VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT

on

Artificial Intelligence (23CS5PCAIN)

Submitted by

Aditya Sharma (1BM22CS021)

in partial fulfilment 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)

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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 **Aditya Sharma (1BM22CS021),** 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/aditya-sharma1230/AI-LAB

Program 1:

a) Implement Tic –Tac –Toe Game

b) Implement vacuum cleaner agent

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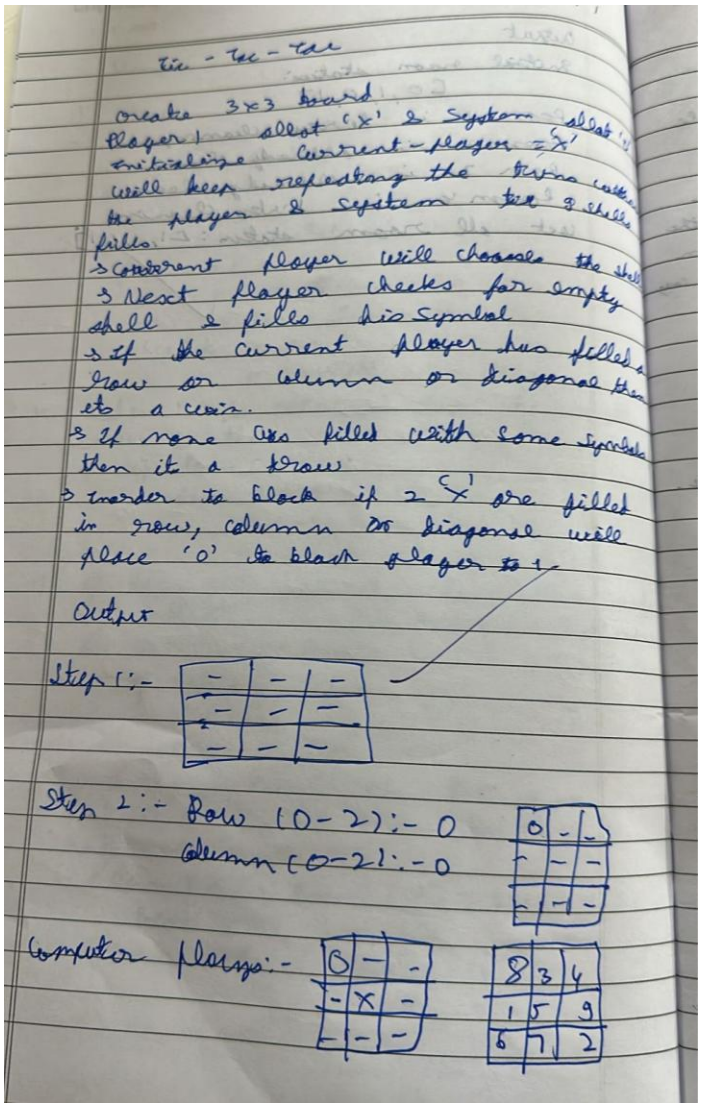
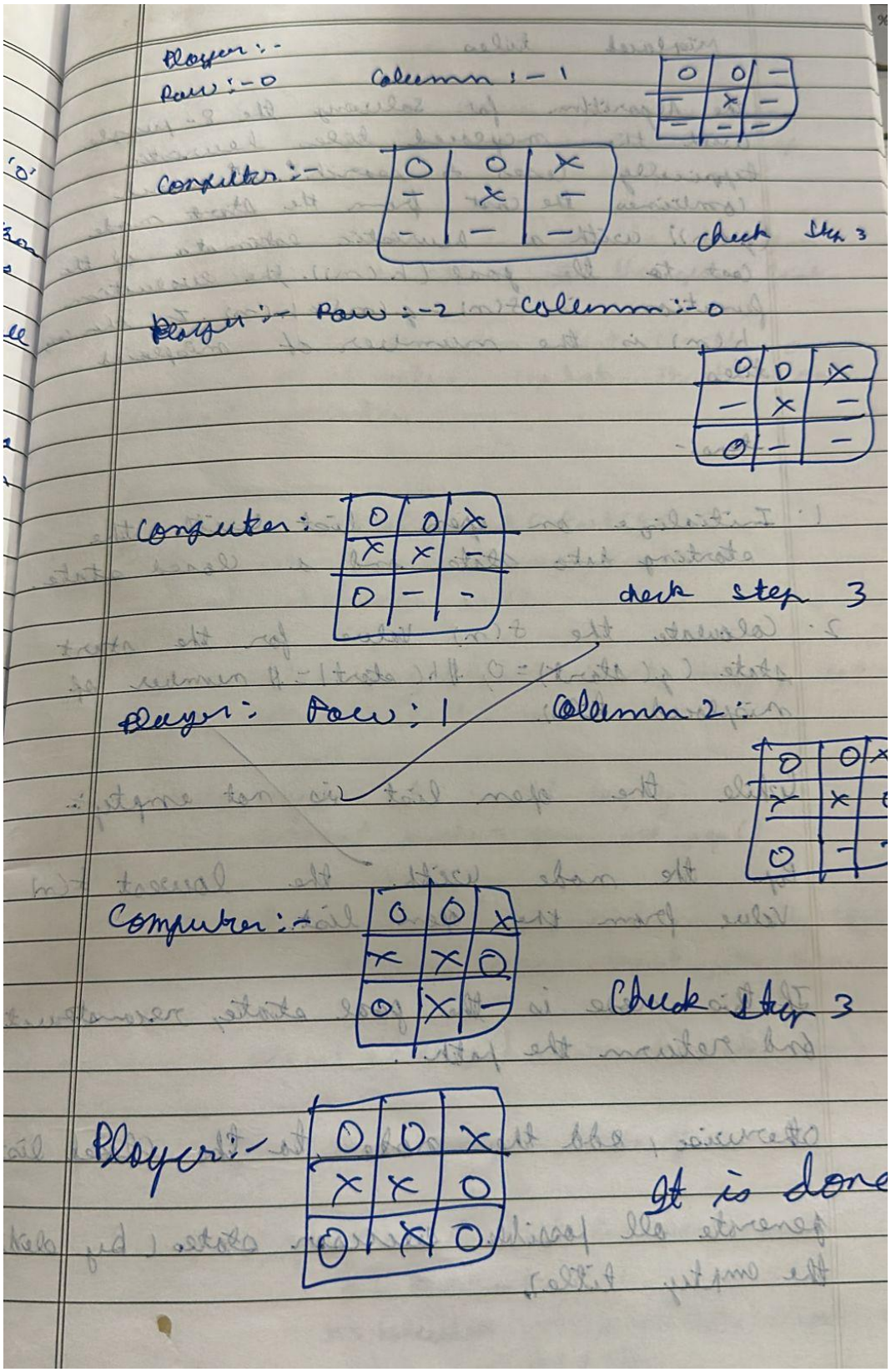
a)Tic Tac Toe

Algorithm:




Player :-
Row :- 0
Column :- 1
Computer :-
check step 3
Player :- Row :- 2 Column :- 0
Computer :-
check step 3
Player : Row : 1 Column 2 :-
Computer :-
Check step 3
Player :-
It is done

Player :-
Row :- 0 Column :- 1

0	0	–
–	X	–
–	–	–

Computer :-

0	0	X
–	X	–
–	–	–

check step 3

Player :- Row :- 2 Column :- 0

0	0	X
–	X	–
0	–	–

Computer :-

0	0	X
X	X	–
0	–	–

check step 3

Player : Row : 1 Column 2 :

