VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

ARTIFICIAL INTELLIGENCE

Submitted by

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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)
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Nov -2023 to Feb-2024

B. M. S. College of Engineering,
Bull Temple Road, Bangalore 560019
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Department of Computer Science and Engineering

CERTIFICATE

This is to certify that the Lab work entitled "**Artificial Intelligence**" carried out by **VRISHANK J VASIST(1BM21CS246),** 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 during the academic semester Nov -2023 to Feb-2024. The Lab report has been approved as it satisfies the academic requirements in respect of a **Artificial Intelligence (22CS5PCAIN)** work prescribed for the said degree.

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Index Sheet

Course Outcome

CO1	Apply knowledge of agent architecture, searching and reasoning techniques for different applications.
CO2	Analyse Searching and Inferencing Techniques.
CO3	Design a reasoning system for a given requirement.
CO4	Conduct practical experiments for demonstrating agents, searching and inferencing.

1. Implement Tic –Tac –Toe Game

```
import math

def print_board(board):
    for i in range(len(board)):
        for j in range(len(board[i])):
            print(board[i][j], end='')
            if j < len(board[i]) - 1:
                print('|', end='')
        print()
        if i < len(board) - 1:
            print('-'*5)
    print()

def check_winner(board):
    # Check rows, columns, and diagonals for a winner
    for i in range(3):
        if board[i][0] == board[i][1] == board[i][2] != ' ':
            return board[i][0]
        if board[0][i] == board[1][i] == board[2][i] != ' ':
            return board[0][i]
    if board[0][0] == board[1][1] == board[2][2] != ' ':
        return board[0][0]
    if board[0][2] == board[1][1] == board[2][0] != ' ':
        return board[0][2]
    return None

def get_empty_cells(board):
    # Returns a list of empty cells in the board
    return [(i, j) for i in range(3) for j in range(3) if board[i][j] == '
']

def minimax(board, depth, is_maximizing):
    winner = check_winner(board)
    if winner:
        return 10 - depth if winner == 'X' else -10 + depth
    elif not get_empty_cells(board):
        return 0

    if is_maximizing:
        best_score = -math.inf
        for i, j in get_empty_cells(board):
            board[i][j] = 'X'
```

```
            score = minimax(board, depth + 1, False)
            board[i][j] = ' '
            best_score = max(score, best_score)
        return best_score
    else:
        best_score = math.inf
        for i, j in get_empty_cells(board):
            board[i][j] = 'O'
            score = minimax(board, depth + 1, True)
            board[i][j] = ' '
            best_score = min(score, best_score)
        return best_score

def best_move(board):
    best_score = -math.inf
    move = None
    for i, j in get_empty_cells(board):
        board[i][j] = 'X'
        score = minimax(board, 0, False)
        board[i][j] = ' '
        if score > best_score:
            best_score = score
            move = (i, j)
    return move

def play_game():
    board = [[' ' for _ in range(3)] for _ in range(3)]
    print("Welcome to Tic Tac Toe!")
    print_board(board)

    while not check_winner(board) and get_empty_cells(board):
        user_move = input("Enter your move (row and column separated by a
space): ")
        x, y = map(int, user_move.split())
        if board[x][y] == ' ':
            board[x][y] = 'O'
            print_board(board)
        else:
            print("Invalid move. Try again.")
            continue

        if not get_empty_cells(board):
            break

        computer_move = best_move(board)
```

```
        board[computer_move[0]][computer_move[1]] = 'X'
        print("Computer's move:")
        print_board(board)

    winner = check_winner(board)
    if winner:
        print(f"Player {winner} wins!")
    else:
        print("It's a tie!")

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

OUTPUT

```
Welcome to Tic Tac Toe!
 | |
-----
 | |
-----
 | |

Enter your move (row and column separated by a space): 2 2
 | |
-----
 | |
-----
 | |O

Computer's move:
 | |
-----
 |X|
-----
 | |O

Enter your move (row and column separated by a space): 1 2
 | |
-----
 |X|O
-----
 | |O
```

