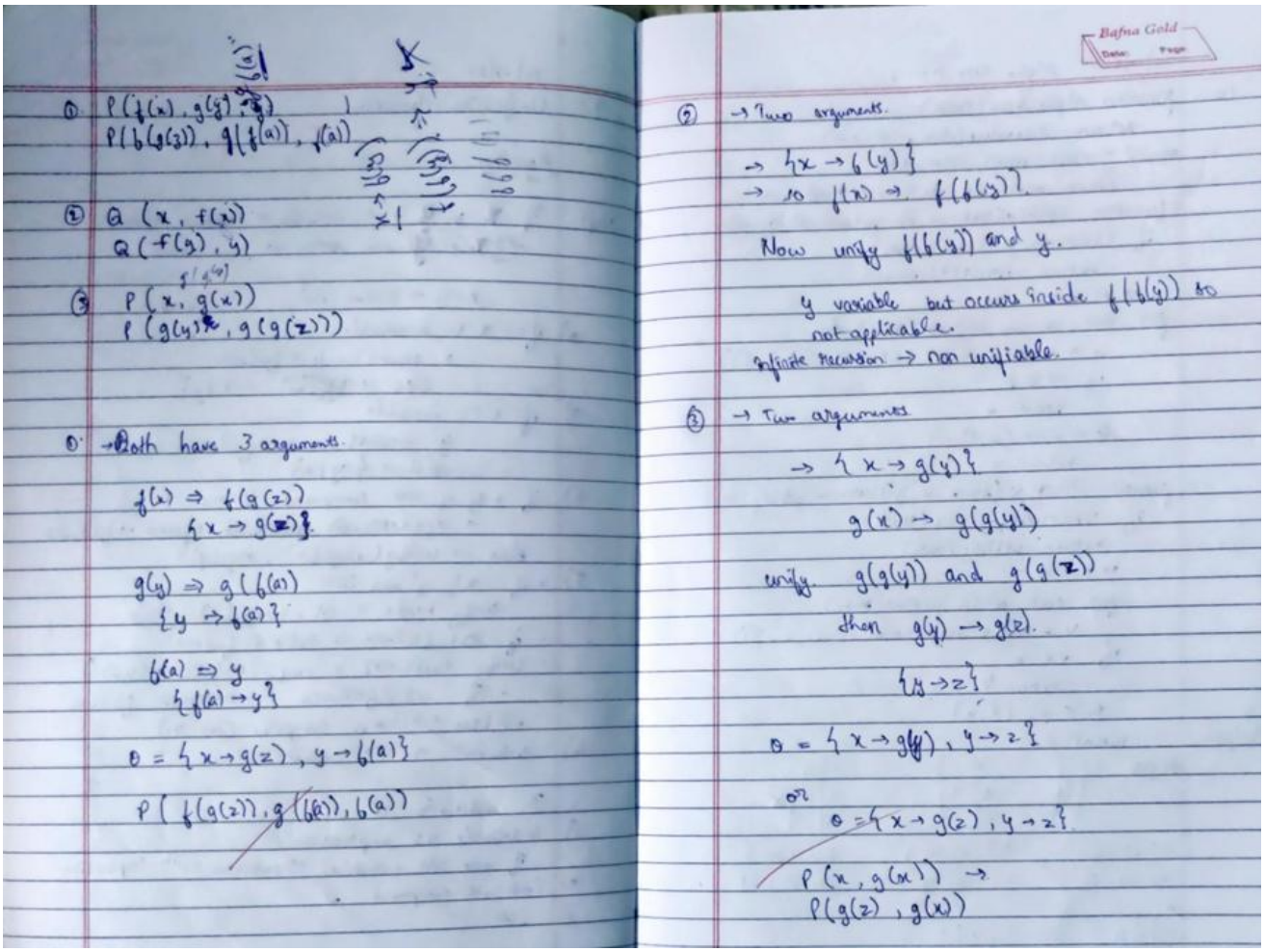
3) if x is variable
   y occurs in x → failure.
   else → {y/x}

4) if x & y are compound terms
   → operator or mismatch occurs → failure.
   else → unify(args(x), args(y))

5) • if x & y are lists.
   unify heads → o1 = unify(x1, y1)
   • if o1 = failure ⇒ return failure.
   • unify tails → o2 = unify(o1(x2), o1(y2))
   • if o2 = failure → return failure
   • Else → return compose(o2, o1)

6) Otherwise → return failure.