0	0	X
X	X	–
0	–	–

Computer :-

0	0	X
X	X	0
0	X	–

Check step 3

Player :-

0	0	X
X	X	0
0	X	0

It is done

Code:

```
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!")
```

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

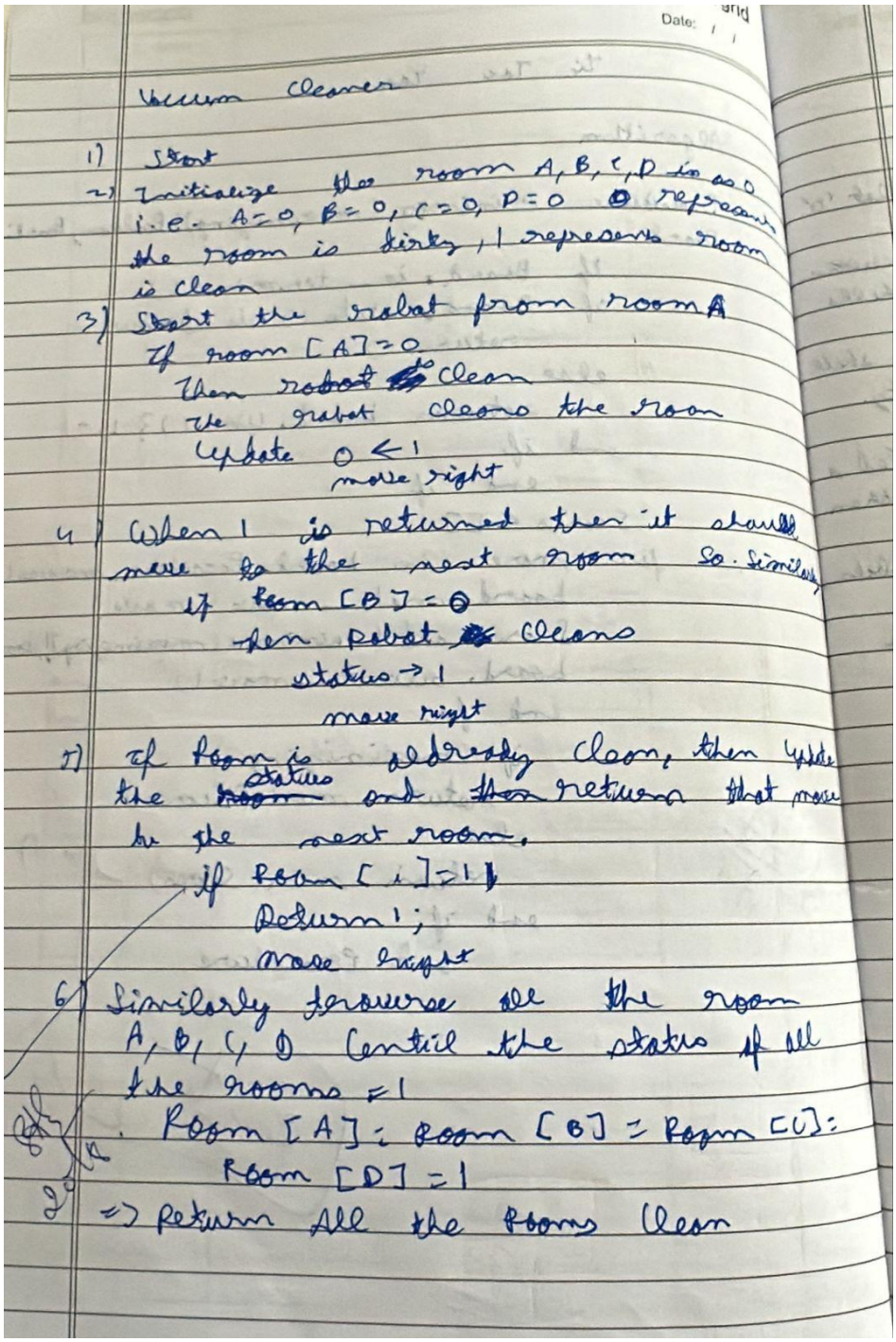
Enter Row (1-3): 2
Enter Column (1-3): 3
['-', 'X', 'O']
['-', 'X', 'O']
['-', '-', '-']

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

X wins!

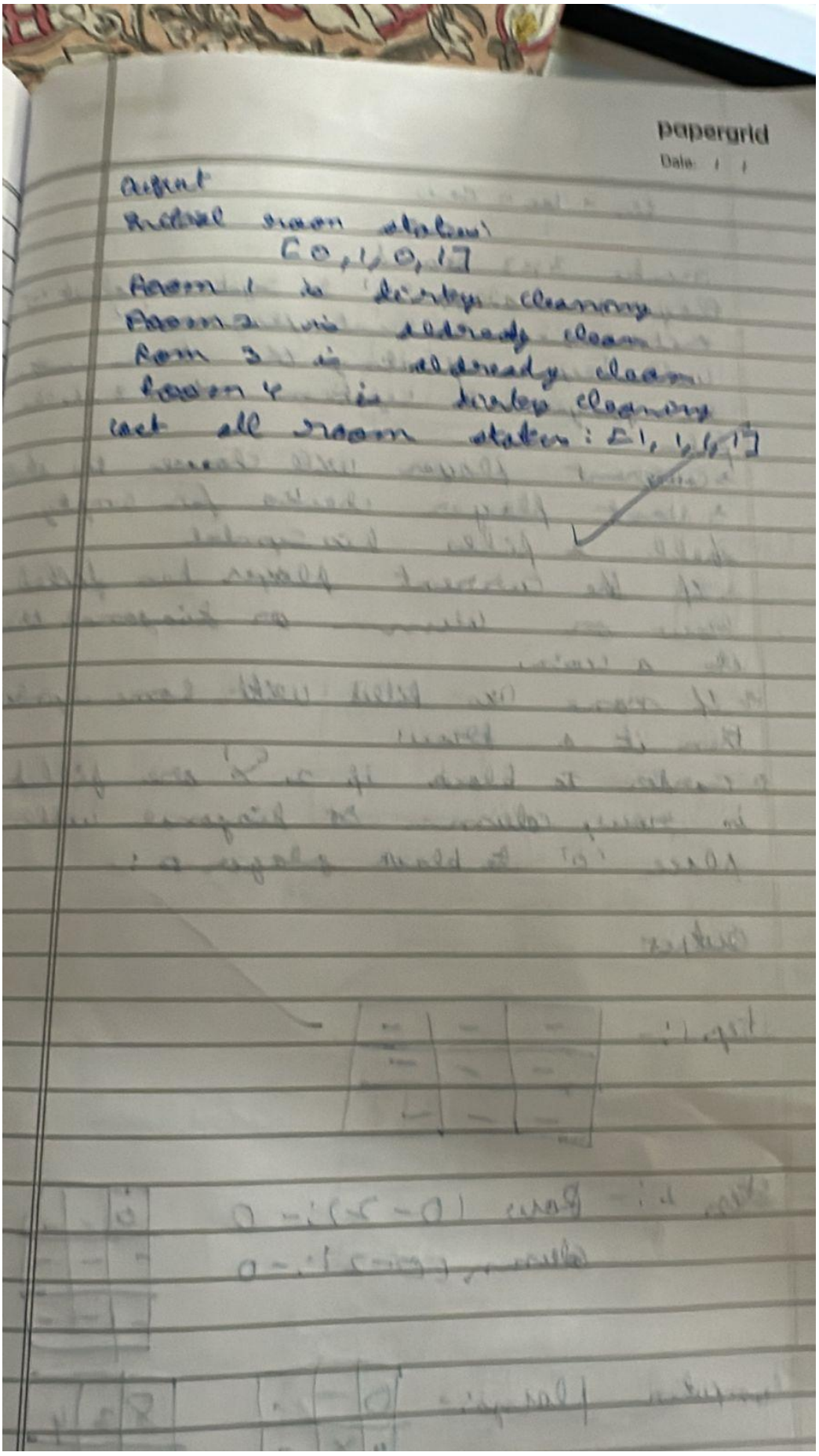
b)Vacuum Cleaner

Algorithm:



Vacuum Cleaner

1) Start
2) Initialize the room A, B, C, D to 0 i.e. A=0, B=0, C=0, D=0 0 represents the room is dirty, 1 represents room is clean
3) Start the robot from room A
   If room [A] = 0
   Then robot clean
   The robot cleans the room
   Update 0 ← 1
   move right
4) When 1 is returned then it should move to the next room. So. Similarly
   If Room [B] = 0
   Then Robot cleans
   status → 1
   move right
5) If Room is already clean, then update the status and then returns that move to the next room.
   if Room [i] = 1
   Return 1;
   move right
6) Similarly traverse all the room A, B, C, D Until the status of all the rooms = 1
   Room [A] = Room [B] = Room [C] = Room [D] = 1
7) => Return All the Rooms clean


papergrid
Date: / /
Output
Initial room status:
[0, 1, 0, 1]
Room 1 is dirty, cleaning
Room 2 is already clean
Room 3 is already clean
Room 4 is dirty, cleaning
Last all room status: [1, 1, 1, 1]

