VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT

on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Annas Sharieff (1BM23CS041)

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 **Annas Sharieff (1BM23CS041),** who is bonafide student of **B.M.S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements in respect of an Artificial Intelligence (23CS5PCAIN) work prescribed for the said degree.

Dr. K.R. Mamatha Assistant Professor Department of CSE, BMSCE	Dr. Kavitha Sooda Professor & HOD Department of CSE, BMSCE

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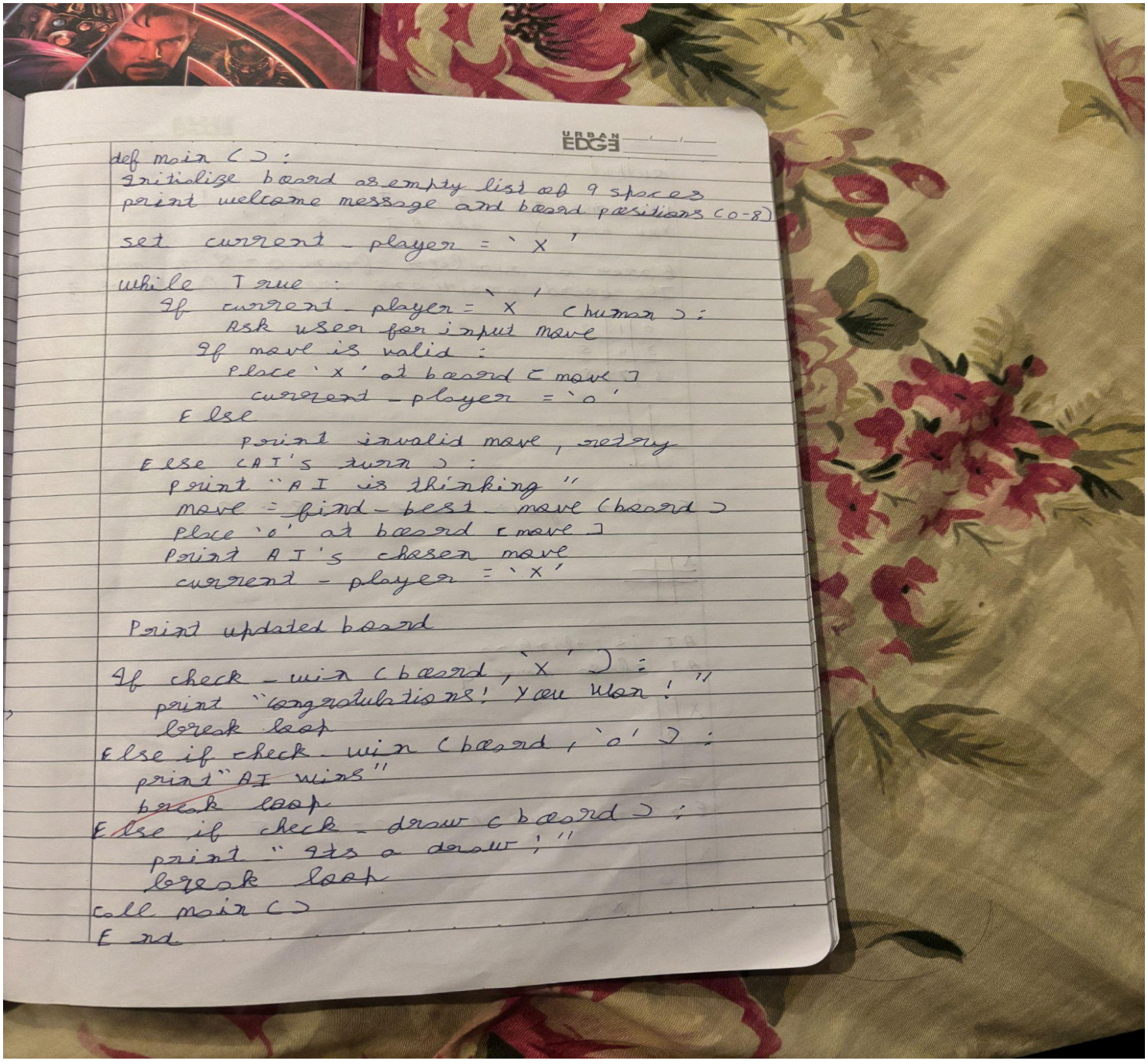
Github Link:
https://github.com/annas05shariff/AI-LAB

Program 1
Implement Tic –Tac –Toe Game
Implement vacuum cleaner agent

Algorithm:
a) Tic Tac Toe



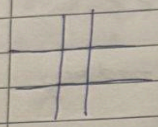
URBAN EDGE

output :

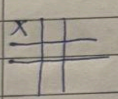
Welcome To Tic Tac Toe !
You are X, the AI is 'O'

Enter a number from 0 - 8 to make a move :
The board positions are as follows :

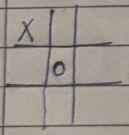
0	1	2
3	4	5
6	7	8



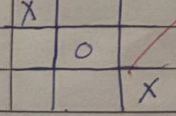
Enter your move 0 - 8 : 0



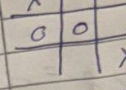
AI is thinking . . .
AI chose move 4



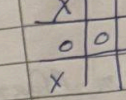
Enter your move 0 - 8 : 8



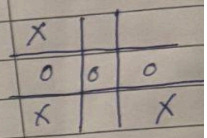
AI is thi
AI chose m



Enter yo



AI is th
AI chose



AI wi

AI is thinking...
AI chose move 3

X		
O	O	
		X

Enter your move 0-8 : 6

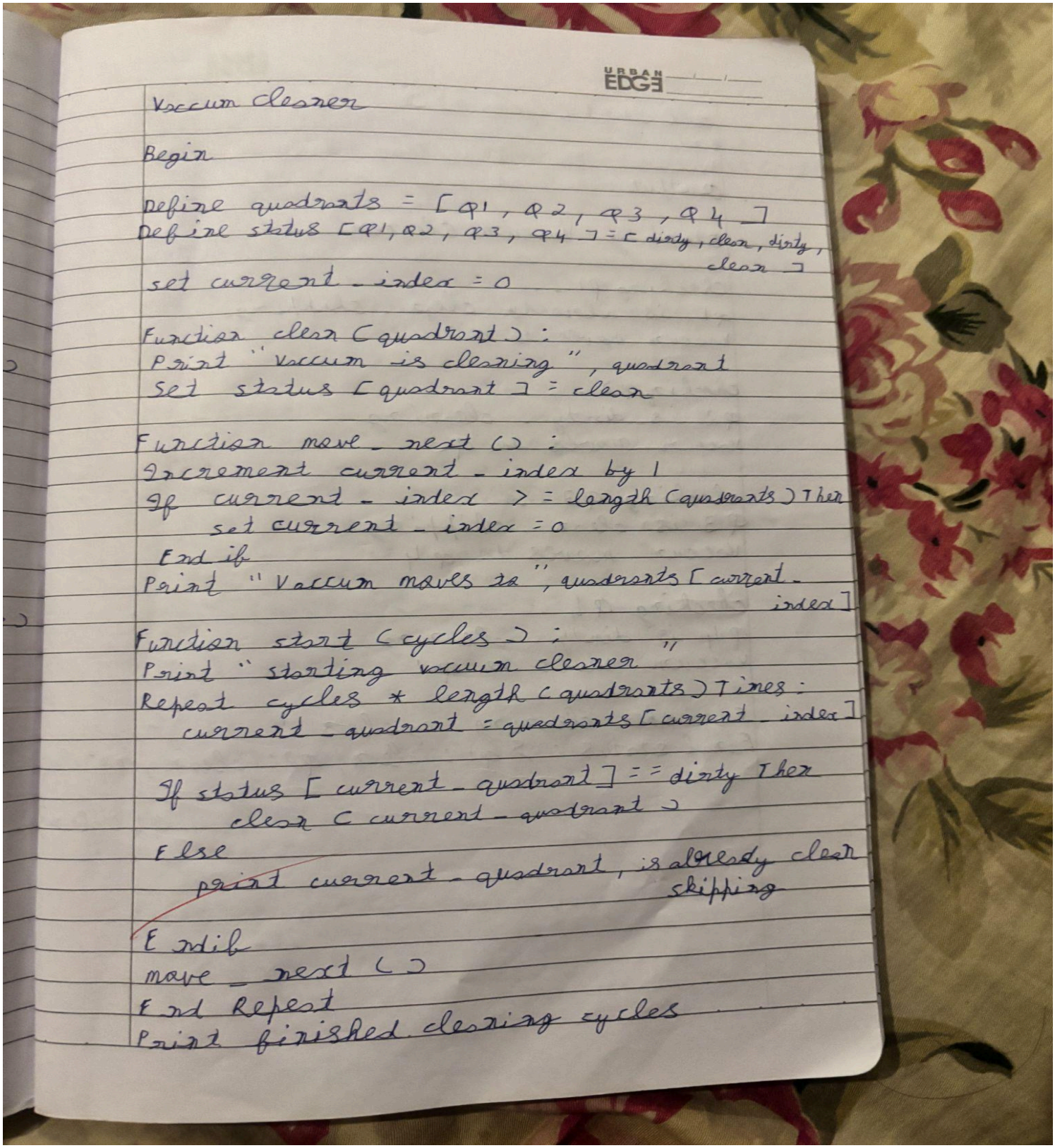
X		
O	O	
X		X

AI is thinking...
AI chose move 5

X		
O	O	O
X		X

AI wins

b) Vacuum Cleaner:



```
Vaccum cleaner

Begin

Define quadrants = [Q1, Q2, Q3, Q4]
Define status [Q1, Q2, Q3, Q4] = [dirty, clean, dirty,
                                  clean]
set current_index = 0

Function clean (quadrant):
Print "Vaccum is cleaning", quadrant
Set status [quadrant] = clean

Function move_next ():
Increment current_index by 1
If current_index >= length (quadrants) Then
    set current_index = 0
End if
Print "Vaccum moves to", quadrants [current_
                                    index]

Function start (cycles):
Print "starting vacuum cleaner"
Repeat cycles * length (quadrants) Times:
   current_quadrant = quadrants [current_index]

   If status [current_quadrant] == dirty Then
       clean (current_quadrant)
   Else
       print current_quadrant, is already clean
                                  skipping
   End if
   move_next ()
End Repeat
Print finished cleaning cycles
```

URBAN EDGE

call start (cycles = 3)
End

output:

starting vaccum cleaner...

checking q1...
q1 is already clean. skipping
vaccum moves to q2

checking q2...
q2 is dirty. cleaning
vaccum moves to q3

checking q3...
q3 is clean. skipping
vaccum moves to q4

checking q4...
q4 is dirty. cleaning
vaccum moves to q1

Finished cleaning cycles!
Final status: {q1: clean, q2: clean, q3: clean, q4: clean}

Code:

a) Tic Tac Toe

```
board = [["-","-","-"],["-","-","-"],["-","-","-"]]
Xrow = {"0":0,"1":0,"2":0}
Orow = {"0":0,"1":0,"2":0}
Xcol = {"0":0,"1":0,"2":0}
Ocol = {"0":0,"1":0,"2":0}
win = False

def checkWin():
    global win
    for key in Xrow:
        if Xrow[key] == 3:
            win = True
    for key in Xcol:
        if Xcol[key] == 3:
            win = True
    for key in Orow:
        if Orow[key] == 3:
            win = True
    for key in Ocol:
        if Ocol[key] == 3:
            win = True
    if board[0][0] == board[1][1] == board[2][2] != "-":
        win = True
    if board[0][2] == board[1][1] == board[2][0] != "-":
        win = True

def place(symbol, row, col):
    if board[row][col] != "-":
        print("Can't place at this spot, try again")
        return False

    if symbol == "1":
        board[row][col] = "X"
        Xrow[str(row)] += 1
        Xcol[str(col)] += 1
    elif symbol == "2":
        board[row][col] = "O"
        Orow[str(row)] += 1
        Ocol[str(col)] += 1
```

```
    return True

def displayBoard():
    for row in board:
        print(row)
    print("\n")
# Game loop
displayBoard()
switch = input("Enter 1 for X, 2 for O to start: ")

while any("-" in row for row in board) and not win:
    try:
        row = int(input("Enter Row (1-3): "))
        col = int(input("Enter Column (1-3): "))
    except ValueError:
        print("Invalid input, enter numbers only.")
        continue

    if row > 3 or col > 3 or row < 1 or col < 1:
        print("Invalid input, please try again.")
        continue

    decision = place(switch, row - 1, col - 1)
    if decision:
        displayBoard()
        checkWin()
        if not win:
            switch = "2" if switch == "1" else "1"

if win:
    winner = "X" if switch == "1" else "O"
    print(f"{winner} wins!")
else:
    print("It's a draw!")
print("Annas
1BM23CS041")
```

Output:

```
['-', '-', '-']
['-', '-', '-']
```

['-', '-', '-']

Enter 1 for X, 2 for O to start: 1
Enter Row (1-3): 2
Enter Column (1-3): 2
['-', '-', '-']
['-', 'X', '-']
['-', '-', '-']