```
Computer's move:
 | |X
-----
 |X|O
-----
 | |O

Enter your move (row and column separated by a space): 2 0
 | |X
-----
 |X|O
-----
O| |O

Computer's move:
 | |X
-----
 |X|O
-----
O|X|O

Enter your move (row and column separated by a space): 1 1
Invalid move. Try again.
Enter your move (row and column separated by a space): 0 1
 |O|X
-----
 |X|O
-----
O|X|O
```

```
Computer's move:
X|O|X
-----
 |X|O
-----
O|X|O

Enter your move (row and column separated by a space): 1 0
X|O|X
-----
O|X|O
-----
O|X|O

It's a tie!
```

6/11/23

Date / /
Page 1

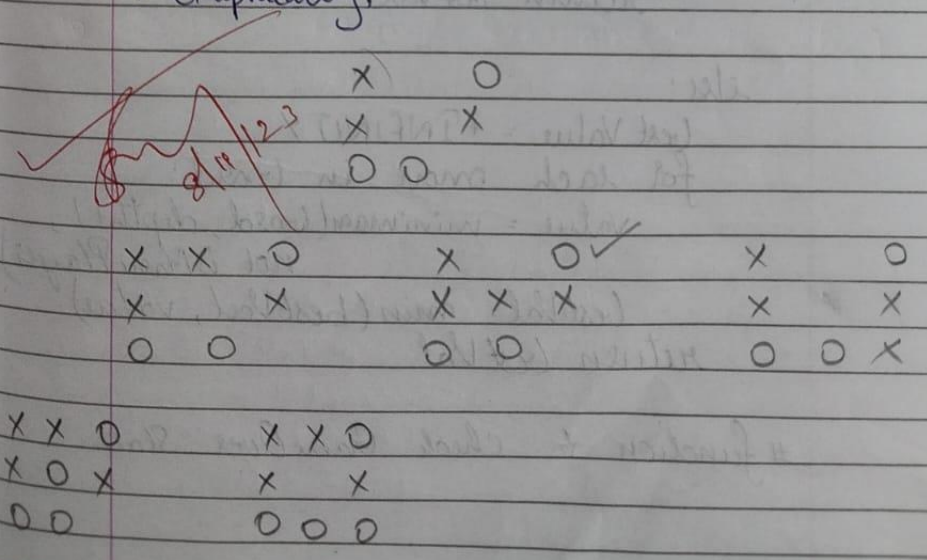
Tic Tac Toe with MiniMax Algorithm

→ The MiniMax Algorithm is a recursive program to find the best move that minimizes any tendency to lose a game while maximizing opportunity to win.

→ It uses DFS to evaluate the score with positive values for winning 0 for ties or no good moves & -ve values for losing.

→ In case a -ve move appears during recursion, it is prevented beforehand by the program.

→ Graphically,



2. Implement vaccum cleaner agent

```
def printInformation(location):
    print("Location " + location + " is Dirty.")
    print("Cost for CLEANING " + location + ": 1")
    print("Location " + location + " has been Cleaned.")


def vacuumCleaner(goalState, currentState, location):
    # printing necessary data
    print("Goal State Required:", goalState)
    print("Vacuum is placed in Location " + location)

    # cleaning locations
    totalCost = 0

    while (currentState != goalState):
        if (location == "A"):
            # cleaning
            if (currentState["A"] == 1):
                currentState["A"] = 0
                totalCost += 1
                printInformation("A")
            # moving
            elif (currentState["B"] == 1 ):
                print("Moving right to the location B.\nCost for moving
RIGHT: 1")
                location = "B"
                totalCost += 1

        elif (location == "B"):
            # cleaning
            if (currentState["B"] == 1):
                currentState["B"] = 0
                totalCost += 1
                printInformation("B")
            # moving
            elif (currentState["A"] == 1):
                print("Moving left to the location A.\nCost for moving LEFT:
1")
                location = "A"
                totalCost += 1
```