3 conditions
1) variable vs expression
   if one side variable → substitute with expression
2) Both are compound. ✓
3) Lists



Code:

```
def occurs_check(var, expr):
    if var == expr:
        return True
    elif isinstance(expr, tuple):
        return any(occurs_check(var, sub) for sub in expr)
    return False

def unify(x, y, subst={}):
    if subst is None:
        return None
    elif x == y:
        return subst
    elif isinstance(x, str) and x.islower():  # x is a variable
        return unify_var(x, y, subst)
    elif isinstance(y, str) and y.islower():  # y is a variable
        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(apply(subst, a), apply(subst, 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 occurs_check(var, x):
        return None
    else:
        subst[var] = x
        return subst

def apply(subst, expr):
    if isinstance(expr, str):
        return subst.get(expr, expr)
    elif isinstance(expr, tuple):
        return (expr[0],) + tuple(apply(subst, arg) for arg in expr[1:])
    else:
        return expr

# Represent terms as tuples: ('P', arg1, arg2), ('g', arg), etc.
expr1 = ('P', 'x', ('g', 'x'))
expr2 = ('P', ('g', 'y'), ('g', ('g', 'z')))

result = unify(expr1, expr2)
print("Unification result:", result)
```

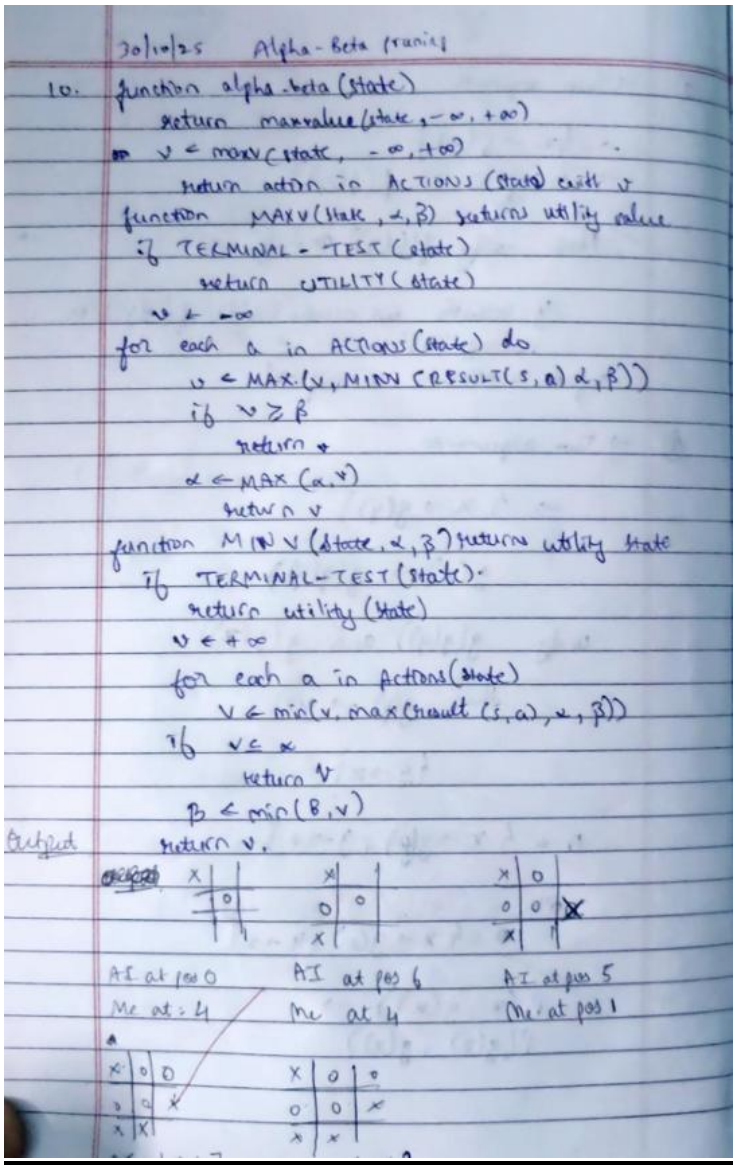
Output:

```
[Running] python -u "c:\Users\BMSCECSE\Desktop\Unify\prg.py"
Unification result: {'x': ('g', 'y'), 'y': 'z'}

[Done] exited with code=0 in 0.138 seconds
```

Program 10

Implement Alpha-Beta Pruning.