Enter Row (1-3): 1
Enter Column (1-3): 3
['-', '-', 'O']
['-', 'X', '-']
['-', '-', '-']

Enter Row (1-3): 1
Enter Column (1-3): 2
['-', 'X', 'O']
['-', 'X', '-']
['-', '-', '-']

Enter Row (1-3): 2
Enter Column (1-3): 3
['-', 'X', 'O']
['-', 'X', 'O']
['-', '-', '-']

Enter Row (1-3): 3
Enter Column (1-3): 2
['-', 'X', 'O']
['-', 'X', 'O']
['-', 'X', '-']

X wins!
Annas 1BM23CS041

b) Vacuum Cleaner

```
rooms = int(input("Enter Number of rooms: "))
Rooms = "ABCDEFGHIJKLMNOPQRSTUVWXYZ"
cost = 0
Roomval = {}
for i in range(rooms):
    print(f"Enter Room {Rooms[i]} state (0 for clean, 1 for dirty): ")
    n = int(input())
    Roomval[Rooms[i]] = n
loc = input(f"Enter Location of vacuum ({Rooms[:rooms]}): ").upper()
while 1 in Roomval.values():
    if Roomval[loc] == 1:
        print(f"Room {loc} is dirty. Cleaning...")
        Roomval[loc] = 0
        cost += 1
    else:
        print(f"Room {loc} is already clean.")
    move = input("Enter L or R to move left or right (or Q to quit): ").upper()

    if move == "L":

        if loc != Rooms[0]:
            loc = Rooms[Rooms.index(loc) - 1]
        else:
            print("No room to move left.")
    elif move == "R":
        if loc != Rooms[rooms - 1]:
            loc = Rooms[Rooms.index(loc) + 1]
        else:
            print("No room to move right.")
    elif move == "Q":
        break
    else:
        print("Invalid input. Please enter L, R, or Q.")

print("\nAll Rooms Cleaned." if 1 not in Roomval.values() else "Exited before cleaning all rooms.")
print(f"Total cost: {cost}")
```

```
print("1BM23CS041")
```

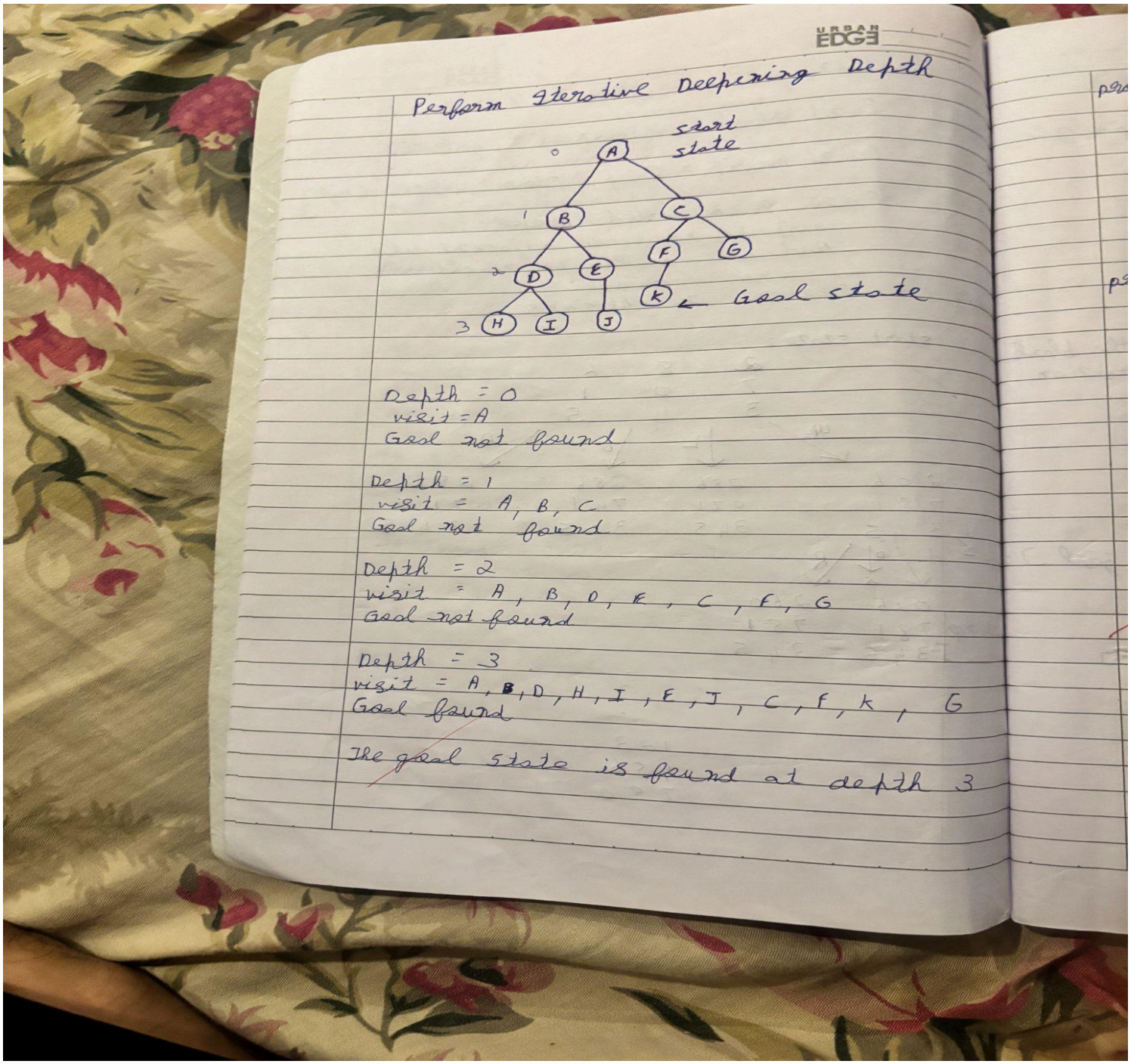
Output:

```
Enter Number of rooms: 3
Enter Room A state (0 for clean, 1 for dirty):
1
Enter Room B state (0 for clean, 1 for dirty):
0
Enter Room C state (0 for clean, 1 for dirty):
1
Enter Location of vacuum (ABC): B
Room B is already clean.
Enter L or R to move left or right (or Q to quit): L
Room A is dirty. Cleaning...
Enter L or R to move left or right (or Q to quit): R
Room B is already clean.
Enter L or R to move left or right (or Q to quit): R
Room C is dirty. Cleaning...
Enter L or R to move left or right (or Q to quit): R
No room to move right.

All Rooms Cleaned.
Total cost: 2
1BM23CS041
```

Program 2

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

Algorithm:



```
procedure IDDFS(root, goal_test):
    depth ← 0
    loop forever:
        found, path ← DLS(root, depth, goal_test,
        stack_path = [root])
        if found = True:
            return path
        depth ← depth + 1

procedure DLS(node, limit, goal_test, stack_
        if goal_test(node) = True:                path):
            return (True, stack_path)

        if limit = 0:
            return (False, None)

        for each_child in expand(node)
            if child not in stack_path
                found, path ← DLS(child, limit-1, goal_
                        test, stack_path + [child])
            if found = True
                return (True, path)

        return (False, None)
```

Soon
31/10/25

URBAN EDGE

8 puzzle

start with initial state of the puzzle
set depth limit = 0

Misplace Tiles heuristic :

Algo :

count = 0

for each tiles puzzle (except the blank)
if tiles not in the correct position
→ increment count

return count

Pseudocode

```
function misplaced_tiles (state, goal):
    count ← 0
    for i from 0 to 8
        if state[i] ≠ '-' and
            state[i] ≠ goal[i]
        count ← count + 1

    Return count
```

Example

5		8
4	2	1
7	3	6

Initial state

1	2	3
4	5	6
7	8	

Goal state

misplaced = 6 tiles

Manhattan Distance heuristic

distance = 0
for each tile in the puzzle
    find its goal position in the goal state
    compute row diff + column diff
Return distance

function Manhattan-Distance(state, goal)

    distance ← 0
    for i from 0 to 8
        if state[i] ≠ ' '
            goal_index ← position of state[i]

            (x1, y1) ← (i div 3, i mod 3)
            (x2, y2) ← (goal index div 3, goal index mod 3)
            distance ← distance + |x1 - x2| + |y1 - y2|

    return distance

Example

2	8	3
1	6	4
7		5

Initial state

1	2	3
4	5	6
7	8	

Goal state

Tile 2 : (0-1) + (0-0) = 1+0 = 1
Tile 8 : (1-1) + (0-2) = 0+2 = 2
Tile 3 : (2-2) + (0-0) = 0+0 = 0
Tile 1 : (0-0) + (1-0) = 1+0 = 1
Tile 6 : (1-2) + (1-1) = 1+0 = 1
Tile 4 : (2-0) + (1-1) = 2+0 = 2
Tile 7 : (0-0) + (2-2) = 0
Tile 5 : (2-1) + (2-1) = 1+1 = 2

A* another example :

Start state

1	2	3
	4	5
6	7	8

Goal State

1	2	3
4	5	6
7	8	

f = g + h
g
h

g=1, h=4, f=5

-	2	3
1	4	6
7	5	8

g=2, h=■, f=3

1	2	3
4	5	6
7	-	8

1	2	3
4	5	6
7	8	-

g = 3, h = 0

Learn

10/9/25

URBAN EDGE

1	2	3
-	4	6
7	5	8

$g = 0, h = 3, f = 3$

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

-	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	-	3
4	2	6
7	5	8

$g = 2, h = \blacksquare, f = 3$

1	2	3
4	5	6
7	-	8

1	2	3
4	6	-
7	5	8

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

1	-	3
4	2	6
7	5	8

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

1	2	3
4	5	6
7	8	-

1	2	3
4	5	6
-	7	8

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

$g = 3, h = 0, f = 3$

Misplaced Tile

Learn

10/9/25

Code:

a) DFS

```
goal_state = '123456780'

moves = {
    'U': -3,
    'D': 3,
    'L': -1,
    'R': 1
}

invalid_moves = {
    0: ['U', 'L'], 1: ['U'], 2: ['U', 'R'],
    3: ['L'],        5: ['R'],
    6: ['D', 'L'], 7: ['D'], 8: ['D', 'R']
}

def move_tile(state, direction):
    index = state.index('0')
    if direction in invalid_moves.get(index, []):
        return None

    new_index = index + moves[direction]
    if new_index < 0 or new_index >= 9:
        return None

    state_list = list(state)
    state_list[index], state_list[new_index] = state_list[new_index], state_list[index]
    return ''.join(state_list)

def print_state(state):
    for i in range(0, 9, 3):
        print(' '.join(state[i:i+3]).replace('0', ' '))
    print()

def dfs(start_state, max_depth=50):
    visited = set()
    stack = [(start_state, [])] # Each element: (state, path)

    while stack:
        current_state, path = stack.pop()
```

```
        if current_state in visited:
            continue

        # Print every visited state
        print("Visited state:")
        print_state(current_state)

        if current_state == goal_state:
            return path
        visited.add(current_state)


        if len(path) >= max_depth:


            continue

        for direction in moves:
            new_state = move_tile(current_state, direction)
            if new_state and new_state not in visited:
                stack.append((new_state, path + [direction]))

    return None

start = input("Enter start state (e.g., 724506831): ")

if len(start) == 9 and set(start) == set('012345678'):
    print("Start state:")
    print_state(start)

    result = dfs(start)

    if result is not None:
        print("Solution found!")
        print("Moves:", ' '.join(result))
        print("Number of moves:", len(result))
        print("1BM23CS041 Annas\n")

        current_state = start
        for i, move in enumerate(result, 1):
            current_state = move_tile(current_state, move)
```

```
            print(f"Move {i}: {move}")
            print_state(current_state)
    else:
        print("No solution exists for the given start state or max depth reached.")
else:
    print("Invalid input! Please enter a 9-digit string using digits 0-8 without repetition.")
```

Output:

```
Enter start state (e.g., 724506831): 123456078
Start state:
1 2 3
4 5 6
 7 8

Visited state:
1 2 3
4 5 6
 7 8

Visited state:
1 2 3
4 5 6
7  8

Visited state:
1 2 3
4 5 6
7 8

Solution found!
Moves: R R
Number of moves: 2
1BM23CS041

Move 1: R
1 2 3
4 5 6
7  8

Move 2: R
1 2 3
```