```
    print("GOAL STATE:", currentState)
    return totalCost


# declaring dictionaries
goalState = {"A": 0, "B": 0}
currentState = {"A": -1, "B": -1}

# taking input from user
location = input("Enter Location of Vacuum (A/B): ");
currentState["A"] = int(input("Enter status of A (0/1): "))
currentState["B"] = int(input("Enter status of B (0/1): "))

# calling function
totalCost = vacuumCleaner(goalState, currentState, location)
print("Performance Measurement:", totalCost)
```

OUTPUT

```
Enter Location of Vacuum (A/B): B
Enter status of A (0/1): 1
Enter status of B (0/1): 1
Goal State Required: {'A': 0, 'B': 0}
Vacuum is placed in Location B
Location B is Dirty.
Cost for CLEANING B: 1
Location B has been Cleaned.
Moving left to the location A.
Cost for moving LEFT: 1
Location A is Dirty.
Cost for CLEANING A: 1
Location A has been Cleaned.
GOAL STATE: {'A': 0, 'B': 0}
Performance Measurement: 3
```

22/11/23

Vaccum World Program:

→ Takes I/P of initial location & the status of locations A & B
→ If it is in location A & it is dirty it 'CLEANS', if B is then dirty, moves to B & then 'CLEANS' until {A:0,B:0} is achieved.
→ Cost is 1 each. Performance measure is total cost.

Algorithm:

```
def PrintInfo(location):
    *print the location, whether its dirty & clean & the cost of cleaning.

def vaccumClean(goalState, currentState, loc):
    tot_cost = 0
    while currentState != goalState:
        if loc == 'A':
            if currentState['A'] == 1:
                currentState = 0
                tot_cost += 1
                PrintInfo('A')
        endif
        elif loc = 'B':
            if currentState['B'] = 1:
                currentState = 0
                tot_cost += 1
                PrintInfo('B')
        endif
    //endwhile
```

Date
Page 8

print ('Goal State: ", currentState)
return totalCost

goalState = {'A: 0, B: 0}
currentState = {A: -1, B: -1}

loc = input ("Enter loc A/B")
currentState['A'] = int(input("State of A"))
currentState['B'] = int(input("State of B"))

Output:

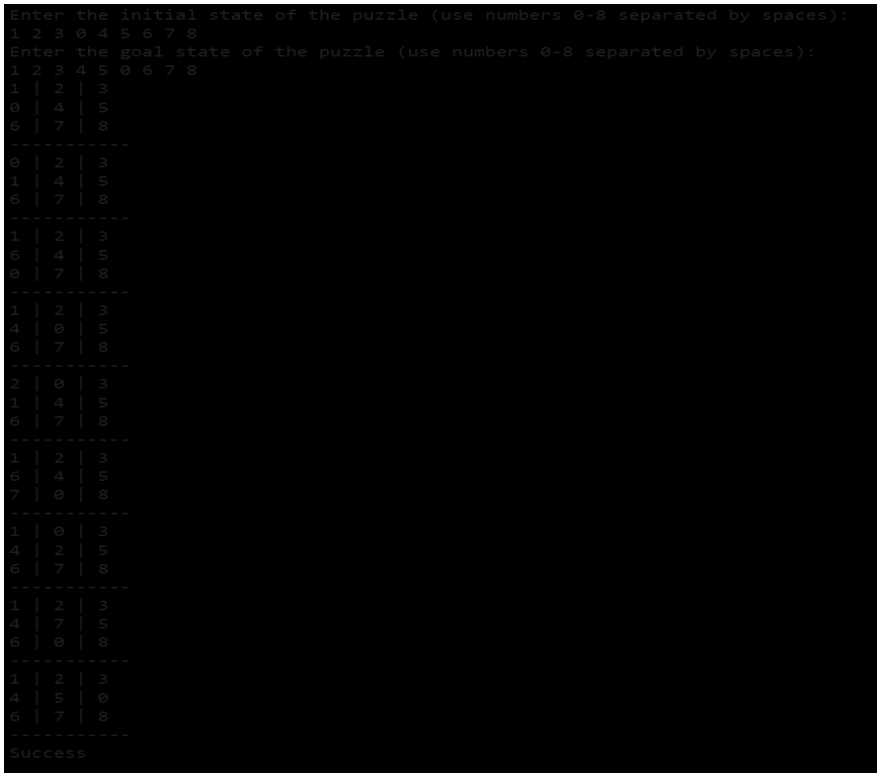
Enter loc A/B: → B
State of A : → 1
State of B: → 1
Vaccum in B, B is dirty, Cleaning B,
Cost = 1. Moving left to A, Cost = 2.
loc A is Dirty, Cost of cleaning A = 1,
Tot Cost = 3.
Goal State Achieved. Performance Measure
= 3.

3. Analyse 8 Puzzle problem and implement the same using Breadth First Search Algorithm