Code:

```
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

Program 2:

Implement 8 puzzle problems using DFS
Implement Iterative deepening search

a) DFS

Code:

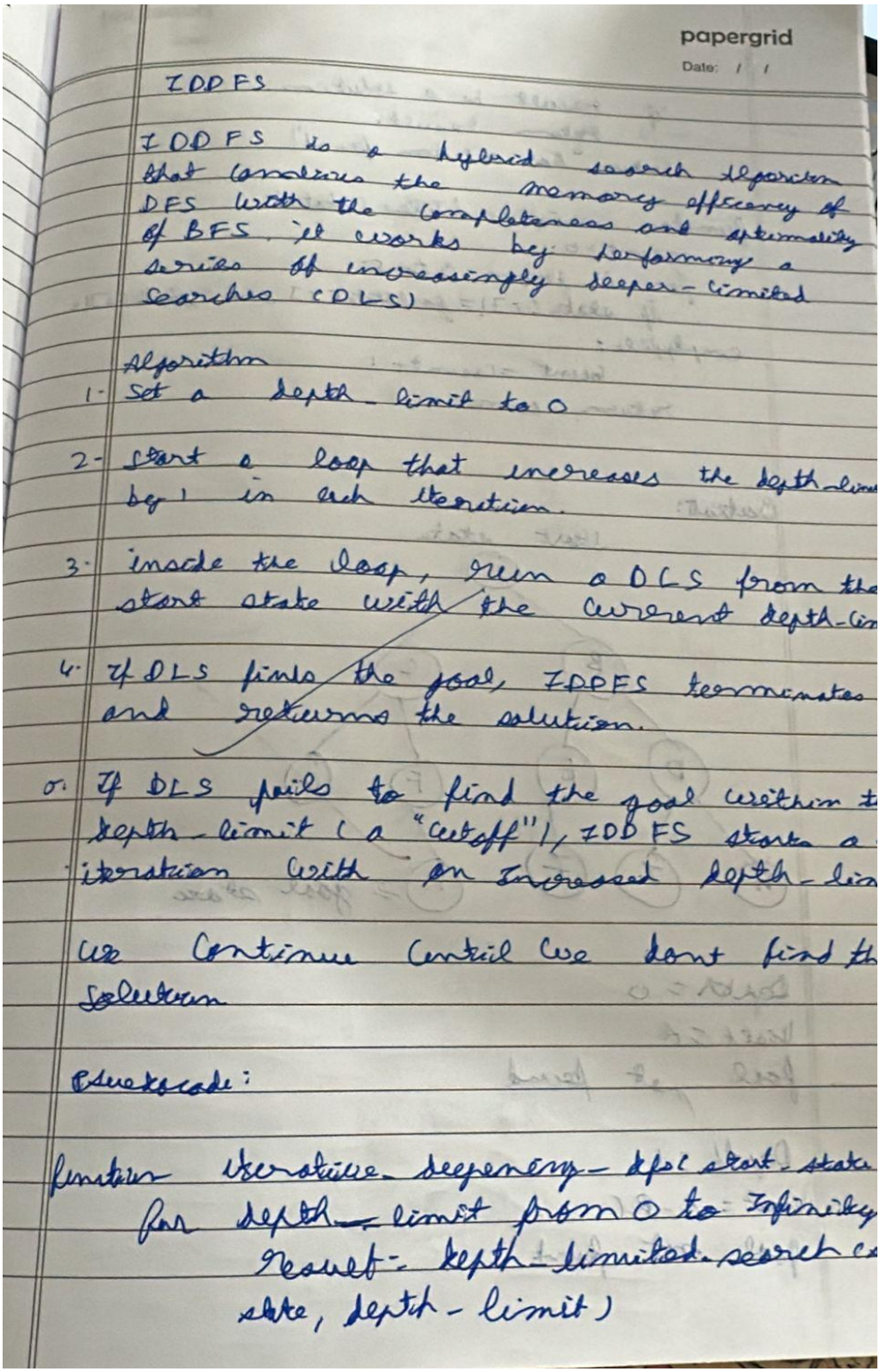
```
goal_state = '123456780'

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

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

Algorithm:



papergrid
Date: / /

IDDFS

IDDFS is a hybrid search algorithm that combines the memory efficiency of DFS with the completeness and optimality of BFS. It works by performing a series of increasingly deeper-limited searches (DLS)

Algorithm
1. Set a depth_limit to 0

2. Start a loop that increases the depth_limit by 1 in each iteration.

3. Inside the loop, run a DLS from the start state with the current depth-limit

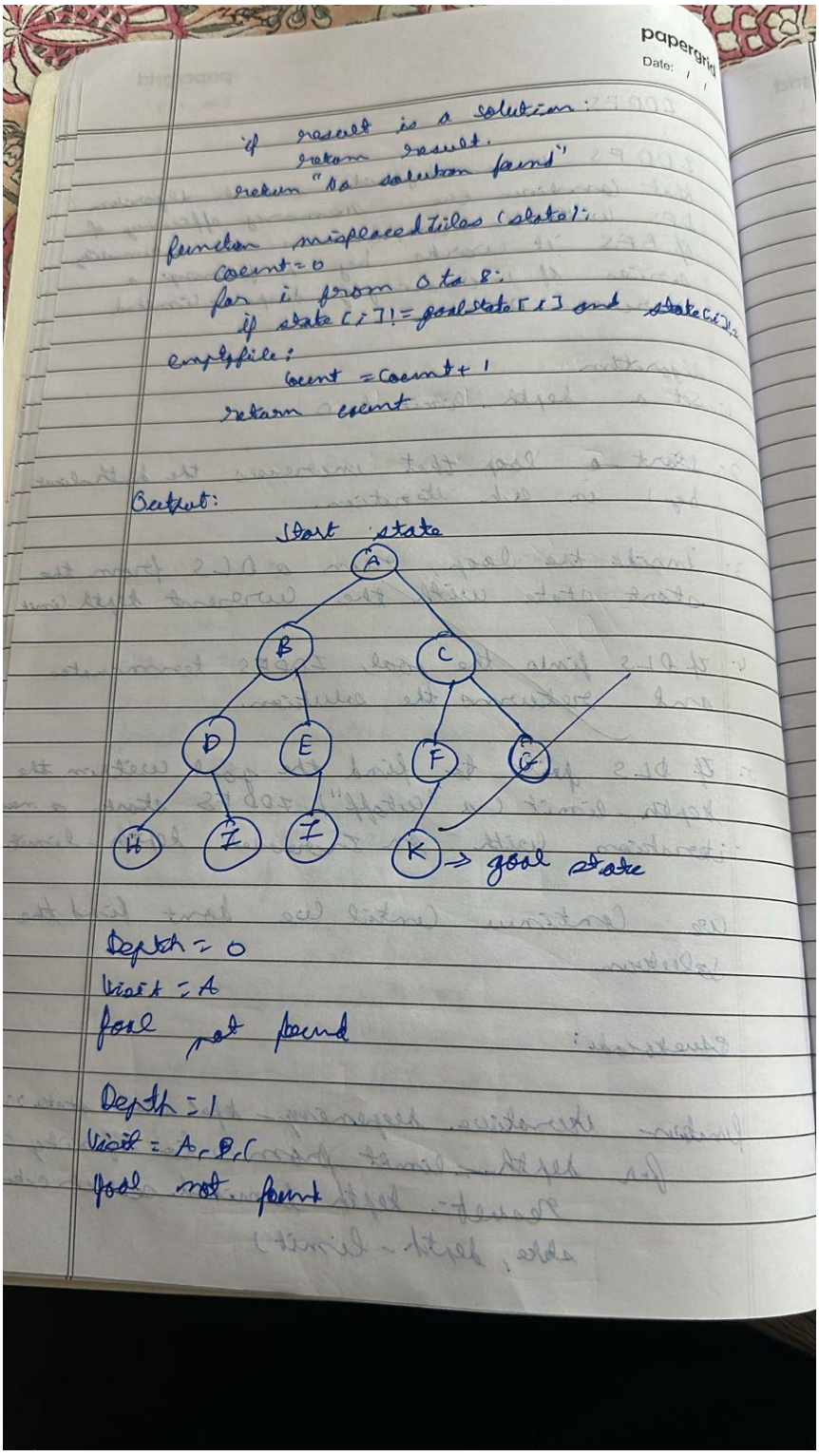
4. If DLS finds the goal, IDDFS terminates and returns the solution.