Algorithm:



Code:

```
import math

PLAYER = 'X'
OPPONENT = 'O'
```

```
def check_winner(board):
    win_combos = [
        [0,1,2], [3,4,5], [6,7,8],
        [0,3,6], [1,4,7], [2,5,8],
        [0,4,8], [2,4,6]
    ]
    for combo in win_combos:
        if board[combo[0]] == board[combo[1]] == board[combo[2]] != ' ':
            return board[combo[0]]
    return None

def is_full(board):
    return ' ' not in board

def evaluate(board):
    winner = check_winner(board)
    if winner == PLAYER:
        return 10
    elif winner == OPPONENT:
        return -10
    else:
        return 0

def get_children(board, player):
    children = []
    for i in range(9):
        if board[i] == ' ':
            new_board = board[:]
            new_board[i] = player
            children.append((new_board, i))
    return children

def alpha_beta(board, depth, alpha, beta, maximizing):
    score = evaluate(board)
    if depth == 0 or score in [10, -10] or is_full(board):
        return score

    if maximizing:
        max_eval = -math.inf
        for child, _ in get_children(board, PLAYER):
            eval = alpha_beta(child, depth - 1, alpha, beta, False)
            max_eval = max(max_eval, eval)
            alpha = max(alpha, eval)
            if beta <= alpha:
                break
```

```
            return max_eval
        else:
            min_eval = math.inf
            for child, _ in get_children(board, OPPONENT):
                eval = alpha_beta(child, depth - 1, alpha, beta, True)
                min_eval = min(min_eval, eval)
                beta = min(beta, eval)
                if beta <= alpha:
                    break
            return min_eval

    def find_best_move(board):
        best_val = -math.inf
        best_move = -1
        for child, move in get_children(board, PLAYER):
            move_val = alpha_beta(child, depth=5, alpha=-math.inf, beta=math.inf, maximizing=False)
            if move_val > best_val:
                best_val = move_val
                best_move = move
        return best_move


    if __name__ == "__main__":
        board = [' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ']
        while not is_full(board) and not check_winner(board):
            print("\nCurrent board:")
            print(f"{board[0]} | {board[1]} | {board[2]}")
            print(f"{board[3]} | {board[4]} | {board[5]}")
            print(f"{board[6]} | {board[7]} | {board[8]}")

            move = find_best_move(board)
            board[move] = PLAYER
            print(f"\nAI plays at position {move}")

            if check_winner(board) or is_full(board):
                break

            user_move = int(input("Your move (0-8): "))
            if board[user_move] == ' ':
                board[user_move] = OPPONENT
            else:
                print("Invalid move. Try again.")

        print("\nFinal board:")
        print(f"{board[0]} | {board[1]} | {board[2]}")
```

```
    print(f"{board[3]} | {board[4]} | {board[5]}")
    print(f"{board[6]} | {board[7]} | {board[8]}")
    winner = check_winner(board)
    if winner:
        print(f"Winner: {winner}")
    else:
        print("It's a draw!")
```