4 5 6
7 8

b) Iterative Deepening

Search goal_state =

'123456780'

```
moves = {
   'U': -3,
   'D': 3,
   'L': -1,
   'R': 1
}

invalid_moves = {
   0: ['U', 'L'], 1: ['U'], 2: ['U', 'R'],
   3: ['L'],       5: ['R'],
   6: ['D', 'L'], 7: ['D'], 8: ['D', 'R']
}

def move_tile(state, direction):
   index = state.index('0')
   if direction in invalid_moves.get(index, []):
      return None

   new_index = index + moves[direction]
   if new_index < 0 or new_index >= 9:
      return None

   state_list = list(state)
   state_list[index], state_list[new_index] = state_list[new_index], state_list[index]
   return ''.join(state_list)

def print_state(state):
   for i in range(0, 9, 3):
      print(' '.join(state[i:i+3]).replace('0', ' '))
   print()

def dls(state, depth, path, visited, visited_count):
   visited_count[0] += 1 # Increment visited states count
   if state == goal_state:
      return path
```

```
    if depth == 0:
    return None visited.add(state)
    for direction in moves:
        new_state = move_tile(state, direction)
        if new_state and new_state not in visited:
            result = dls(new_state, depth - 1, path + [direction], visited, visited_count)
            if result is not None:
                return result

    visited.remove(state)
    return None

def iddfs(start_state, max_depth=50):
    visited_count = [0] # Using list to pass by reference
    for depth in range(max_depth + 1):
        visited = set()
        result = dls(start_state, depth, [], visited, visited_count)
        if result is not None:
            return result, visited_count[0]
    return None, visited_count[0]

# Main
start = input("Enter start state (e.g., 724506831): ")

if len(start) == 9 and set(start) == set('012345678'):
    print("Start state:")
    print_state(start)

    result, visited_states = iddfs(start,15)
    print(f"Total states visited: {visited_states}")
    if result is not None:
        print("Solution found!")
        print("Moves:", ' '.join(result))
        print("Number of moves:", len(result))
        print("1BM23CS041\n")

        current_state = start
```

```
        for i, move in enumerate(result, 1):
            current_state = move_tile(current_state, move)
            print(f"Move {i}: {move}")
            print_state(current_state)
    else:
        print("No solution exists for the given start state or max depth reached.")
else:
    print("Invalid input! Please enter a 9-digit string using digits 0-8 without repetition.")
```

Output:
Enter start state (e.g., 724506831): 123405678
Start state:
1 2 3
4 5
6 7 8

Total states visited: 24298
Solution found!
Moves: R D L L U R D R U L L D R R
Number of moves: 14
1BM23CS041

Move 1: R
1 2 3
4 5
6 7 8

Move 2: D
1 2 3
4 5 8
6 7

Move 3: L
1 2 3
4 5 8
6 7

Move 4: L
1 2 3
4 5 8
 6 7

Move 5: U
1 2 3
  5 8
4 6 7

Move 6: R
1 2 3
5 8
4 6 7

Move 7: D
1 2 3
5 6 8
4 7

Move 8: R
1 2 3
5 6 8
4 7

Move 9: U
1 2 3
5 6
4 7 8

Move 10: L
1 2 3
5 6
4 7 8

Move 11: L
1 2 3
  5 6
4 7 8

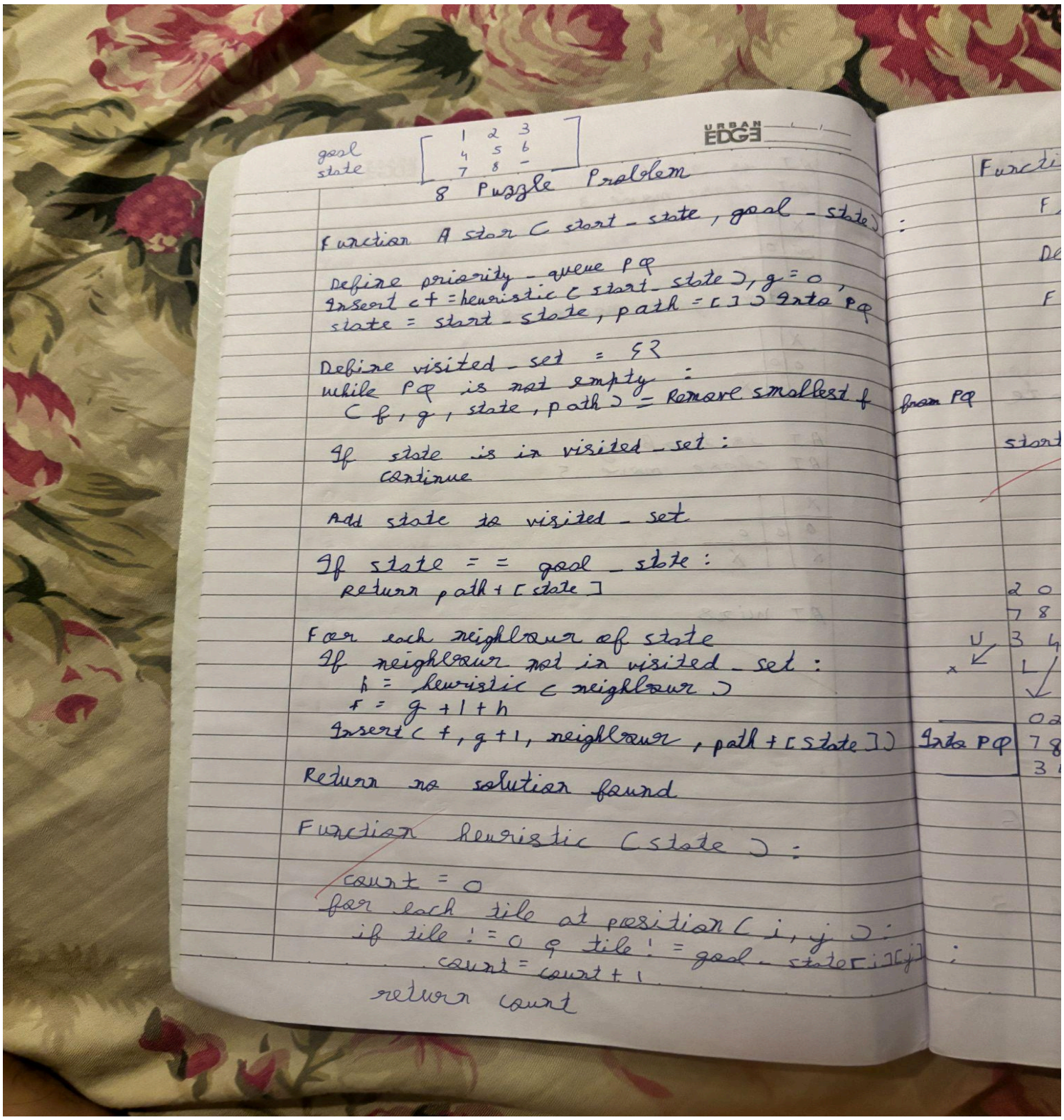
Move 12: D
1 2 3
4 5 6
  7 8

Move 13: R
1 2 3
4 5 6
7 8

Move 14: R
1 2 3
4 5 6
7 8

Program 3

Implement A* search algorithm



URBAN EDGE

Function get_neighbours(state):

Find blank_position (x, y)

Define Moves = [(up), (down), (left), (right)]

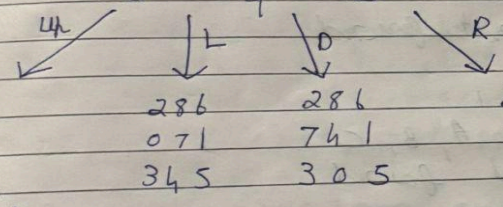
For each valid move:
swap blank with adjacent tile
Add new_state to neighbours

return neighbours

from PQ

start state:

2 8 6
7 0 1
3 4 5



2 0 6
7 8 1
3 4 5

2 8 6
0 7 1
3 4 5

2 8 6
7 4 1
3 0 5

2 8 6
7 1 0
3 4 5

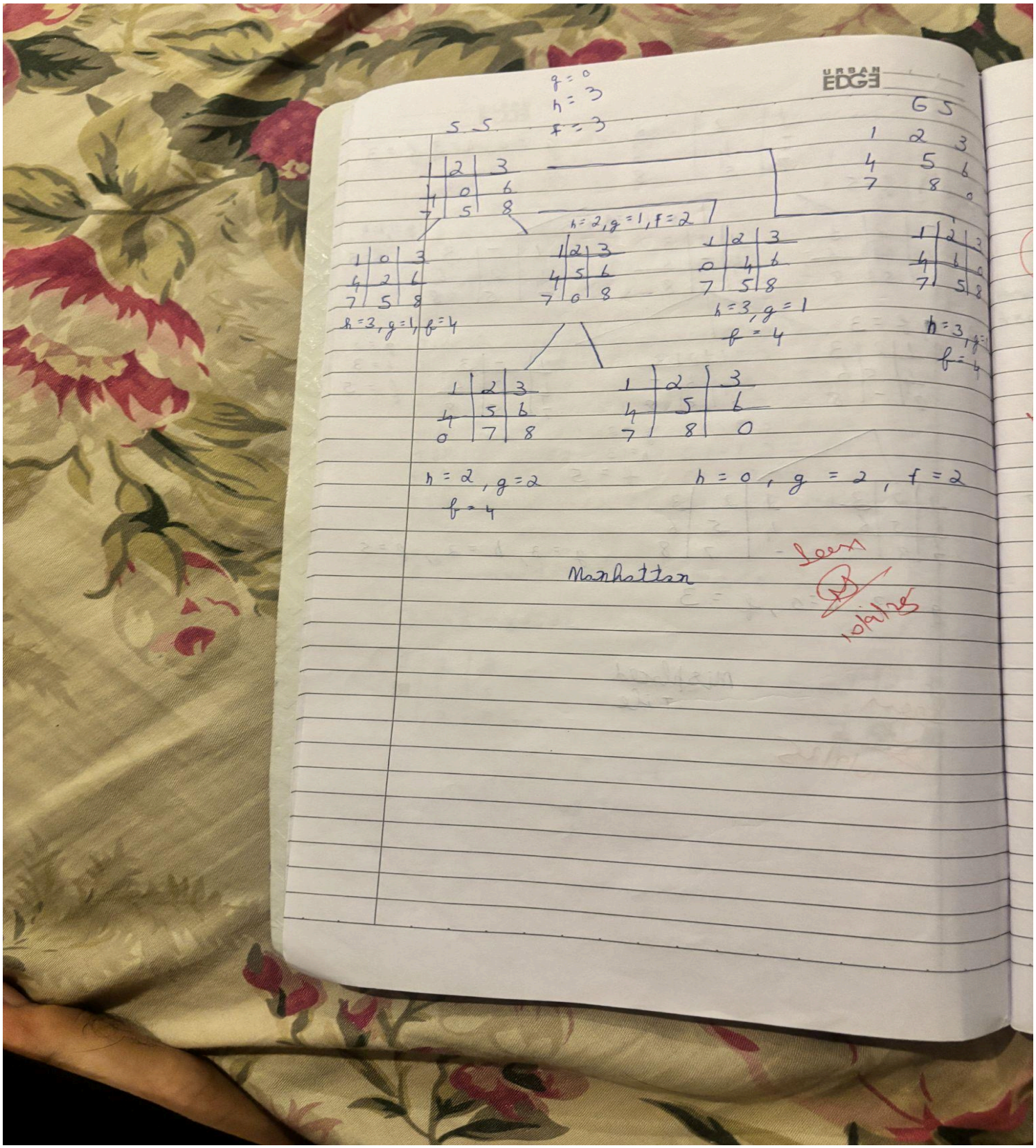
U
L
D
R

0 2 6
7 8 1
3 4 5

2 6 0
7 8 1
3 4 5

into PQ

1 2 3
4 5 6
7 8 0


g = 0
h = 3
f = 3
S S
1 2 3
4 0 6
7 5 8
h = 2, g = 1, f = 2
1 0 3
4 2 6
7 5 8
h = 3, g = 1, f = 4
1 2 3
4 5 6
7 0 8
1 2 3
0 4 6
7 5 8
h = 3, g = 1
f = 4
G S
1 2 3
4 5 6
7 8 0
1 2 3
4 5 6
0 7 8
h = 2, g = 2
f = 4
1 2 3
4 5 6
7 8 0
h = 0, g = 2, f = 2
Manhattan
Learn
10/9/25

Code:
Misplaced Tiles

```
import heapq
goal_state = '123804765'

moves = {

    'U': -3,
    'D': 3,
    'L': -1,
    'R': 1
}

invalid_moves = {
    0: ['U', 'L'], 1: ['U'], 2: ['U', 'R'],
    3: ['L'],        5: ['R'],
    6: ['D', 'L'], 7: ['D'], 8: ['D', 'R']
}

def move_tile(state, direction):
    index = state.index('0')
    if direction in invalid_moves.get(index, []):
        return None

    new_index = index + moves[direction]
    if new_index < 0 or new_index >= 9:
        return None

    state_list = list(state)
    state_list[index], state_list[new_index] = state_list[new_index], state_list[index]
    return ''.join(state_list)

def print_state(state):
    for i in range(0, 9, 3):
        print(' '.join(state[i:i+3]).replace('0', ' '))
    print()

def misplaced_tiles(state):
    """Heuristic: count of tiles not in their goal position (excluding zero)."""
    return sum(1 for i, val in enumerate(state) if val != '0' and val != goal_state[i])

def a_star(start_state):
    visited_count = 0
    open_set = []
    heapq.heappush(open_set, (misplaced_tiles(start_state), 0, start_state, []))
```

```
    visited = set()

    while open_set:
        f, g, current_state, path = heapq.heappop(open_set)
        visited_count += 1

        if current_state == goal_state:
            return path, visited_count
        if current_state in visited:
            continue
        visited.add(current_state)

        for direction in moves:
            new_state = move_tile(current_state, direction)
            if new_state and new_state not in visited:
                new_g = g + 1
                new_f = new_g + misplaced_tiles(new_state)
                heapq.heappush(open_set, (new_f, new_g, new_state, path + [direction]))

    return None, visited_count

# Main
start = input("Enter start state (e.g., 724506831): ")

if len(start) == 9 and set(start) == set('012345678'):
    print("Start state:")
    print_state(start)
    result, visited_states = a_star(start)

    print(f"Total states visited: {visited_states}")

    if result is not None:

        print("Solution found!")
        print("Moves:", ' '.join(result))
        print("Number of moves:", len(result))
        print("1BM23CS041 Annas\n")

        current_state = start
        g = 0 # initialize cost so far
        for i, move in enumerate(result, 1):
            new_state = move_tile(current_state, move)
            g += 1
            h = misplaced_tiles(new_state)
            f = g + h
```

```
            print(f"Move {i}: {move}")
            print_state(new_state)
            print(f"g(n) = {g}, h(n) = {h}, f(n) = g(n) + h(n) = {f}\n")
            current_state = new_state
    else:
        print("No solution exists for the given start state.")
Else:
print("Invalid input! Please enter a 9-digit string using digits 0-8 without repetition.")
```