```
def bfs(src, target):
    queue = []
    queue.append(src)
    visited = set()

    while queue:
        source = queue.pop(0)
        visited.add(tuple(source))  # Store visited states as tuples for
faster lookup

        print(source[0], '|', source[1], '|', source[2])
        print(source[3], '|', source[4], '|', source[5])
        print(source[6], '|', source[7], '|', source[8])
        print("-----------")

        if source == target:
            print("Success")
            return

        poss_moves_to_do = possible_moves(source, visited)
        for move in poss_moves_to_do:
            queue.append(move)

def possible_moves(state, visited_states):
    b = state.index(0)
    d = []

    # Add possible directions to move based on the position of the empty
cell
    if b not in [0, 1, 2]:
        d.append('u')
    if b not in [6, 7, 8]:
        d.append('d')
    if b not in [0, 3, 6]:
        d.append('l')
    if b not in [2, 5, 8]:
        d.append('r')

    pos_moves_it_can = []

    for i in d:
```

```
            pos_moves_it_can.append(gen(state, i, b))

    # Return possible moves that have not been visited yet
    return [move_it_can for move_it_can in pos_moves_it_can if
tuple(move_it_can) not in visited_states]

def gen(state, move, b):
    temp = state.copy()
    if move == 'd':
        temp[b + 3], temp[b] = temp[b], temp[b + 3]
    if move == 'u':
        temp[b - 3], temp[b] = temp[b], temp[b - 3]
    if move == 'l':
        temp[b - 1], temp[b] = temp[b], temp[b - 1]
    if move == 'r':
        temp[b + 1], temp[b] = temp[b], temp[b + 1]
    return temp

# Taking input for initial and goal states
print("Enter the initial state of the puzzle (use numbers 0-8 separated by
spaces):")
src = list(map(int, input().split()))

print("Enter the goal state of the puzzle (use numbers 0-8 separated by
spaces):")
target = list(map(int, input().split()))

bfs(src, target)
```

OUTPUT


Enter the initial state of the puzzle (use numbers 0-8 separated by spaces):
1 2 3 0 4 5 6 7 8
Enter the goal state of the puzzle (use numbers 0-8 separated by spaces):
1 2 3 4 5 0 6 7 8
1 | 2 | 3
0 | 4 | 5
6 | 7 | 8
0 | 2 | 3
1 | 4 | 5
6 | 7 | 8
1 | 2 | 3
6 | 4 | 5
0 | 7 | 8
1 | 2 | 3
4 | 0 | 5
6 | 7 | 8
2 | 0 | 3
1 | 4 | 5
6 | 7 | 8
1 | 2 | 3
6 | 4 | 5
7 | 0 | 8
1 | 0 | 3
4 | 2 | 5
6 | 7 | 8
1 | 2 | 3
4 | 7 | 5
6 | 0 | 8
1 | 2 | 3
4 | 5 | 0
6 | 7 | 8
Success

29/11/23

8-Puzzle Problem Using BFS

→ Queue is used to hold all states that have to be visited
→ When visited, popped into a list called 'exp'.
→ Moves are: down, up, right, left.

* Goal State is usually
1 2 3 4 5 6 7 8 *

Begining state can be anything.

0 2 3
1 4 5
6 7 8

1 2 3
0 4 5
6 7 8

1 2 3
6 4 5
0 7 8

1 2 3
4 0 5
6 7 8

2 0 3
1 4 5
6 7 8

1 0 3
4 2 5
6 7 8

1 2 3
4 7 5
6 0 8

1 2 3
4 5 0
7 6 8

Success.

4. Analyse Iterative Deepening Search Algorithm. Demonstrate how 8 Puzzle problem could be solved using this algorithm