5. If DLS fails to find the goal within the depth_limit (a "cutoff"), IDDFS starts a new iteration with an increased depth_limit

Use Continue until we don't find the solution

Pseudocode:

function iterative_deepening_dfs(start_state)
for depth_limit from 0 to Infinity
result = depth_limited_search(start_state, depth_limit)


papergrip
Date: / /
if result is a solution:
return result.
return "No solution found"
function misplacedTiles (state):
count = 0
for i from 0 to 8:
if state[i] != goalState[i] and state[i] != 0:
emptyfile:
count = count + 1
return count
Output:
Start state
A
B
C
D
E
F
G
H
I
J
K
goal state
Depth = 0
Visit = A
goal not found
Depth = 1
Visit = A, B, C
goal not found

Depth = 2
Visited = A, B, D, H, E, E, I, C, F, K → V
Goal found

path to goal : A → C → F → K

Output for Misplaced tiles

Start state:
1	2	3
4	0	6
7	5	8

goal state:
1	2	3
4	5	6
7	8	0

misplaced tiles : 2
5 → ✗
8 → ✗

Output for Manhattan distance:

Example
Start state:
1	2	3
4	0	6
7	5	8

goal state:
1	2	3
4	5	6
7	8	0

Misplaced Tiles : 2

5 → ✗

8 → ✗

Manhattan Distance

→ 5 → in start (2,1) but goal (1,1) → |2-1| + |1-1| = 1

→ 8 → in start (3,2) but goal (2,1) → |2-2| + |2-1| = 1

Manhattan Distance = 1+1 = 2.

3/9/25

```
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

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

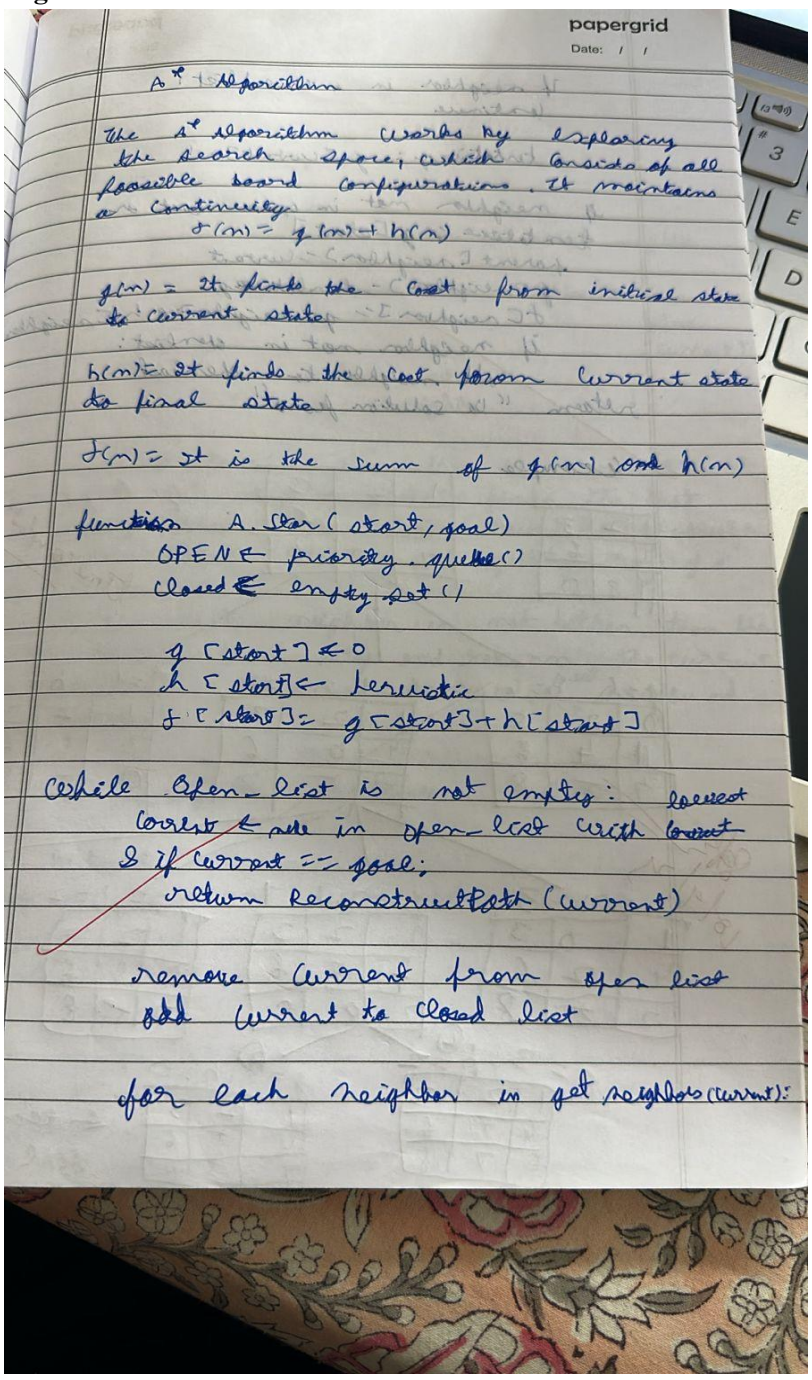
Move 12: D
1 2 3
4 5 6
  7 8
Move 13: R
1 2 3
4 5 6
7 8

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

Program 3

Implement A* search algorithm

Algorithm:



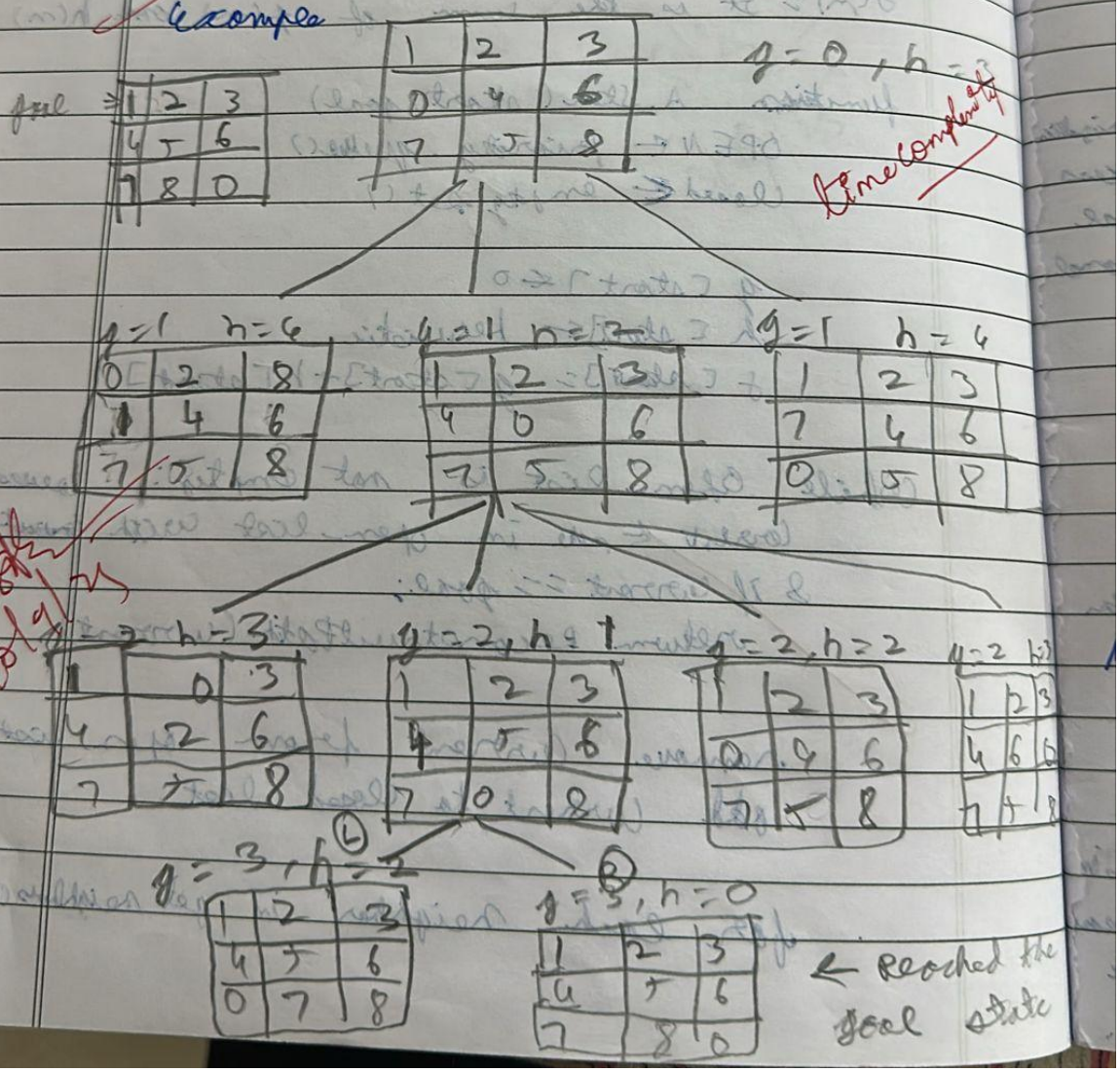
if neighbor in closedlist:
continue

tentativeg = g[current] + 1

if neighbor not in openlist or
tentativeg < g[child]
parent[neighbor] = current
g[neighbor] = tentativeg
f[neighbor] = g[neighbor] + h[neighbor]
if neighbor not in openlist:
add neighbor to openlist
return "No solution found"

8/10/25

Example



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


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

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

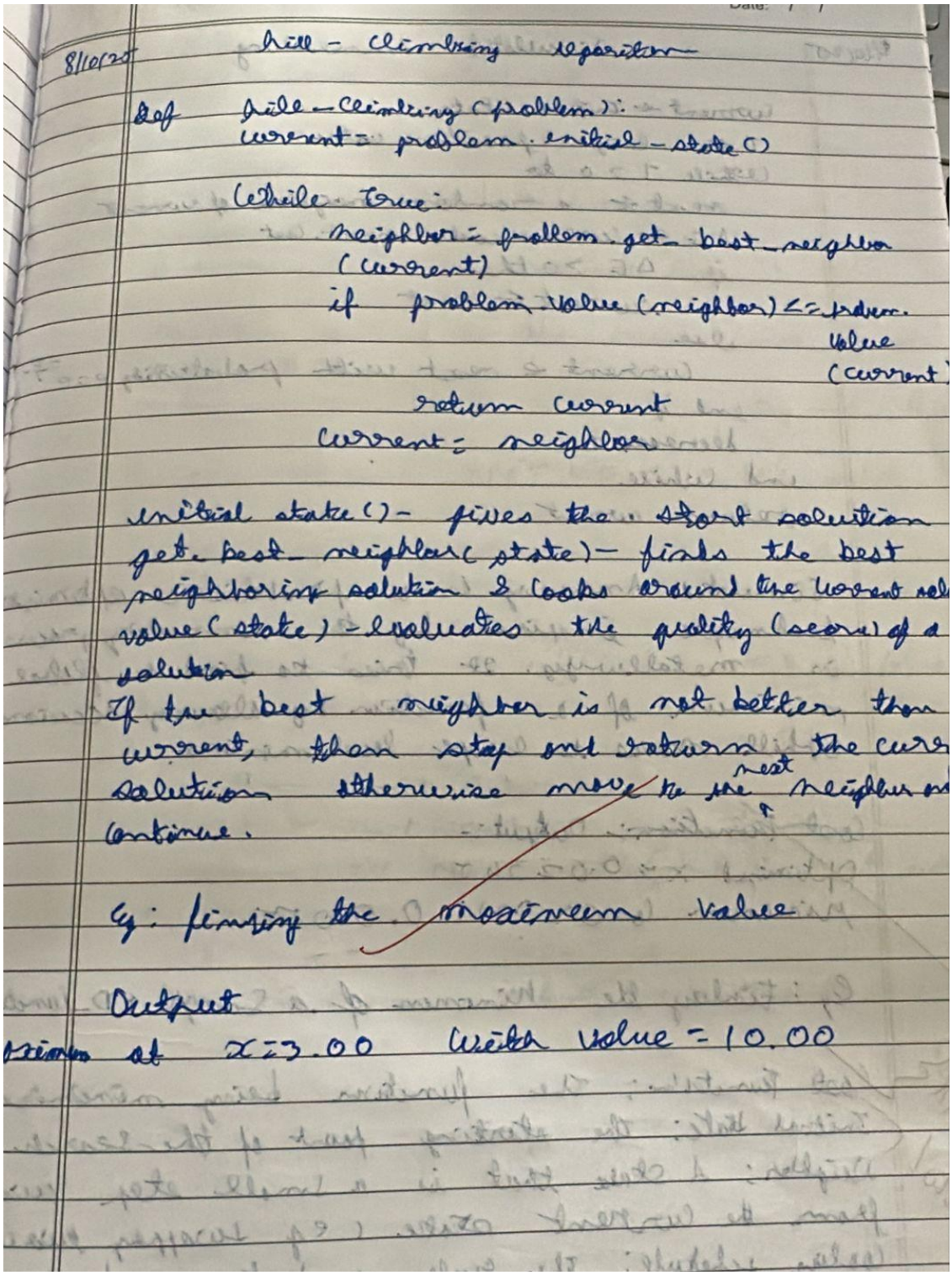
1 2 3
4 5 6
7 8

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)
```