Output:

```
Enter start state (e.g., 724506831): 283164705
Start state:
2 8 3
1 6 4
7  5

Total states visited: 7
Solution found!
Moves: U U L D R
Number of moves: 5
1BM23CS041 Annas

Move 1: U
2 8 3
1  4
7 6 5
g(n) = 1, h(n) = 3, f(n) = g(n) + h(n) = 4

Move 2: U

2  3
1 8 4
7 6 5
g(n) = 2, h(n) = 3, f(n) = g(n) + h(n) = 5
Move 3: L
  2 3
1 8 4
7 6 5
g(n) = 3, h(n) = 2, f(n) = g(n) + h(n) = 5

Move 4: D

1 2 3
  8 4
7 6 5
```

g(n) = 4, h(n) = 1, f(n) = g(n) + h(n) = 5
Move 5: R
1 2 3
8 4
7 6 5

g(n) = 5, h(n) = 0, f(n) = g(n) + h(n) = 5

a) Manhattan
Distance import heapq
goal_state = '123456780'

moves = {

  'U': -3,
  'D': 3,
  'L': -1,
  'R': 1
}

invalid_moves = {
  0: ['U', 'L'], 1: ['U'], 2: ['U', 'R'],
  3: ['L'], 5: ['R'],
  6: ['D', 'L'], 7: ['D'], 8: ['D', 'R']
}

```
def move_tile(state, direction):
    index = state.index('0')
    if direction in invalid_moves.get(index, []):
        return None

    new_index = index + moves[direction]
    if new_index < 0 or new_index >= 9:
        return None

    state_list = list(state)
    state_list[index], state_list[new_index] = state_list[new_index], state_list[index]
    return ''.join(state_list)

def print_state(state):
    for i in range(0, 9, 3):
        print(' '.join(state[i:i+3]).replace('0', ' '))
    print()

def manhattan_distance(state):
```

```
    distance = 0
    for i, val in enumerate(state):
        if val == '0':
    continue
        goal_pos = int(val) - 1
        current_row, current_col = divmod(i, 3)
        goal_row, goal_col = divmod(goal_pos, 3)
        distance += abs(current_row - goal_row) + abs(current_col - goal_col)
    return distance

def a_star(start_state):
    visited_count = 0
    open_set = []
    heapq.heappush(open_set, (manhattan_distance(start_state), 0, start_state, []))
    visited = set()

    while open_set:
        f, g, current_state, path = heapq.heappop(open_set)
        visited_count += 1

        if current_state == goal_state:
            return path, visited_count

        if current_state in visited:
            continue
        visited.add(current_state)

        for direction in moves:
            new_state = move_tile(current_state, direction)
            if new_state and new_state not in visited:
                new_g = g + 1
                new_f = new_g + manhattan_distance(new_state)
                heapq.heappush(open_set, (new_f, new_g, new_state, path + [direction]))
    return None, visited_count

# Main

start = input("Enter start state (e.g., 724506831): ")

if len(start) == 9 and set(start) == set('012345678'):
    print("Start state:")
    print_state(start)

    result, visited_states = a_star(start)
```

```
    print(f"Total states visited: {visited_states}")

    if result is not None:
    print("Solution found!") print("Moves:", ' '.join(result)) print("Number of moves:", len(result))
    print("1BM23CS041\n")

        current_state = start
        g = 0 # initialize cost so far
        for i, move in enumerate(result, 1):
            new_state = move_tile(current_state, move)
            g += 1
            h = manhattan_distance(new_state)
            f = g + h
            print(f"Move {i}: {move}")
            print_state(new_state)
            print(f"g(n) = {g}, h(n) = {h}, f(n) = g(n) + h(n) = {f}\n")
            current_state = new_state
    else:
        print("No solution exists for the given start state.")
else:
    print("Invalid input! Please enter a 9-digit string using digits 0-8 without repetition.")
```

Output:

```
Enter start state (e.g., 724506831): 123678450
Start state:
1 2 3
6 7 8
4 5

Total states visited: 21
Solution found!
Moves: L U L D R R U L D R
Number of moves: 10
1BM23CS041

Move 1: L
1 2 3
6 7 8
4  5
g(n) = 1, h(n) = 9, f(n) = g(n) + h(n) = 10
Move 2: U
1 2 3
6  8
4 7 5
```

g(n) = 2, h(n) = 8, f(n) = g(n) + h(n) = 10

Move 3: L
1 2 3
  6 8
4 7 5
g(n) = 3, h(n) = 7, f(n) = g(n) + h(n) = 10
Move 4: D
1 2 3
4 6 8
  7 5
g(n) = 4, h(n) = 6, f(n) = g(n) + h(n) = 10

Move 5: R

1 2 3
4 6 8
7 5
g(n) = 5, h(n) = 5, f(n) = g(n) + h(n) = 10
Move 6: R
1 2 3
4 6 8
7 5
g(n) = 6, h(n) = 4, f(n) = g(n) + h(n) = 10

Move 7: U

1 2 3
4 6
7 5 8
g(n) = 7, h(n) = 3, f(n) = g(n) + h(n) = 10
Move 8: L
1 2 3
4 6
7 5 8

g(n) = 8, h(n) = 2, f(n) = g(n) + h(n) = 10

Move 9: D
1 2 3
4 5 6
7 8
g(n) = 9, h(n) = 1, f(n) = g(n) + h(n) = 10

Move 10: R

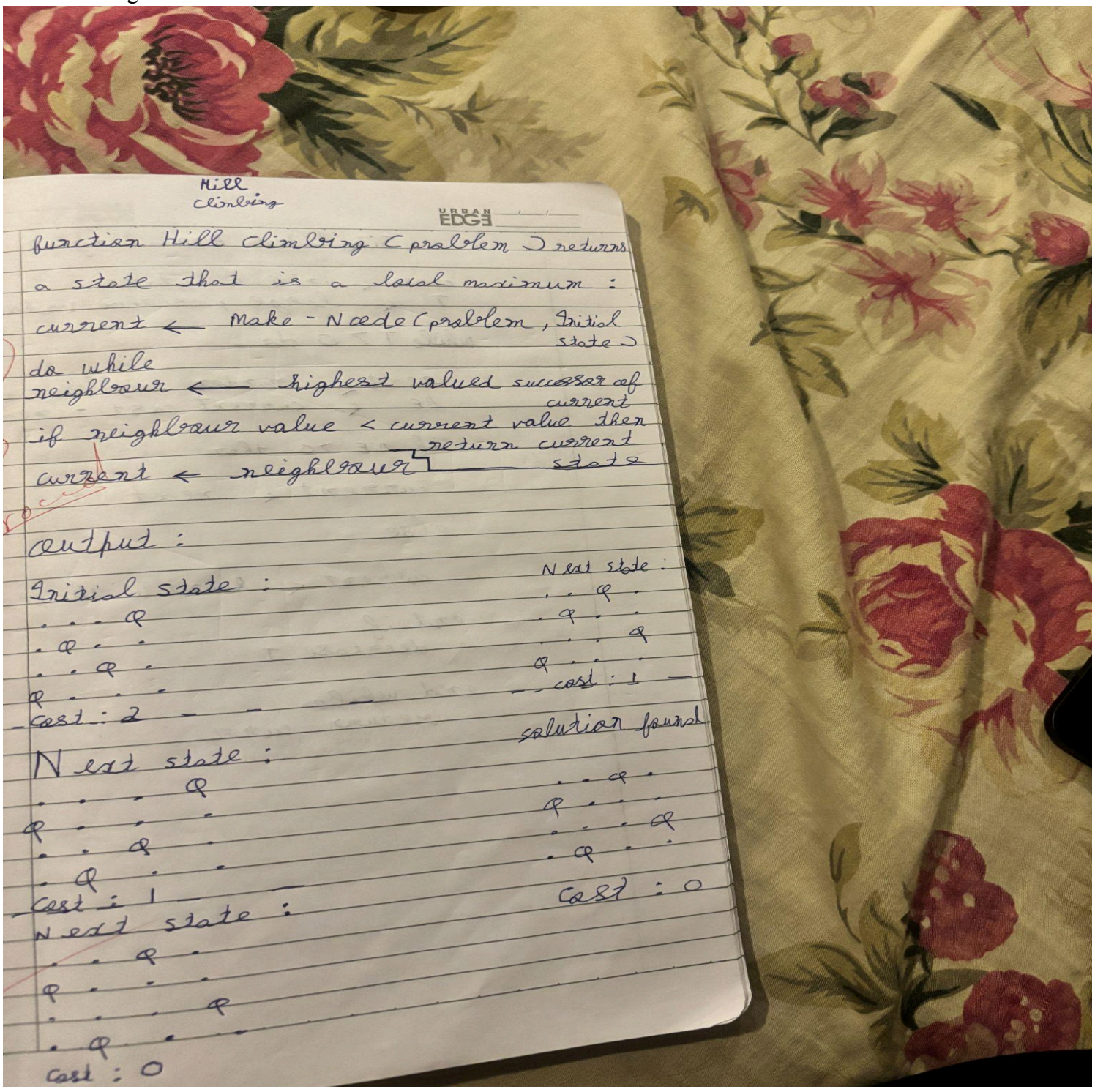
1 2 3
4 5 6
7 8

g(n) = 10, h(n) = 0, f(n) = g(n) + h(n) = 10

Program 4

Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm:



Code:

```
import random
import time

def print_board(state):
    """Prints the chessboard for a given state."""
    n = len(state)
    for row in range(n):
        line = ""
        for col in range(n):
            if state[col] == row:
                line += "Q "
            else:
                line += ". "
        print(line)
    print()

def compute_heuristic(state):
    """Computes the number of attacking pairs of queens."""
    h = 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):
                h += 1
    return h

def get_neighbors(state):
    """Generates all possible neighbors by moving one queen in its column."""
    neighbors = []
    n = len(state)
    for col in range(n):
        for row in range(n):
            if row != state[col]:
                neighbor = list(state)
                neighbor[col] = row
                neighbors.append(neighbor)
    return neighbors

def hill_climb_verbose(initial_state, step_delay=0.5):
```

```
    """Hill climbing algorithm with verbose output at each step."""
    current = initial_state
    current_h = compute_heuristic(current)
    step = 0

    print(f"Initial state (heuristic: {current_h}):")
    print_board(current)
    time.sleep(step_delay)

    while True:
        neighbors = get_neighbors(current)
        next_state = None
        next_h = current_h

        for neighbor in neighbors:
            h = compute_heuristic(neighbor)
            if h < next_h:
                next_state = neighbor
                next_h = h

        if next_h >= current_h:
            print(f"Reached local minimum at step {step}, heuristic: {current_h}")
            return current, current_h

        current = next_state
        current_h = next_h
        step += 1
        print(f"Step {step}: (heuristic: {current_h})")
        print_board(current)
        time.sleep(step_delay)

def solve_n_queens_verbose(n, max_restarts=1000):
    """Solves N-Queens problem using hill climbing with restarts and verbose output."""
    for attempt in range(max_restarts):
        print(f"\n=== Restart {attempt + 1} ===\n")
        initial_state = [random.randint(0, n - 1) for _ in range(n)]
        solution, h = hill_climb_verbose(initial_state)
        if h == 0:
            print(f"  Solution found after {attempt + 1} restart(s):")
            print_board(solution)
```

```
            return solution
        else:
            print(f"  No solution in this attempt (local minimum).\n")
    print("Failed to find a solution after max restarts.")
            return None

# --- Run the algorithm ---
if __name__ == "__main__":
    N = int(input("Enter the number of queens (N): "))
    solve_n_queens_verbose(N)
    print("1BM23CS041")
```

Output:

```
Enter the number of queens (N): 4

=== Restart 1 ===

Initial state (heuristic: 3):
Q . Q .
. Q . .
. . . Q
. . . .

Step 1: (heuristic: 1)
. . Q .
. Q . .
. . . Q
Q . . .

Reached local minimum at step 1, heuristic: 1
  No solution in this attempt (local minimum).


=== Restart 2 ===

Initial state (heuristic: 3):
. Q . .
. . Q .
. . . . Q
. . Q
```

Step 1: (heuristic: 1)
. Q . .
. . Q .
Q . . .
. . . Q

Reached local minimum at step 1, heuristic: 1
No solution in this attempt (local minimum).