```
def dfs(src,target,limit,visited_states):
    if src == target:
        return True
    if limit <= 0:
        return False
    visited_states.append(src)
    moves = possible_moves(src,visited_states)
    for move in moves:
        if dfs(move, target, limit-1, visited_states):
            return True
    return False

def possible_moves(state,visited_states):
    b = state.index(-1)
    d = []
    if b not in [0,1,2]:
        d += 'u'
    if b not in [6,7,8]:
        d += 'd'
    if b not in [2,5,8]:
        d += 'r'
    if b not in [0,3,6]:
        d += 'l'
    pos_moves = []
    for move in d:
        pos_moves.append(gen(state,move,b))
    return [move for move in pos_moves if move not in visited_states]

def gen(state, move, blank):
    temp = state.copy()
    if move == 'u':
        temp[blank-3], temp[blank] = temp[blank], temp[blank-3]
    if move == 'd':
        temp[blank+3], temp[blank] = temp[blank], temp[blank+3]
    if move == 'r':
        temp[blank+1], temp[blank] = temp[blank], temp[blank+1]
    if move == 'l':
        temp[blank-1], temp[blank] = temp[blank], temp[blank-1]
    return temp

def iddfs(src,target,depth):
```

```
    for i in range(depth):
        visited_states = []
        if dfs(src,target,i+1,visited_states):
            return True, i+1
    return False

print("Enter the initial state of the puzzle (use numbers 0-8 separated by spaces):")
src = list(map(int, input().split()))

print("Enter the goal state of the puzzle (use numbers 0-8 separated by spaces):")
target = list(map(int, input().split()))
depth = 8
iddfs(src, target, depth)
```

OUTPUT

```
Enter the initial state of the puzzle (use numbers 0-8 separated by spaces):
1 2 3 -1 4 5 6 7 8
Enter the goal state of the puzzle (use numbers 0-8 separated by spaces):
1 2 3 6 4 5 7 8 -1
(True, 3)
```

Date / /
Page 7

8-Puzzle Problem Using IDS

→ Gives a True or False depending on whether goal state can be reached with depth = l.

→ IDS method is a mix of BFS & DFS by using the depth & incrementing it by 1 ~~until~~ & calling DFS until Goal State is achieved.

Input: Target:

1	2	3
4	4	5
7	8	-1

Input:

1	2	3
-1	4	5
6	7	8

swapping d = u

-1	2	3
1	4	5
6	7	8

d = d

1	2	3
6	4	5
-1	7	8

d = l

1	2	3
4	-1	5
6	7	8

↓ Target.

5. Implement A* search algorithm

```
class Node:
    def __init__(self,data,level,fval):

        self.data = data
        self.level = level
        self.fval = fval

    def generate_child(self):

        x,y = self.find(self.data,'_')

        val_list = [[x,y-1],[x,y+1],[x-1,y],[x+1,y]]
        children = []
        for i in val_list:
            child = self.shuffle(self.data,x,y,i[0],i[1])
            if child is not None:
                child_node = Node(child,self.level+1,0)
                children.append(child_node)
        return children

    def shuffle(self,puz,x1,y1,x2,y2):

        if x2 >= 0 and x2 < len(self.data) and y2 >= 0 and y2 <
len(self.data):
            temp_puz = []
            temp_puz = self.copy(puz)
            temp = temp_puz[x2][y2]
            temp_puz[x2][y2] = temp_puz[x1][y1]
            temp_puz[x1][y1] = temp
            return temp_puz
        else:
            return None


    def copy(self,root):

        temp = []
        for i in root:
            t = []
            for j in i:
                t.append(j)
            temp.append(t)
```