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 .

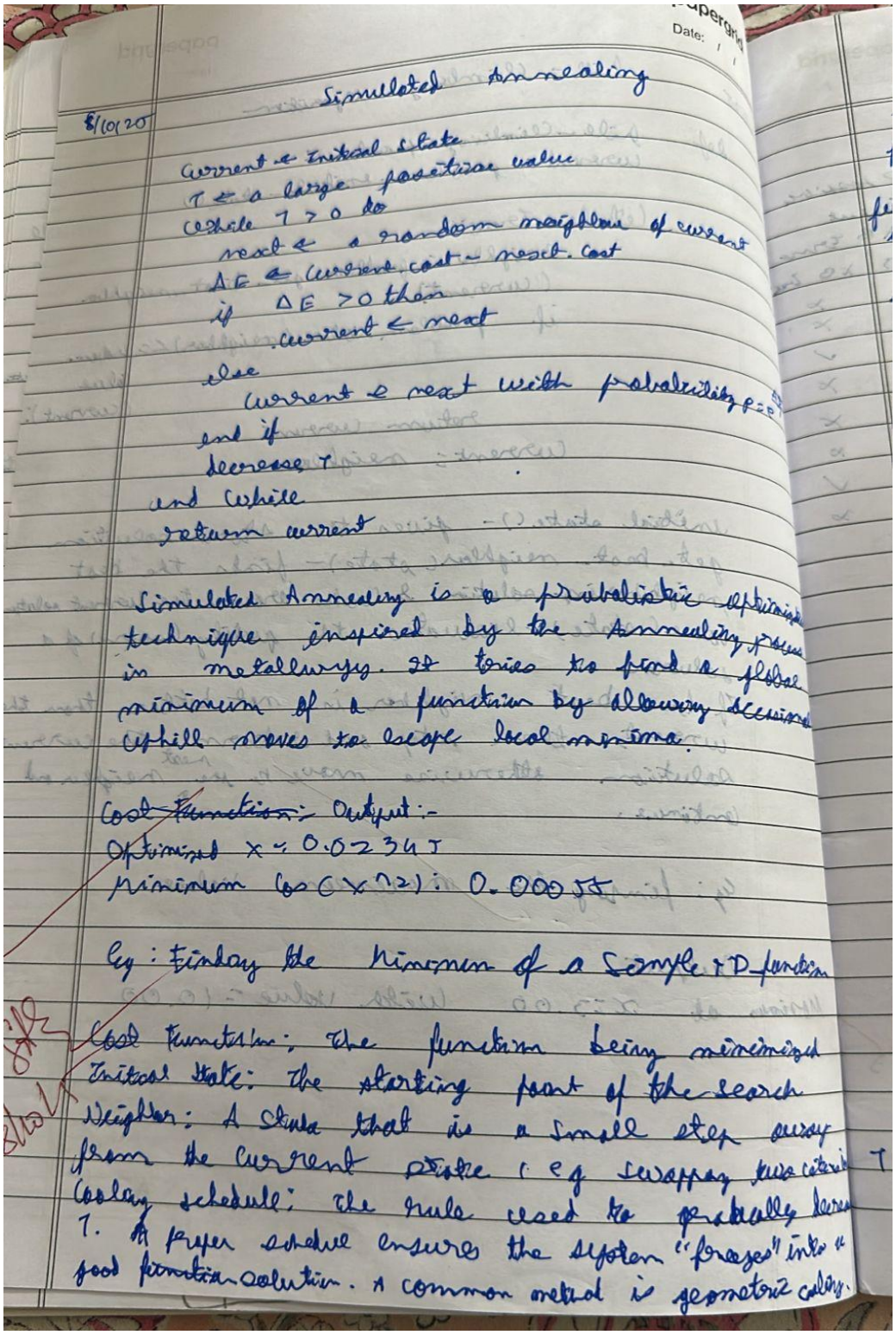
Step 2: (heuristic: 0) .
Q . .
. . . Q Q
. . .
. . Q .