=== Restart 3 ===

Initial state (heuristic: 2):
. . . .
. Q . Q
. . . . Q
. Q .

Step 1: (heuristic: 1)
. Q . .
. . . Q
. . . . Q
. Q .

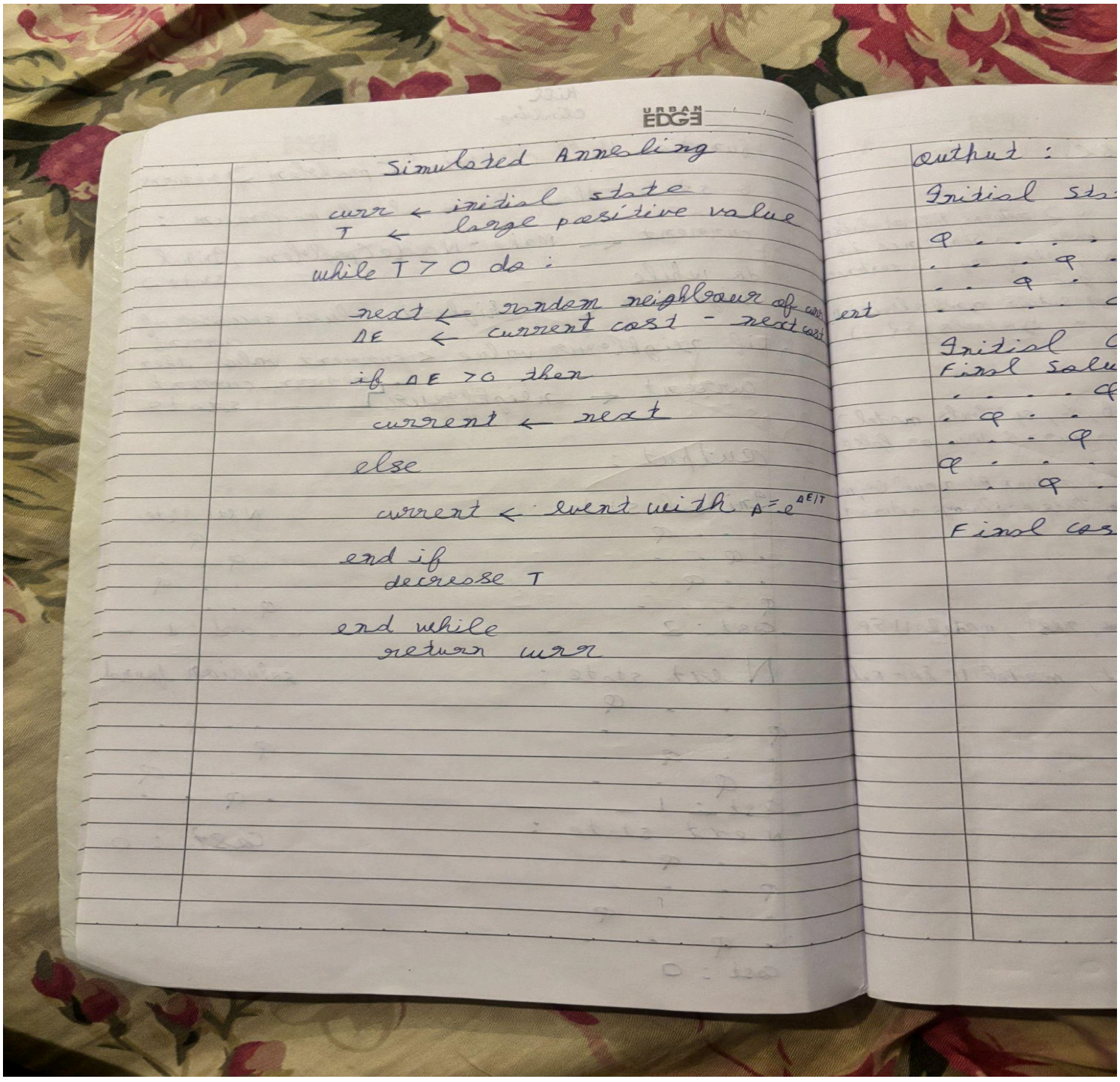
Step 2: (heuristic: 0)
. Q . .
. . . Q
Q . . .
. . Q .

Reached local minimum at step 2, heuristic: 0
Solution found after 3 restart(s):
. Q . .
. . . Q
Q . . .
. . Q .

1BM23CS041

Program 5

Simulated Annealing to Solve 8-Queens problem



Simulated Annealing

curr ← initial state
T ← large positive value

while T > 0 do :

next ← random neighbour of curr
ΔE ← current cost - next cost

if ΔE > 0 then

current ← next

else

current ← next with $p = e^{\Delta E/T}$

end if
decrease T

end while
return curr

output :

Output :

Initial state :

Q . . . .
. . . Q .
. . Q . .
. . . . Q

Initial cost : 6
Final solution Found :

. . . . Q
. Q . . .
. . . Q .
Q . . . .
. . Q . .

Final cost : 0

Code:

```
import random
import math

def compute_heuristic(state):
    """Number of attacking pairs."""
    h = 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):
                h += 1
    return h

def random_neighbor(state):
    """Returns a neighbor by randomly changing one queen's row."""
    n = len(state)
    neighbor = state[:]
    col = random.randint(0, n - 1)
    old_row = neighbor[col]
    new_row = random.choice([r for r in range(n) if r != old_row])
    neighbor[col] = new_row
    return neighbor

def dual_simulated_annealing(n, max_iter=10000, initial_temp=100.0, cooling_rate=0.99):
    """Simulated Annealing with dual acceptance strategy."""
    current = [random.randint(0, n - 1) for _ in range(n)]
    current_h = compute_heuristic(current)
    temperature = initial_temp

    for step in range(max_iter):
        if current_h == 0:
            print(f"  Solution found at step {step}")
            return current

        neighbor = random_neighbor(current)
        neighbor_h = compute_heuristic(neighbor)
        delta = neighbor_h - current_h
```

```
        if delta < 0:
            current = neighbor
            current_h = neighbor_h
        else:
            # Dual acceptance: standard + small chance of higher uphill move
            probability = math.exp(-delta / temperature)
            if random.random() < probability:
                current = neighbor
                current_h = neighbor_h

        temperature *= cooling_rate
        if temperature < 1e-5: # Restart if stuck
            temperature = initial_temp
        current = [random.randint(0, n - 1) for _ in
            range(n)] current_h =
            compute_heuristic(current)

    print("  Failed to find solution within max iterations.")
    return None

# --- Run the algorithm ---
if __name__ == "__main__":
    N = int(input("Enter number of queens (N): "))
    solution = dual_simulated_annealing(N)

    if solution:
        print("Position format:")
        print("[", " ".join(str(x) for x in solution), "]")
        print("Heuristic:", compute_heuristic(solution))
        print("1BM23CS041")
```

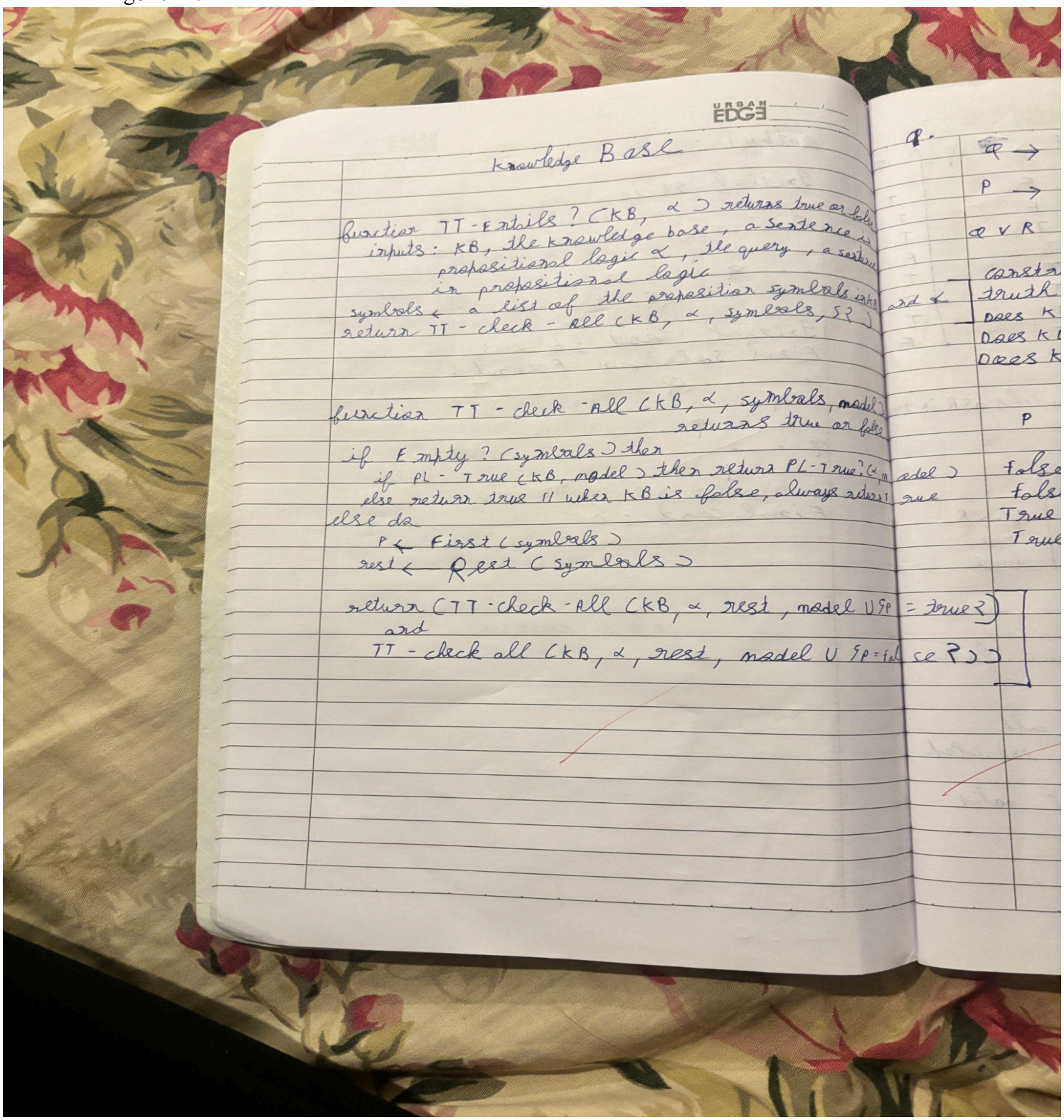
Output:

```
Enter number of queens (N): 8
  Solution found at step 675
Position format:
[ 3 0 4 7 5 2 6 1 ]
Heuristic: 0
1BM23CS041
```

Program 6

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

Algorithm:



URBAN EDGE

Q.

$Q \rightarrow P$

$P \rightarrow \neg Q$

$Q \vee R$

Construct a truth table that shows the truth value of each sentence in KB & indicate the models in which KB is true

Does KB entail R ? Yes

Does KB entail $R \rightarrow P$? Yes

Does KB entail $Q \rightarrow R$

P	Q	$Q \rightarrow P$	$P \rightarrow \neg Q$
false	false	false	true
false	true	True	true
True	False	false	true
True	True	True	false

Q	R	$Q \vee R$
true	true	true
true	false	true
false	true	true
false	false	false

P	Q	R	Q → P	P → ¬ Q	Q ∨ R
T	T	F	T	F	T
T	T	T	T	F	T
T	F	F	T	T	F
T	F	T	F	T	T
F	T	F	T	T	T
F	T	T	T	T	T
F	F	F	T	T	F
F	F	T	T	T	T

i. Yes, R is entailed for all valid models as R is true
ii. No,
iii. Yes, Q → R is entailed

P	Q	R	R → P
T	F	T	T
F	F	T	False

proved

P	Q	R	Q → R
T	F	T	true
F	F	T	true

i. Yes R is entailed as R is true for all valid models

ii. as R → P is not true for all valid models of KB, it is not entailed

iii as Q → R is true for all valid models it is entailed

A	B	C	A ∨ C	B ∨ ¬ 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

Yes, it entails α as α is true for all valid models.