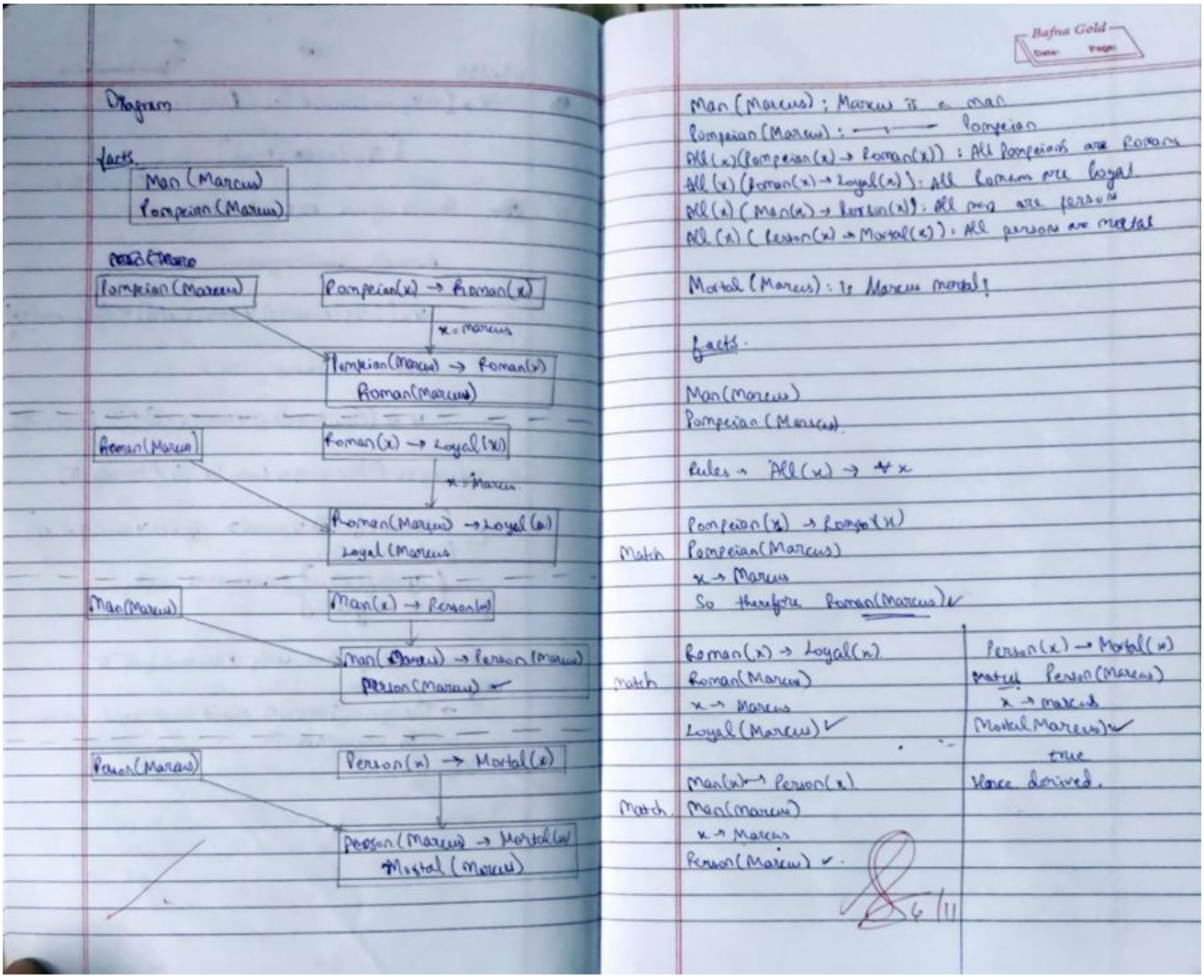
Output:

```
Current board:
  |   |
  |   |
  |   |

AI plays at position 0
Your move (0-8): 4

Current board:
X |   |
  | O |
  |   |

AI plays at position 1
Your move (0-8): 2

Current board:
X | X | O
  | O |
  |   |

AI plays at position 6
Your move (0-8): 3

Current board:
X | X | O
O | O |
X |   |

AI plays at position 5
Your move (0-8): 7

Current board:
X | X | O
O | O | X
X | O |

AI plays at position 8

Final board:
X | X | O
O | O | X
X | O | X
It's a draw!

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

Program 11

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

Algorithm:



Code:

```
def unify(x, y):
    # A simple unifier (can be replaced by your detailed unify function)
    if x == y:
        return {}
    if isinstance(x, str) and x.islower():
        return {x: y}
```