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

Program 5

Simulated Annealing to Solve 8-Queens problem

Algorithm:



Simulated Annealing

8/10/20

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

Simulated Annealing is a probabilistic optimization technique inspired by the annealing process in metallurgy. It tries to find a global minimum of a function by allowing occasional uphill moves to escape local minima.

Cost function:- Output:-
Optimized x = 0.02364
minimum cos(x^2): 0.00055

Eg: Finding the minimum of a simple 1D function

Cost function: The function being minimized
Initial state: The starting point of the search
Neighbor: A state that is a small step away from the current state (e.g. swapping two cities in
Cooling schedule: The rule used to gradually decrease T.
A proper schedule ensures the algorithm "freezes" into a good (not perfect) solution. A common method is geometric cooling.

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")
```

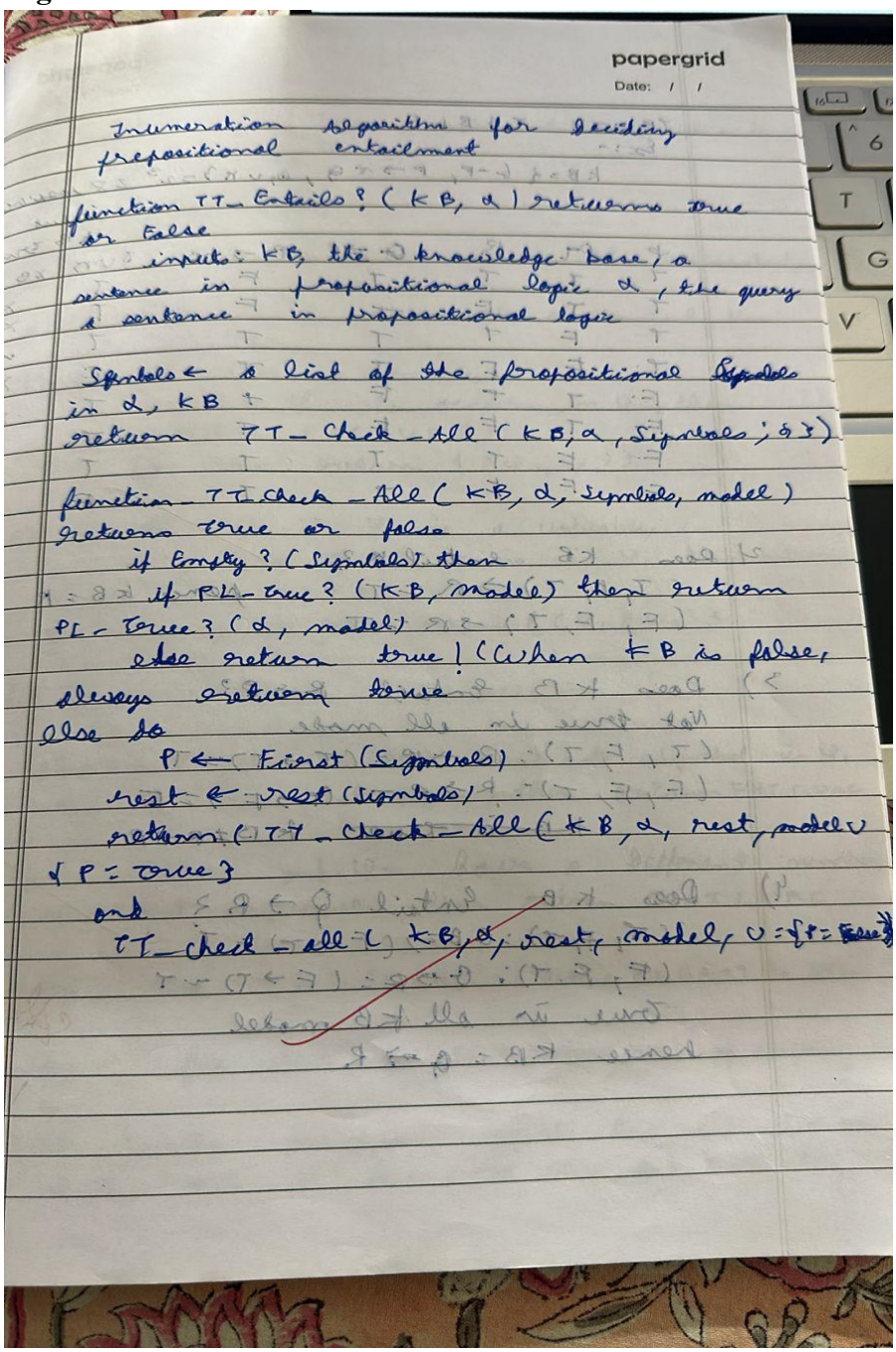
Output:

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

Program 6

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

Algorithm:



TRUTH TABLE

Ex:-

KB = $q \wedge \neg P$, $P \rightarrow \neg Q$, $Q \vee R$ — $2^3 = 8$ rows

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

2) Does KB entail R?

(T, F, T) → R = T ; hence KB ⊨ R

(F, F, T) → R = T

3) Does KB Entail R → P?

Not true in all model

(T, F, T): R → P = (T → T) = T

(F, F, T): R → P = (T → F) = F

~~KB is true~~ KB ⊭ R → P

4) Does KB Entail Q → R?

(T, F, T): GB ⇒ (F → T) = T

(F, F, T): Q → R = (F → T) ~ T

True in all KB model

hence KB ⊨ Q → R

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)

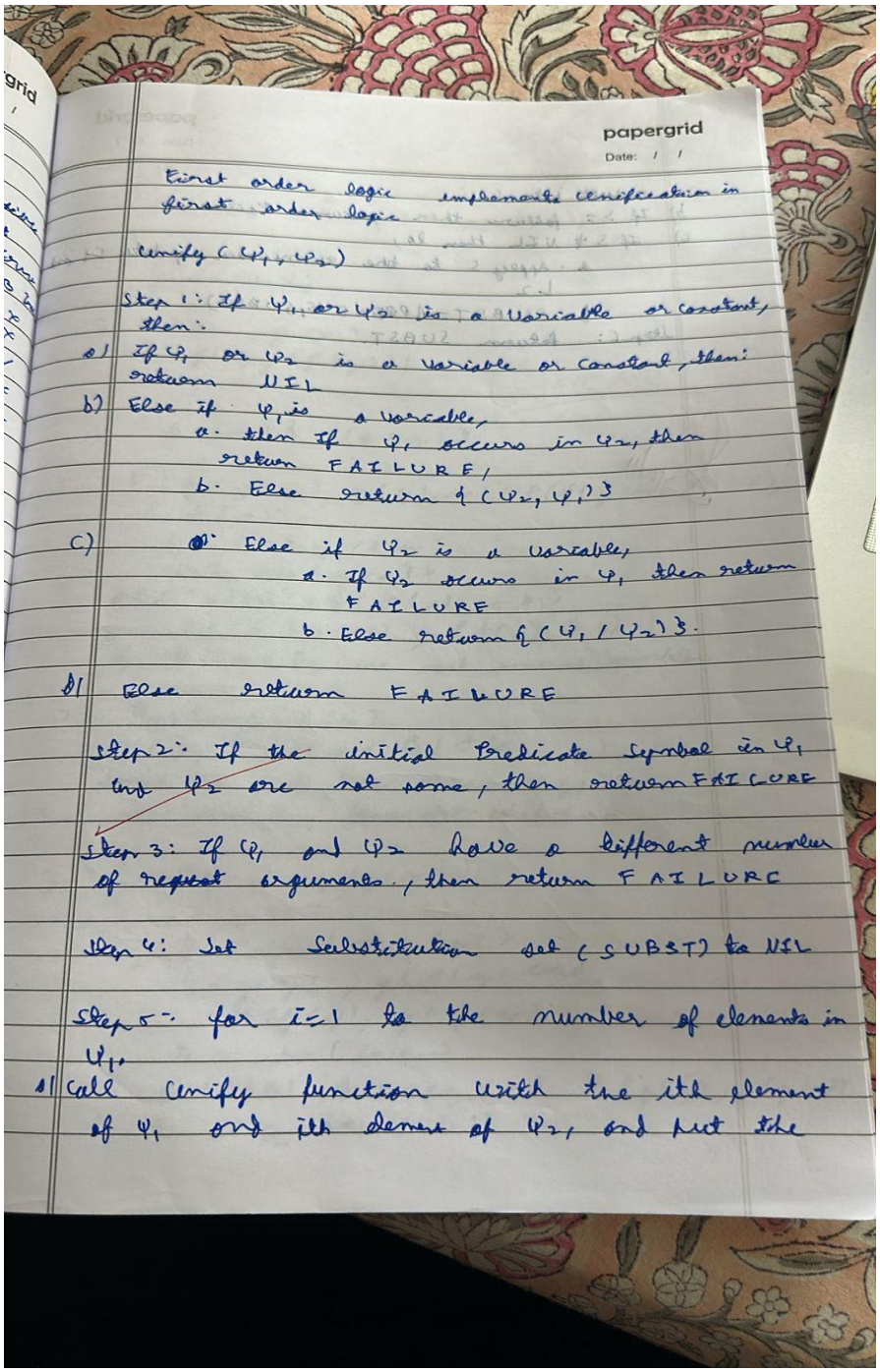
```
  P  |  Q  | KB  | Query