Code:

```
from itertools import product

# ----------------- Propositional Logic Symbols
-----------------class Symbol:
    def __init__(self, name):
        self.name = name

    def __invert__(self): # ~P
        return Not(self)

    def __and__(self, other): # P & Q
        return And(self, other)

    def __or__(self, other): # P | Q
        return Or(self, other)

    def __rshift__(self, other): # P >> Q (implication) return
        Or(Not(self), other)

    def __eq__(self, other): # P == Q (biconditional) return
        And(Or(Not(self), other), Or(Not(other), self))

    def eval(self, model):
        return model[self.name]

    def symbols(self):
        return {self.name}

    def __repr__(self):
        return self.name

class Not:
    def __init__(self, operand):
        self.operand = operand

    def eval(self, model):
        return not self.operand.eval(model)

    def symbols(self):
        return self.operand.symbols()
```

```
    def __repr__(self):
        return f"~{self.operand}"

    def __invert__(self): # allow ~~A
        return Not(self)


class And:
    def __init__(self, left, right):
        self.left, self.right = left, right

    def eval(self, model):
        return self.left.eval(model) and self.right.eval(model)

    def symbols(self):
        return self.left.symbols() | self.right.symbols()

    def __repr__(self):
        return f"({self.left} & {self.right})"

    def __invert__(self): # allow ~(A & B) return
        Not(self)


class Or:
    def __init__(self, left, right):
        self.left, self.right = left, right

    def eval(self, model):
        return self.left.eval(model) or self.right.eval(model)

    def symbols(self):
        return self.left.symbols() | self.right.symbols()

    def __repr__(self):
        return f"({self.left} | {self.right})"

    def __invert__(self): # allow ~(A | B) return
        Not(self)
```

```
# ---------- Truth Table Entailment def --------
tt_entails(kb, alpha, show_table=False):
    symbols = sorted(list(kb.symbols() | alpha.symbols()))
    if show_table:
        print_truth_table(kb, alpha, symbols)
    return tt_check_all(kb, alpha, symbols, {})


def tt_check_all(kb, alpha, symbols, model):
    if not symbols: # all symbols assigned
        if kb.eval(model): # KB is true
            return alpha.eval(model)
        else:
            return True # if KB is false, entailment holds
    else:
        P, rest = symbols[0], symbols[1:]

        model_true = model.copy()
        model_true[P] = True
        result_true = tt_check_all(kb, alpha, rest, model_true)

        model_false = model.copy()
        model_false[P] = False
        result_false = tt_check_all(kb, alpha, rest, model_false)

        return result_true and result_false


# ---------- Truth Table Printer ----------
def print_truth_table(kb, alpha, symbols):
    header = symbols + ["KB", "Query"]
    print(" | ".join(f"{h:^5}" for h in header))
    print("-" * (7 * len(header)))

    for values in product([False, True], repeat=len(symbols)):
        model = dict(zip(symbols, values))
        kb_val = kb.eval(model)
        alpha_val = alpha.eval(model)
        row = [str(model[s]) for s in symbols] + [str(kb_val), str(alpha_val)]
        print(" | ".join(f"{r:^5}" for r in row))
```

```
    print()


# ---------- Example ----------
S = Symbol("S")
C = Symbol("C")
T = Symbol("T")


c = T | ~T

# KB: P → Q
kb1 = ~ (S|T)
# Query: Q
alpha1 = S & T



print("Knowledge Base:", kb1)
print("Query:", alpha1)
print()
result = tt_entails(kb1, alpha1, show_table=True)
print("Does KB entail Query?", result)
```

Output:
Knowledge Base: (P | (Q & P))
Query: (Q | P)

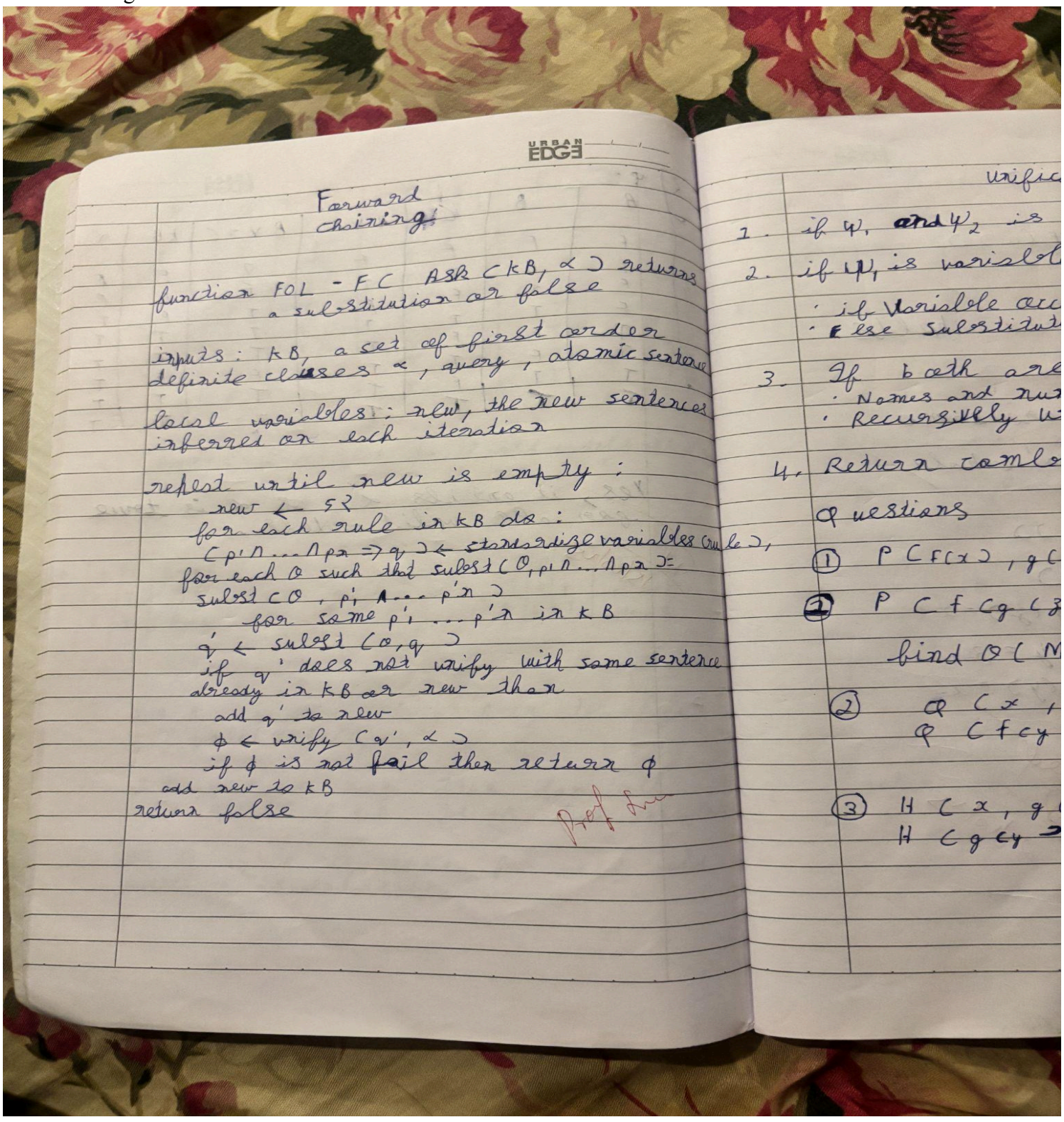
```
  P  |  Q  | KB  | Query
-----------------
False | False | False | False
False  |  True | False | True
True  |  False  |  True  |  True
True | True | True | True
```

Does KB entail Query? True
1BM23CS041

Program 7

Implement unification in first order logic

Algorithm:



Forward chaining:

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

inputs: KB, a set of first order definite clauses α, query, atomic sentence

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

repeat until new is empty:
new ← {}
for each rule in KB do:
(p'1 ∧ ... ∧ p'n ⇒ q) ← standardize variables (rule),
for each θ such that subst(θ, p1 ∧ ... ∧ pn) =
subst(θ, p'1 ∧ ... ∧ p'n)
for some p'1 ... p'n in KB
q' ← subst(θ, q)
if q' does not unify with some sentence already in KB or new then
add q' to new
φ ← unify(q', α)
if φ is not fail then return φ
add new to KB
return false

Unific

1. if ψ1 and ψ2 is
2. if ψ1 is variable
· if variable occ
· Else substitut
3. If both are
· Names and nu
· Recursively u
4. Return comple

Questions

(1) P(F(x), g(

(2) P(f(g(z

find θ(M

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

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

URBAN EDGE

Unification

1. if Ψ_1 and Ψ_2 is identical then Nil
2. if Ψ_1 is variable :
   - if variable occurs in the other → Fail
   - Else substitute and return mapping
3. If both are functions :
   - Names and number of args must match
   - Recursively unify arguements
4. Return combined substitution

Questions

① $P(F(x), g(y), y)$

② $P(f(g(z)), g(f(a)), f(a))$

find $\Theta(MGU)$

② $Q(x, f(x))$
$Q(f(y), y)$

③ $H(x, g(x))$
$H(g(y), g(g(z)))$

URBAN EDGE

1. $f(x) = f(g(z))$
   $x = g(z)$
   $g(y) = g(f(a))$
   $y = f(a)$
   $y = f(a)$ — holds

2. $x = f(y)$
   No. of arguements are same
   $y = f(x)$
   Doesn't halt

3. $x = g(y)$
   $g(x) = g(g(z))$
   $g(g(y)) = g(g(z))$
   $g(y) = g(z)$ $\quad g(z) = x$
   $y = z$
   $g(y) = x$
   ∴ Holds

$x = f(y)$
$y = f(x)$
$f(x) = y$

$x = f(f(x))$
$y = f(f(y))$

proceed
(2) halts

First Orde

function FOL-FC-

inputs: KB, the kn
first order definite

local variables: new
inferred on each

repeat until new
new ← { }
for each rule
$(p_1 \wedge \ldots \wedge p$
for each ϕ su

for some
$q' \leftarrow$ subst (
if q' does

add q
$\phi \leftarrow$ u
if ϕ is
add new to k
return false

Code:

```
class UnificationError(Exception):
    pass

def occurs_check(var, term):
    """Check if a variable occurs in a term (to prevent infinite recursion)."""
    if var == term:
        return True
    if isinstance(term, tuple): # Term is a compound (function term)
        return any(occurs_check(var, subterm) for subterm in term)
    return False

def unify(term1, term2, substitutions=None):
    """Try to unify two terms, return the MGU (Most General Unifier)."""
    if substitutions is None:
        substitutions = {}

    # If both terms are equal, no further substitution is needed
    if term1 == term2:
        return substitutions

    # If term1 is a variable, we substitute it with term2 elif isinstance(term1, str) and term1.isupper():
    # If term1 is already substituted, recurse
    if term1 in substitutions:
        return unify(substitutions[term1], term2, substitutions)
    elif occurs_check(term1, term2):
        raise UnificationError(f"Occurs check fails: {term1} in {term2}")
    else:
        substitutions[term1] = term2
        return substitutions
```

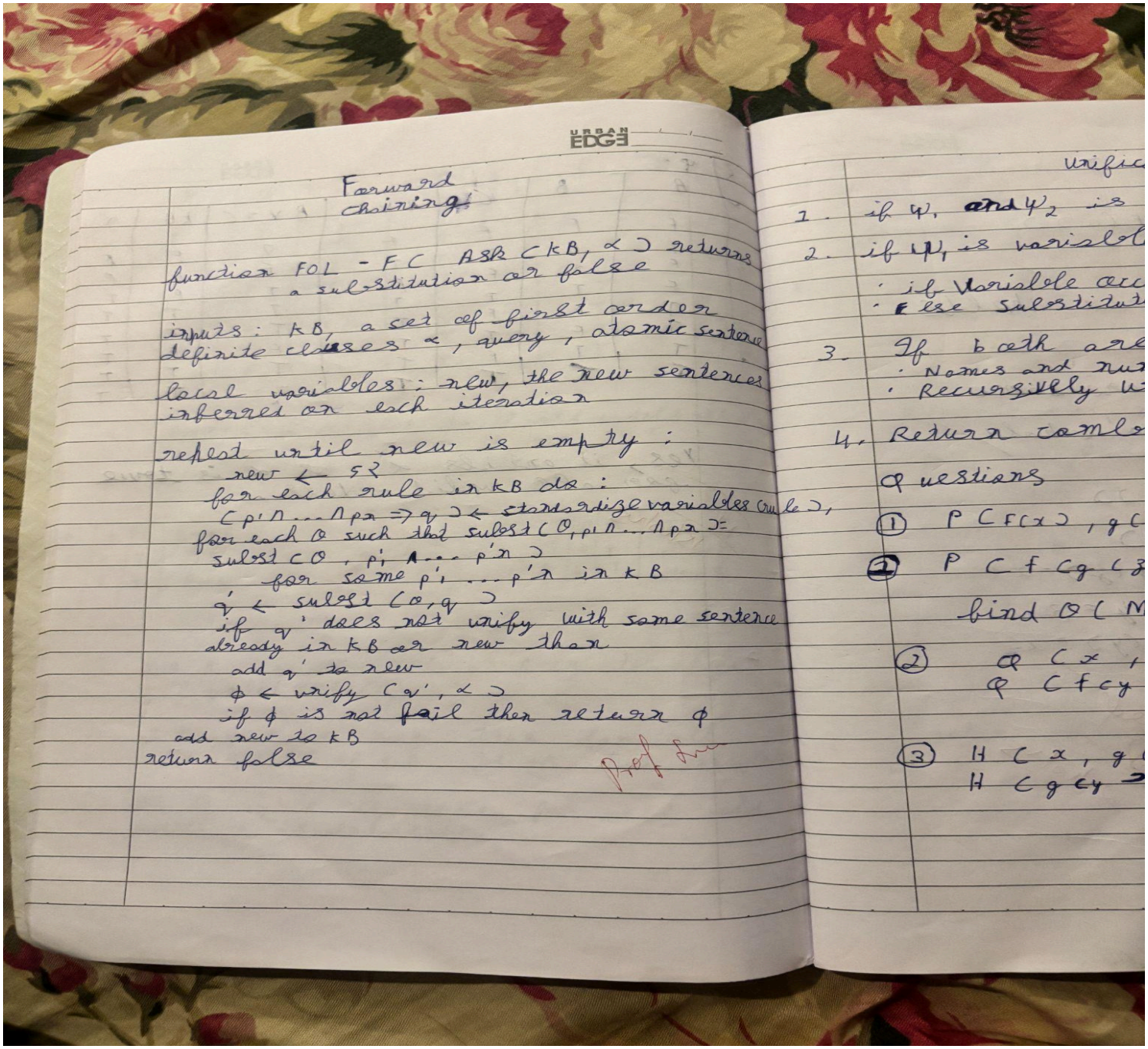
```
    # If term2 is a variable, we substitute it with term1
    elif isinstance(term2, str) and term2.isupper():
        # If term2 is already substituted, recurse
        if term2 in substitutions:
            return unify(term1, substitutions[term2], substitutions)
        elif occurs_check(term2, term1):
            raise UnificationError(f"Occurs check fails: {term2} in {term1}")
        else:
            substitutions[term2] = term1
            return substitutions

    # If both terms are compound (i.e., functions), unify their parts recursively
    elif isinstance(term1, tuple) and isinstance(term2, tuple):
        # Ensure that both terms have the same "functor" and number of arguments
      # if len(term1) != len(term2):
        #     raise UnificationError(f"Function arity mismatch: {term1} vs {term2}")

        for subterm1, subterm2 in zip(term1, term2):
            substitutions = unify(subterm1, subterm2, substitutions)

        return substitutions

    else:
        raise UnificationError(f"Cannot unify: {term1} with {term2}")

# Define the terms as tuples
term1 = ('p', 'b', 'X', ('f', ('g', 'Z')))
term2 = ('p', 'Z', ('f', 'Y'), ('f', 'Y'))

try:
    # Find the MGU
    result = unify(term1, term2)
    print("Most General Unifier (MGU):")
    print(result)
except UnificationError as e:
    print(f"Unification failed: {e}")
finally:
    print("1BM23CS041 Annas")
```