```
    if isinstance(y, str) and y.islower():
        return {y: x}
    return "FAILURE"


def apply_substitution(subst, sentence):
    if isinstance(sentence, str):
        return subst.get(sentence, sentence)
    elif isinstance(sentence, dict):
        return {
            'pred': sentence['pred'],
            'args': [apply_substitution(subst, arg) for arg in sentence.get('args', [])]
        }
    return sentence


def sentence_to_str(sentence):
    if isinstance(sentence, str):
        return sentence
    elif isinstance(sentence, dict):
        args_str = ",".join(sentence_to_str(arg) for arg in sentence.get('args', []))
        return f"{sentence['pred']}({args_str})"
    return str(sentence)


def str_to_sentence(s):
    # Very basic parser assuming format pred(arg1,arg2,...)
    pred_end = s.find("(")
    if pred_end == -1:
        return s
    pred = s[:pred_end]
    args_str = s[pred_end+1:-1]
    args = args_str.split(",") if args_str else []
    return {'pred': pred, 'args': args}


def sentence_in_KB_or_new(sentence, KB, new):
    s_str = sentence_to_str(sentence)
    for rule in KB:
        _, concl = rule
        if sentence_to_str(concl) == s_str:
            return True
    if s_str in new:
        return True
    return False
```

```
def find_substitutions_for_premises(premises, KB):
    # For demo: if no premises, return [{}] (empty substitution)
    if not premises:
        return [{}]
    # Otherwise, just return empty for simplicity
    return [{}]


# Placeholder for the fol_fc_ask function
def fol_fc_ask(KB, alpha):
    """
    A placeholder function for forward chaining inference.
    Replace with your actual implementation.
    """
    print("fol_fc_ask function called.")
    print("Knowledge Base (KB):", KB)
    print("Query (alpha):", alpha)
    # This is where your forward chaining logic would go.
    # For demonstration, let's assume it returns False.
    return False


# Example knowledge base: list of (premises, conclusion)
KB = [
    ([], {'pred': 'prime', 'args': ['11']}),  # Fact: prime(11)
    ([{'pred': 'prime', 'args': ['x']}], {'pred': 'odd', 'args': ['x']})  # Rule: prime(x) => odd(x)
]

alpha = {'pred': 'odd', 'args': ['11']}  # Query: odd(11)

result = fol_fc_ask(KB, alpha)

print("Result:", result)
```

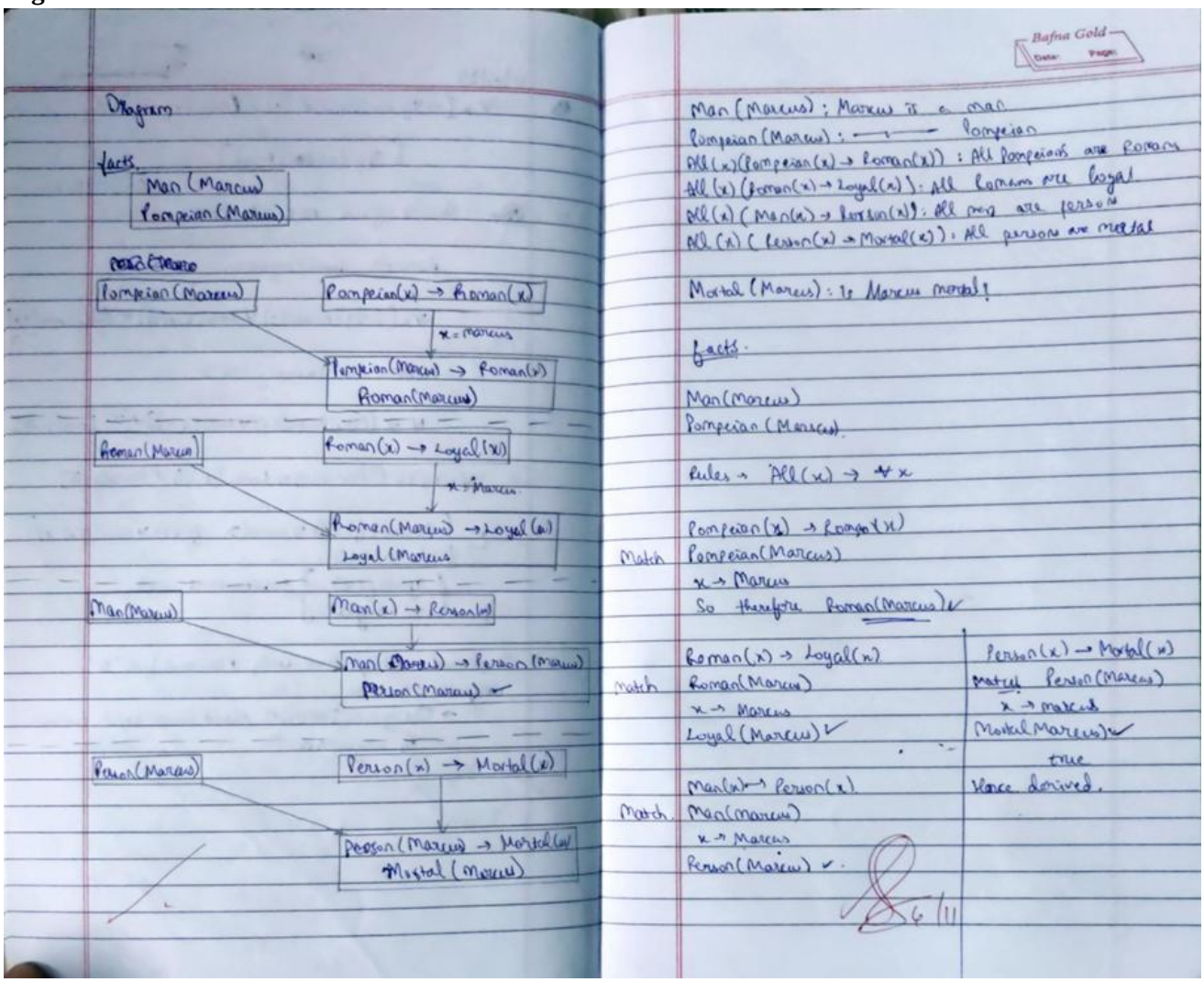
Output:

```
fol_fc_ask function called.
Knowledge Base (KB): [([], {'pred': 'prime', 'args': ['11']}), ([{'pred': 'prime', 'args': ['x']}], {'pred': 'odd', 'args': ['x']})]
Query (alpha): {'pred': 'odd', 'args': ['11']}
Result: False
```

Program 12

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

Algorithm:



Code:

```
from collections import deque, namedtuple


def is_variable(x):
    return isinstance(x, str) and x and x[0].islower()

def atom_str(atom):
    pred, args = atom
    return f"{pred}({', '.join(args)})"

# Substitute according to a mapping (var->constant)
def substitute_atom(atom, subs):
    pred, args = atom
    new_args = []
    for a in args:
        if is_variable(a) and a in subs:
            new_args.append(subs[a])
        else:
            new_args.append(a)
    return (pred, tuple(new_args))

# Unification for single terms (simple: variable -> constant only needed here)
def unify_terms(t1, t2, subs):
    # t1, t2 are strings; subs is dict var->const
    t1_val = subs.get(t1, t1) if is_variable(t1) else t1
    t2_val = subs.get(t2, t2) if is_variable(t2) else t2
    if t1_val == t2_val:
        return subs
    # if t1 is variable, bind it
    if is_variable(t1):
        # don't allow binding variable to another variable in this simple scenario; we'll allow var->const only
        subs2 = dict(subs)
        subs2[t1] = t2_val
        return subs2
    if is_variable(t2):
        subs2 = dict(subs)
        subs2[t2] = t1_val
        return subs2
    return None

def unify_atoms(a1, a2):
    # a1,a2 are atoms with same predicate name and same arity
```

```
    p1, args1 = a1
    p2, args2 = a2
    if p1 != p2 or len(args1) != len(args2):
        return None
    subs = {}
    for x, y in zip(args1, args2):
        subs = unify_terms(x, y, subs)
        if subs is None:
            return None
    return subs