------------------
False | False | False | False
False | True | False | True
True | False | True | True
True | True | True | True
```

Does KB entail Query? True

Program 7

Implement unification in first order logic

Algorithm:



papergrid

Date: / /

First order logic implements unification in first order logic

Unify (Ψ_1, Ψ_2)

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

a) If Ψ_1 or Ψ_2 is a variable or constant, then return NIL

b) Else if Ψ_1 is a variable,
   a. then if Ψ_1 occurs in Ψ_2, then return FAILURE,
   b. Else return {(Ψ_2, Ψ_1)}

c) Else if Ψ_2 is a variable,
   a. If Ψ_2 occurs in Ψ_1 then return FAILURE
   b. Else return {(Ψ_1 / Ψ_2)}.

d) Else return FAILURE

Step 2: If the initial Predicate Symbol in Ψ_1 and Ψ_2 are not same, then return FAILURE

Step 3: If Ψ_1 and Ψ_2 have a different number of request arguments, then return FAILURE

Step 4: Set Substitution set (SUBST) to NIL

Step 5: for i=1 to the number of elements in Ψ_1.

a) Call unify function with the ith element of Ψ_1 and ith element of Ψ_2, and put the

result into S.

b) If S = failure then return failure

c) If S ≠ NIL then do,

a. Apply S to the remainder of both L1 and L2

b. SUBST = APPEND (S, SUBST)

Step 6: Return SUBST.

Date: / /

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

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

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

UNIFICATION

1) θ = subs ({ x / g(z) })

P (f (g(z)), g(y), y) & P(f(g(z)), g(f(a), f(a)))
θ₁ = subs { y / f(a) }
θ₃ = subs { y / a } }
P (f (g(z)), g (f (a)), f(a))
= P (f (g(z)), g (f(a), f(a)))
θ₁, θ₂ and θ₃ are most general unifiers

2. θ₁ = subs (x / y)
q (y, f(y)) and q (f(y), x)
Longer for cant these unless f(y) always is the same hence the generalization not possible

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

θ₁ = subs (x / g(z))
H (g(z), g(g(z))) and
H (g(y), g(g(z)))
θ₂ = subs (y / z)
H (g(z), g(g(z))) and H (g(z), g(g(z)))
θ₁ and θ₂ are MGU

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")
```

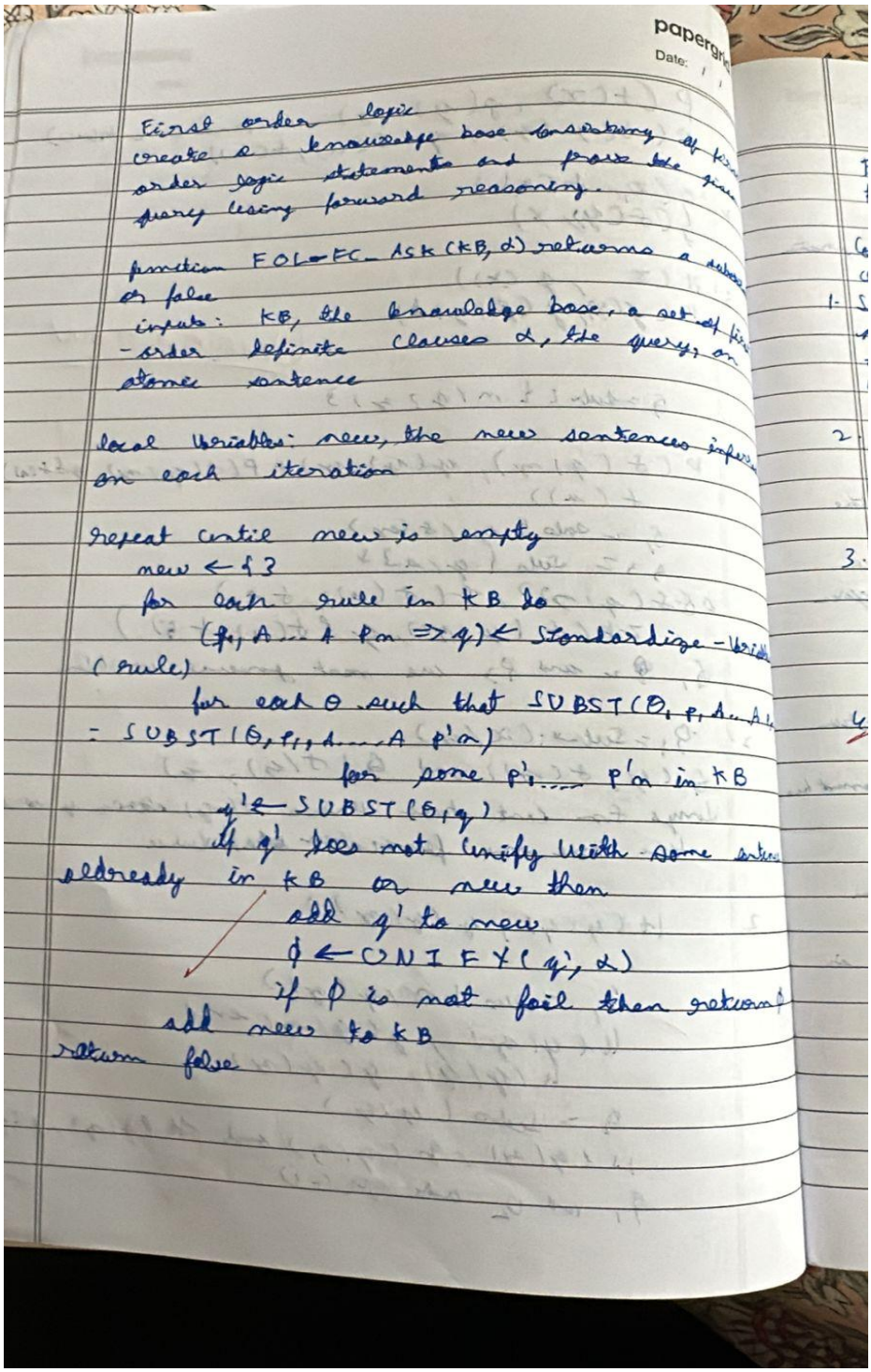
Output:

```
Most General Unifier (MGU):
{'Z': 'b', 'X': ('f', 'Y'), 'Y': ('g', 'Z')}
```

Program 8

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

Algorithm:



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.")
```

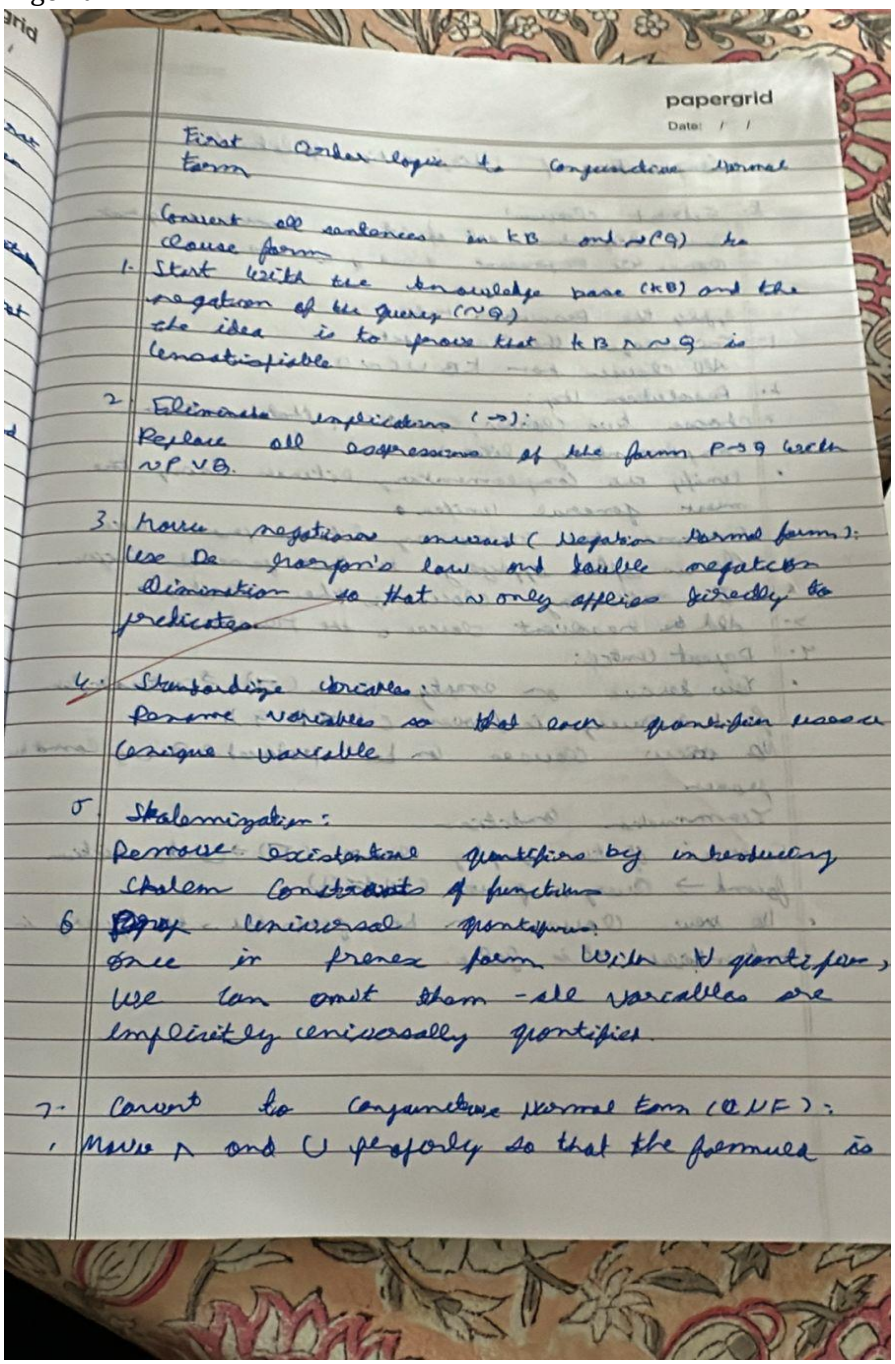
Output:

Robert is a criminal.

Program 9

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

Algorithm:



Conjunctions of disjunctions of literals

8- Extract clauses:
Each disjunction (set of literals) becomes a clause. We represent a set of literals.

Apply the Resolution Rule
1- Initialize the clause set:
All clauses from KB ∪ (¬α).
2. Resolution Step:
- Choose two clauses, C_1 and C_2, that contain complementary literals.
- Unify the complementary literals using the most general unifier.
- Combine the remaining literals from both clauses after applying the most general unifier.
- The resulting clause is the resolvent.
3. Add the resolvent clause to the resolvent.
4. Repeat until:
- You derive an empty clause (□) ⇒ Contradiction found ⇒ Query is proven ($KB \models \alpha$).
- No new clauses can be produced ⇒ Query cannot be proven.

Termination conditions
- Success: If the empty clause (□) → Contradiction found → Query is proven ($KB \models \alpha$).
- No new clauses can be generated → the query is not entailed or it is false.

Code:

```
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)

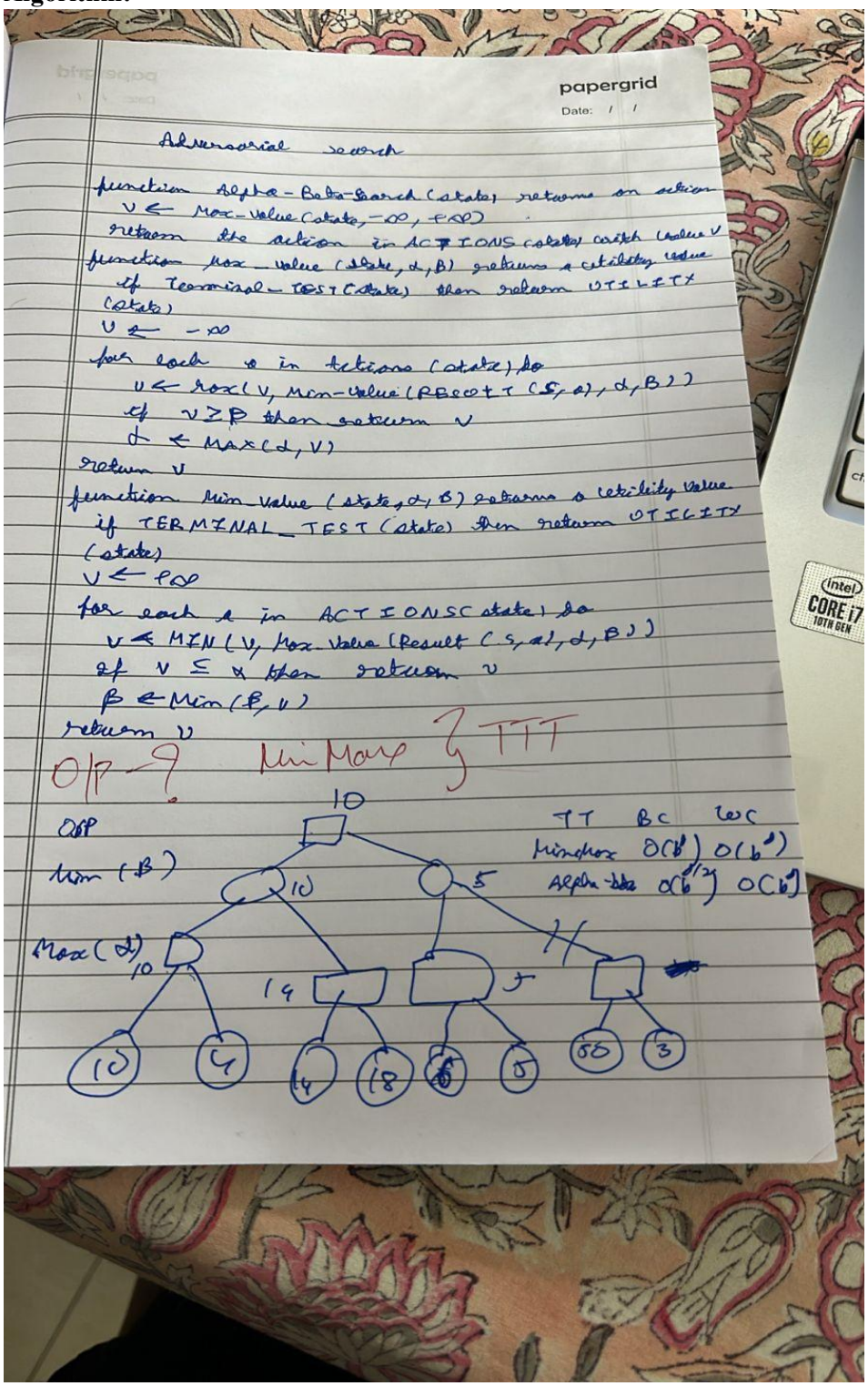
~Parent(x,y)|~Ancestor(y,z)|Ancestor(x,z)

Query: Ancestor(John, Sam) => TRUE

Program 10:

Implement Alpha-Beta Pruning.

Algorithm:



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