Output:
Most General Unifier (MGU):
{'Z': 'b', 'X': ('f', 'Y'), 'Y': ('g', 'Z')}
1BM23CS041 Annas

Program 8

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

Algorithm:



Forward chaining:

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

inputs: KB, a set of first order definite clauses
α, query, atomic sentence

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

repeat until new is empty:
  new ← {}
  for each rule in KB do:
    (p'1 ∧ ... ∧ p'n ⇒ q) ← standardize variables(rule),
    for each θ such that subst(θ, p'1 ∧ ... ∧ p'n) =
      subst(θ, p1 ∧ ... ∧ pn)
      for some p'1, ..., p'n in KB
    q' ← subst(θ, q)
    if q' does not unify with some sentence already in KB or new then
      add q' to new
      φ ← unify(q', α)
      if φ is not fail then return φ
  add new to KB
return false

Unific

1. if ψ1 and ψ2 is
2. if ψ1 is variable
   : if variable occ
   : else substitut
3. If both are
   : Names and nu
   : Recursively u
4. Return compl

questions

(1) P(F(x)), g(

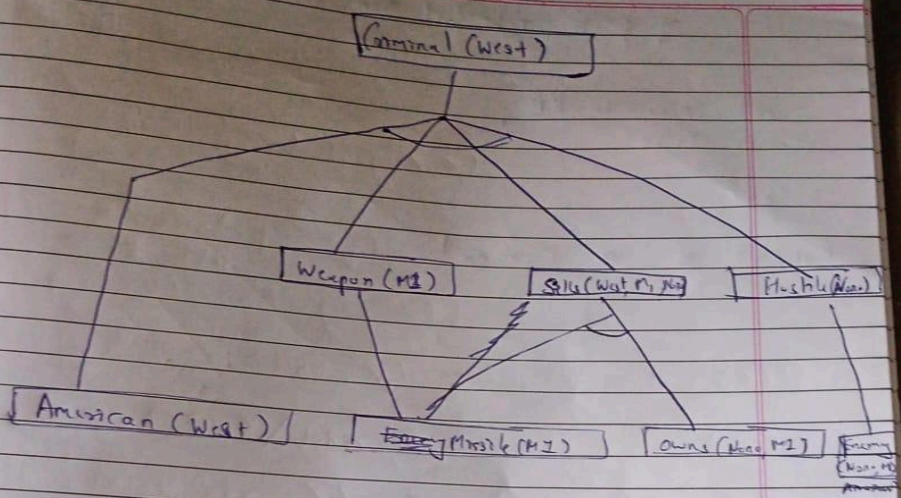
(2) P(f(g(z

find θ(M

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

(3) H(x, g(
H(g(y →

Answer



Algorithm

function FOL-FC-ASK (KB, α) returns a substitution or false
inputs: KB, set of first order
α, the query, an atomic sentence

local variables: new, new sentences inferred on each iteration
repeat until new is empty
new $\leftarrow$ { }
for each rule in KB do
$(p_1 \wedge \ldots \wedge p_n \Rightarrow q) \leftarrow$ Standardize-Variables(rule)
for each θ such that SUBST(θ, $p_1 \wedge \ldots \wedge p_n$)
= SUBST(θ, $p_1' \wedge \ldots \wedge p_n'$)
for some $p_1', \ldots, p_n'$ in KB
$q' \leftarrow$ SUBST(θ, q)
if q' does not unify with some sentence already in KB or new then
add q' to new
$\phi \leftarrow$ Unify(q', α)

Code:

```
# Define the knowledge base
facts = {
    'American(Robert)': True, # Robert is an American
    'Hostile(A)': True,         # Country A is hostile to America
    'Sells_Weapons(Robert, A)': True # Robert sold weapons to Country A
}

# Define the law/rule: If American(X) and Hostile(Y) and Sells_Weapons(X, Y), then Crime(X)
def forward_reasoning(facts):
    # Apply the rule: If American(X) and Hostile(Y) and Sells_Weapons(X, Y), then Crime(X)
    if facts.get('American(Robert)', False) and facts.get('Hostile(A)', False) and
facts.get('Sells_Weapons(Robert, A)', False):
        facts['Crime(Robert)'] = True # Robert is a criminal

# Perform forward reasoning to see if we can deduce that Robert is a criminal
forward_reasoning(facts)
# Output the result based on the fact derived if facts.get('Crime(Robert)', False):
    print("Robert is a criminal.")
    print("Annas 1BM23CS041")
else:
    print("Robert is not a criminal.")
```

Output:

Robert is a criminal.

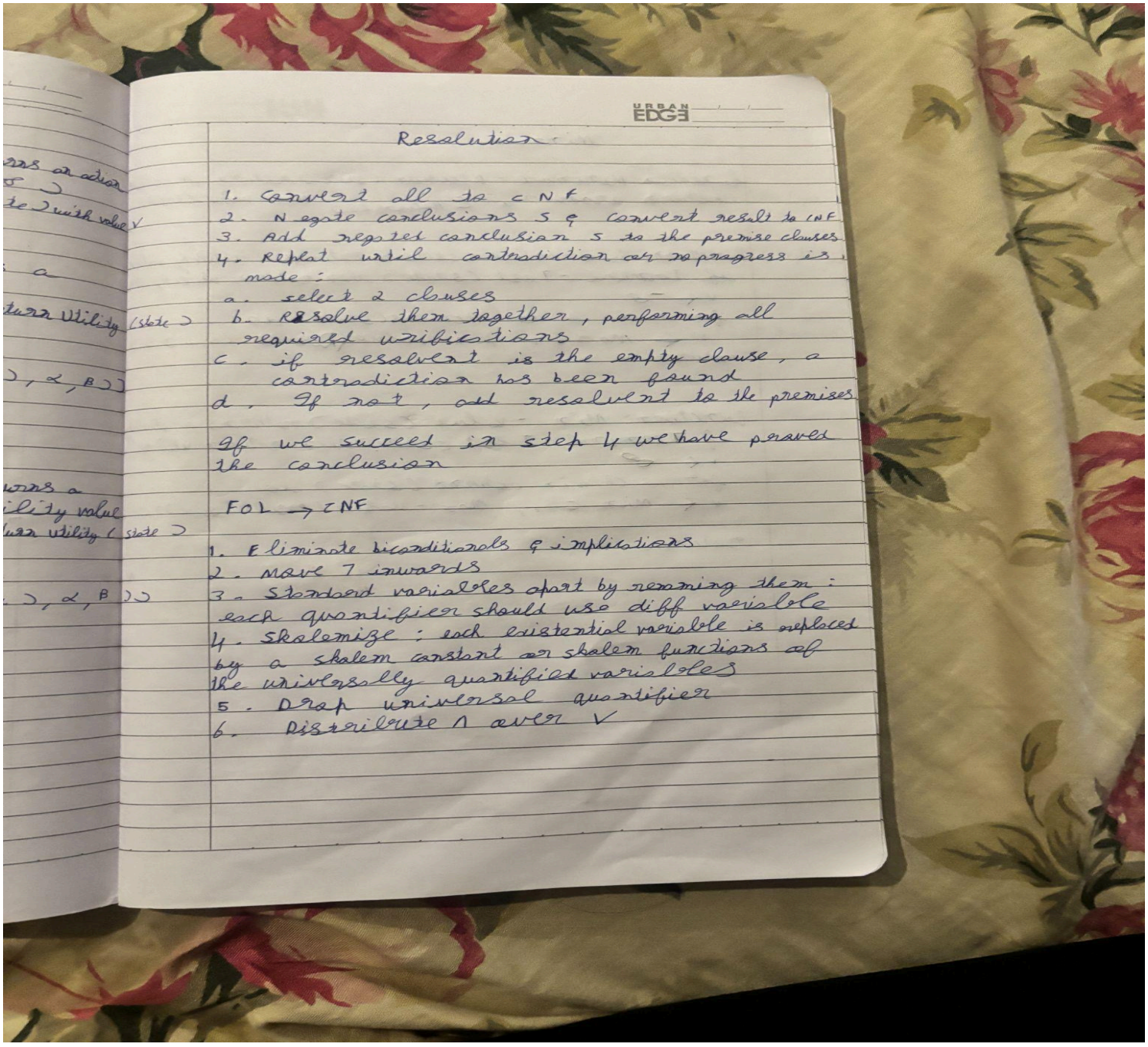
Annas

1BM23CS041

Program 9

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

Algorithm:



Resolution:

1. Convert all to CNF
2. Negate conclusions S & convert result to CNF
3. Add negated conclusion S to the premise clauses
4. Repeat until contradiction or no progress is made:
   a. select 2 clauses
   b. Resolve them together, performing all required unifications
   c. if resolvent is the empty clause, a contradiction has been found
   d. If not, add resolvent to the premises

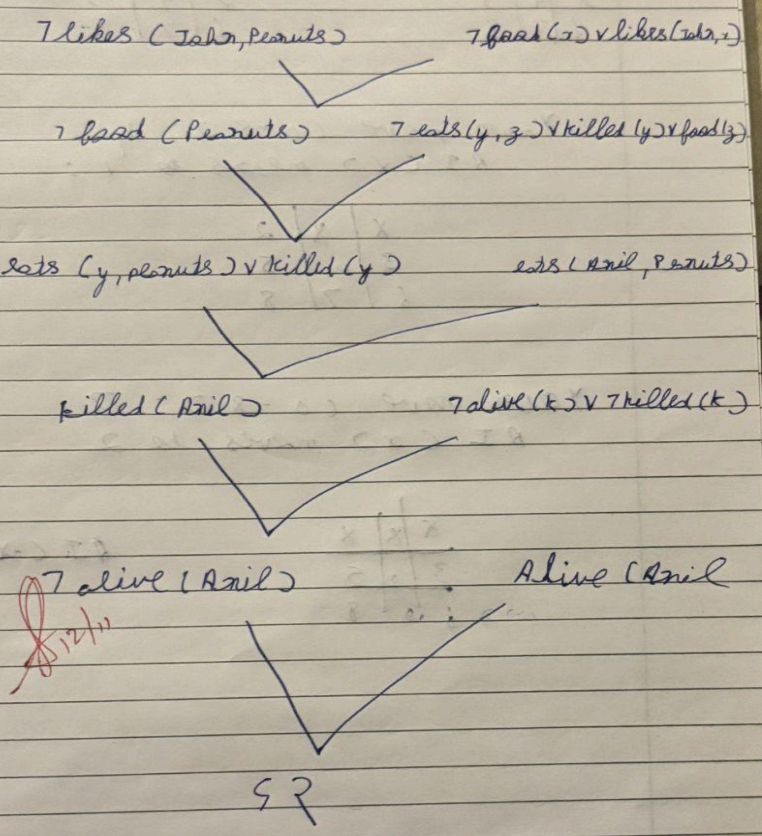
If we succeed in step 4 we have proved the conclusion