# Horn rule: head :- body1, body2, ...
Rule = namedtuple("Rule", ["head", "body"])  # head: atom, body: list of atoms (may contain variables)

def forward_chain(rules, facts, query):
    # rules: list of Rule where variables are lowercase strings like 'x'
    # facts: set of ground atoms (constants only)
    # query: atom (ground) to prove
    inferred = set(facts)
    agenda = deque(facts)  # facts to be used to try rules
    proof = {}  # store how each inferred fact was derived: fact -> (rule, substitutions, premises)

    while agenda:
        fact = agenda.popleft()
        # try every rule: for each rule, try to match a body literal with this fact, then check remaining body literals
        for rule in rules:
            # For each body literal in the rule, attempt to unify it with the current fact
            for i, body_lit in enumerate(rule.body):
                # rename variables in rule to avoid accidental capture (standardize-apart)
                # We'll append a unique suffix for this attempt
                suffix = f"__{id(fact)}_{i}"
                def rename_atom(atom):
                    pred, args = atom
                    new_args = []
                    for a in args:
                        if is_variable(a):
                            new_args.append(a + suffix)
                        else:
                            new_args.append(a)
                    return (pred, tuple(new_args))
                renamed_body = [rename_atom(b) for b in rule.body]
                renamed_head = rename_atom(rule.head)

                target = renamed_body[i]
                subs = unify_atoms(target, fact)
```

```
            if subs is None:
                continue
            # Now we have a substitution for one body literal; check other body literals
            all_ok = True
            premises = [fact]  # start with matched fact
            # For each other literal, try to find a matching ground fact in inferred
            for j, other in enumerate(renamed_body):
                if j == i:
                    continue
                # we need to find some ground fact in inferred that unifies with 'other' under subs
                matched = False
                for candidate in inferred:
                    s2 = unify_atoms(other, candidate)
                    if s2 is None:
                        continue
                    # merge s2 with subs (simple merge; prefer earlier bindings)
                    merged = dict(subs)
                    conflict = False
                    for k,v in s2.items():
                        if k in merged and merged[k] != v:
                            conflict = True; break
                        merged[k] = v
                    if conflict:
                        continue
                    subs = merged
                    premises.append(candidate)
                    matched = True
                    break
                if not matched:
                    all_ok = False
                    break
            if not all_ok:
                continue
            # we can fire the rule with substitution 'subs' to produce head
            new_head = substitute_atom(renamed_head, subs)
            if new_head not in inferred:
                inferred.add(new_head)
                agenda.append(new_head)
                proof[new_head] = (rule, subs, tuple(premises))
                # check query
                if new_head == query:
                    return True, inferred, proof
    return (query in inferred), inferred, proof

# Build KB for Marcus
```

```
facts = {
    ("Man", ("Marcus",)),
    ("Pompeian", ("Marcus",))
}

rules = [
    Rule(head=("Roman", ("x",)), body=[("Pompeian", ("x",))]),
    Rule(head=("Loyal", ("x",)), body=[("Roman", ("x",))]),
    Rule(head=("Person", ("x",)), body=[("Man", ("x",))]),
    Rule(head=("Mortal", ("x",)), body=[("Person", ("x",))])
]

query = ("Mortal", ("Marcus",))

proved, inferred, proof = forward_chain(rules, facts, query)

print("Forward chaining proof result for query Mortal(Marcus):", proved)
print("\nAll inferred facts:")
for f in sorted(inferred):
    print(" -", atom_str(f))

if proved:
    print("\nProof trace (derived facts and how):")
    # walk backwards from query using the proof dict
    def show_derivation(fact, depth=0):
        indent = "  " * depth
        if fact not in proof:
            print(indent + f"{atom_str(fact)}  (given)")
            return
        rule_used, subs_used, premises = proof[fact]
        head = rule_used.head
        print(indent + f"{atom_str(fact)}  (derived via {atom_str(head)} :- {', '.join(atom_str(b) for b in
rule_used.body)})")
        print(indent + f"  substitution: {subs_used}")
        for p in premises:
            show_derivation(p, depth+1)
    show_derivation(query)
```

Output:

```
Forward chaining proof result for query Mortal(Marcus): True

All inferred facts:
 - Man(Marcus)
 - Mortal(Marcus)
 - Person(Marcus)
 - Pompeian(Marcus)
 - Roman(Marcus)

Proof trace (derived facts and how):
Mortal(Marcus)  (derived via Mortal(x) :- Person(x))
  substitution: {'x__2573327946496_0': 'Marcus'}
  Person(Marcus)  (derived via Person(x) :- Man(x))
    substitution: {'x__2573327854976_0': 'Marcus'}
    Man(Marcus)  (given)

[Done] exited with code=0 in 0.203 seconds
```