FOL → CNF

1. Eliminate biconditionals & implications
2. Move ¬ inwards
3. Standard variables apart by renaming them: each quantifier should use diff variable
4. Skolemize: each existential variable is replaced by a skolem constant or skolem functions of the universally quantified variables
5. Drop universal quantifier
6. Distribute ∧ over ∨

URBAN EDGE

Ex. John likes peanuts



Code:

```
import re
import copy

class Predicate:
    def __init__(self, predicate_string):
        self.predicate_string = predicate_string
        self.name, self.arguments, self.negative = self.parse_predicate(predicate_string)

    def parse_predicate(self, predicate_string):
        neg = predicate_string.startswith('~')
        if neg:
            predicate_string = predicate_string[1:]
        m = re.match(r"([A-Za-z_][A-Za-z0-9_]*)\((.*?)\)", predicate_string)
        if not m:
            raise ValueError(f"Invalid predicate: {predicate_string}")
        name, args = m.groups()
        args = [a.strip() for a in args.split(",")]
        return name, args, neg

    def negate(self):
        self.negative = not self.negative
        if self.predicate_string.startswith('~'):
            self.predicate_string = self.predicate_string[1:]
        else:
            self.predicate_string = '~' + self.predicate_string

    def unify_with_predicate(self, other):
        """Attempt to unify two predicates; return substitution dict or False."""
        if self.name != other.name or len(self.arguments) != len(other.arguments):
            return False
        subs = {}
        for a, b in zip(self.arguments, other.arguments):
            if a == b:
                continue
            if a[0].islower():
                subs[a] = b
```

```
            elif b[0].islower():
                subs[b] = a
            else:
                return False
        return subs

    def substitute(self, subs):
        """Apply substitution dictionary."""
        self.arguments = [subs.get(a, a) for a in self.arguments]
        self.predicate_string = (
            ('~' if self.negative else '') +
            self.name + '(' + ','.join(self.arguments) + ')'
        )

    def __repr__(self):
        return self.predicate_string


class Statement:
    def __init__(self, statement_string):
        self.statement_string = statement_string
        self.predicate_set = self.parse_statement(statement_string)

    def parse_statement(self, statement_string):
        parts = statement_string.split('|')
        predicates = []
        for p in parts:
            predicates.append(Predicate(p.strip()))
        return set(predicates)

    def add_statement_to_KB(self, KB, KB_HASH):
        KB.add(self)
        for predicate in self.predicate_set:
            key = predicate.name
            if key not in KB_HASH:
                KB_HASH[key] = set()
            KB_HASH[key].add(self)
```

```
    def get_resolving_clauses(self, KB_HASH):
        resolving_clauses = set()
        for predicate in self.predicate_set:
            key = predicate.name
            if key in KB_HASH:
                resolving_clauses |= KB_HASH[key]
        return resolving_clauses

    def resolve(self, other):
        """Resolve two statements; return new derived statements or False if contradiction."""
        new_statements = set()
        for p1 in self.predicate_set:
            for p2 in other.predicate_set:
                if p1.name == p2.name and p1.negative != p2.negative:
                    subs = p1.unify_with_predicate(p2)
                    if subs is False:
                        continue
                    new_pred_set = set()
                    for pred in self.predicate_set.union(other.predicate_set):
                        if pred not in (p1, p2):
                            pred_copy = copy.deepcopy(pred)
                            pred_copy.substitute(subs)
                            new_pred_set.add(pred_copy)
                    if not new_pred_set:
                        return False  # contradiction
                    new_stmt = Statement('|'.join(sorted([str(p) for p in new_pred_set])))
                    new_statements.add(new_stmt)
        return new_statements

    def __repr__(self):
        return self.statement_string


def fol_to_cnf_clauses(sentence):
    """
    Convert simple implications and conjunctions into CNF.
```

```
    Example:
    "A(x,y) => B(x,y)" becomes "~A(x,y)|B(x,y)"
    "A(x,y) & B(y,z) => C(x,z)" becomes "~A(x,y)|~B(y,z)|C(x,z)"
    """
    sentence = sentence.replace(' ', '')
    if '=>' in sentence:
        lhs, rhs = sentence.split('=>')
        parts = lhs.split('&')
        negated_lhs = ['~' + p for p in parts]
        disjunction = '|'.join(negated_lhs + [rhs])
        return [disjunction]

    # Split conjunctions into separate clauses
    if '&' in sentence:
        return sentence.split('&')
    return [sentence]


KILL_LIMIT = 8000


def prepare_knowledgebase(fol_sentences):
    KB = set()
    KB_HASH = {}
    for sentence in fol_sentences:
        clauses = fol_to_cnf_clauses(sentence)
        for clause in clauses:
            stmt = Statement(clause)
            stmt.add_statement_to_KB(KB, KB_HASH)
    return KB, KB_HASH


def FOL_Resolution(KB, KB_HASH, query):
    KB2 = set()
    query.add_statement_to_KB(KB2, KB_HASH)
    # Note: Adding query to main KB logic depends on implementation,
    # but usually we add Negated Query to KB. Here logic seems to handle it externally.
```

```
    while True:
        new_statements = set()
        if len(KB) > KILL_LIMIT:
            return False
        for s1 in KB:
            for s2 in s1.get_resolving_clauses(KB_HASH):
                if s1 == s2:
                    continue
                resolvents = s1.resolve(s2)
                if resolvents is False:
                    return True
                new_statements |= resolvents

        if new_statements.issubset(KB):
            return False

        # Add new statements to KB and Hash
        for s in new_statements:
            if s not in KB:
                s.add_statement_to_KB(KB, KB_HASH)


def main():
    fol_sentences = [
        "Parent(John, Mary)",
        "Parent(Mary, Sam)",
        "Parent(x, y) => Ancestor(x, y)",
        "Parent(x, y) & Ancestor(y, z) => Ancestor(x, z)"
    ]
    queries = ["Ancestor(John, Sam)"]

    KB, KB_HASH = prepare_knowledgebase(fol_sentences)
    print("\nKnowledge Base CNF Clauses:")
    for stmt in KB:
        print(" ", stmt)
```

```
    for query_str in queries:
        query_predicate = Predicate(query_str)
        query_predicate.negate()
        query_stmt = Statement(str(query_predicate))

        # We pass a copy because resolution modifies the KB
        satisfiable = FOL_Resolution(copy.deepcopy(KB), copy.deepcopy(KB_HASH), query_stmt)
        print(f"\nQuery: {query_str} =>", "TRUE" if satisfiable else "FALSE")

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

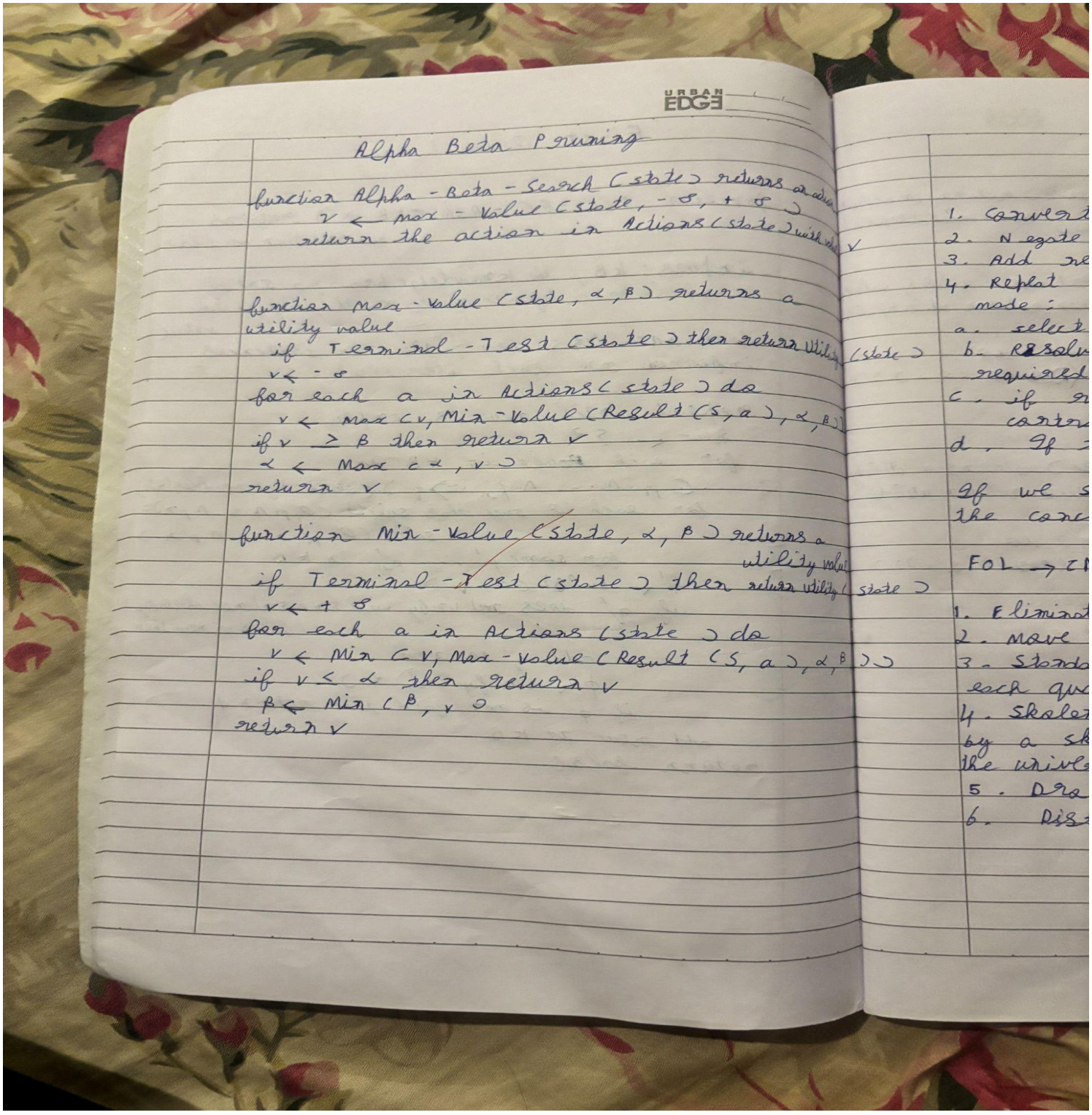
Output:

```
Knowledge Base CNF Clauses:
 ~Parent(x,y)|Ancestor(x,y)
 Parent(John,Mary)
 Parent(Mary,Sam)
 ~Parent(x,y)|~Ancestor(y,z)|Ancestor(x,z)
Query: Ancestor(John, Sam) => TRUE
```

Program 10:

Implement Alpha-Beta Pruning.

Algorithm:



URBAN EDGE

Minmax

function Minimax - Decision (state) returns an action
return argmax a ∈ Actions(s) Min-value (Result (state, a))

function Max-value (state) 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)))
return v

function Min-Value (state) 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)))

return v

12/11

Ex

7 likes (

7 food

7 eats (y,

kille

7 ali

12/11

URBAN EDGE

0	1	2
3	4	5
6	7	8

X	1	2
3	4	5
6	7	8

AI (X) means to

Your move (0-8): 4
AI (X) means to 1:

X	X	2
3	0	5
6	7	8

Your move (0-8): 7
AI (X) moves to 2

X	X	X
3	0	5
6	0	8

AI (X) wins

Code:

```
import math

def alpha_beta(node, depth, alpha, beta, maximizingPlayer, game_tree):
    """
    Alpha-Beta pruning search algorithm
      node: current node in game tree
      depth: current depth

      alpha: best value for maximizer
      beta: best value for minimizer
    maximizingPlayer: True if maximizer's turn
    game_tree: dictionary representing tree {node: children or value}
    """
    # If leaf node or depth 0, return its value
    if depth == 0 or isinstance(game_tree[node], int):
        return game_tree[node]

    if maximizingPlayer:
        maxEval = -math.inf
        for child in game_tree[node]:
            eval = alpha_beta(child, depth-1, alpha, beta, False, game_tree)
            maxEval = max(maxEval, eval)
            alpha = max(alpha, eval)
            if beta <= alpha:
                break # Beta cut-off
        return maxEval
    else:
        minEval = math.inf
        for child in game_tree[node]:
            eval = alpha_beta(child, depth-1, alpha, beta, True, game_tree)
            minEval = min(minEval, eval)
            beta = min(beta, eval)
            if beta <= alpha:
                break # Alpha cut-off
        return minEval

# Example game tree
```

```
game_tree = {
    'A': ['B', 'C'],
    'B': ['D', 'E'],
    'C': ['F', 'G'],
    'D': 3,
    'E': 5,
    'F': 2,
    'G': 9
}
best_value = alpha_beta('A', depth=3, alpha=-math.inf, beta=math.inf, maximizingPlayer=True,
game_tree=game_tree)
print("Best value for maximizer:", best_value)
```

Output:

Best value for maximizer: 3