```
        return temp

    def find(self,puz,x):

        for i in range(0,len(self.data)):
            for j in range(0,len(self.data)):
                if puz[i][j] == x:
                    return i,j


class Puzzle:
    def __init__(self,size):

        self.n = size
        self.open = []
        self.closed = []

    def accept(self):

        puz = []
        for i in range(0,self.n):
            temp = input().split(" ")
            puz.append(temp)
        return puz

    def f(self,start,goal):

        return self.h(start.data,goal)+start.level

    def h(self,start,goal):

        temp = 0
        for i in range(0,self.n):
            for j in range(0,self.n):
                if start[i][j] != goal[i][j] and start[i][j] != '_':
                    temp += 1
        return temp


    def process(self):

        print("Enter the start state matrix \n")
        start = self.accept()
        print("Enter the goal state matrix \n")
        goal = self.accept()
```

```
        start = Node(start,0,0)
        start.fval = self.f(start,goal)

        self.open.append(start)
        print("\n\n")
        while True:
            cur = self.open[0]
            print("")
            print("  | ")
            print("  | ")
            print(" \\\'/ \n")
            for i in cur.data:
                for j in i:
                    print(j,end=" ")
                print("")

            if(self.h(cur.data,goal) == 0):
                break
            for i in cur.generate_child():
                i.fval = self.f(i,goal)
                self.open.append(i)
            self.closed.append(cur)
            del self.open[0]


            self.open.sort(key = lambda x:x.fval,reverse=False)


puz = Puzzle(3)
puz.process()
```

OUTPUT


Enter the start state matrix
1 2 3
_ 4 6
7 5 8
Enter the goal state matrix
1 2 3
4 5 6
7 8 _
1 2 3
_ 4 6
7 5 8
1 2 3
4 _ 6
7 5 8
1 2 3
4 5 6
7 _ 8
1 2 3
4 5 6
7 8

8-Puzzle with A* search:

Initial State:
1 2 3
5 4 ← 0 → → Start Node
8 ← 7 ↓ 6

Inserted to visited

neighbours: ① DOWN

1 2 3
5 4 6
8 7 0

6-1=5 1-3
q=1, r=2
c=0

② UP

1 2 0
5 4 3
8 7 6

2 1 3=
q=0 r=1
c=1

③ LEFT

1 2 3
5 0 4
8 7 6

3 1 3
q=1, r=1
c=2

④ RIGHT
→ Not Possible as it is not a valid state.

10/10

Heuristic Cost: i=1, j=2
goal_i, goal_j = divmod (state[i][j]-1, 3)
cost = 0

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

```
def tell(kb, rule):
    kb.append(rule)

combinations = [(True, True, True), (True, True, False),
                (True, False, True), (True, False, False),
                (False, True, True), (False, True, False),
                (False, False, True), (False, False, False)]


def ask(kb, q):
    for c in combinations:
        s = r1(c)
        f = q(c)
        print(s, f)
        if s != f and s != False:
            return 'Does not entail'
    return 'Entails'


kb = []

rule_str = input("Enter Rule 1 as a lambda function (e.g., lambda x: x[0] or
x[1] and (x[0] and x[1]): ")
r1 = eval(rule_str)
tell(kb, r1)

query_str = input("Enter Query as a lambda function (e.g., lambda x: x[0]
and x[1] and (x[0] or x[1]): ")
q = eval(query_str)


result = ask(kb, q)
print(result)
```

OUTPUT 1

```
Enter Rule 1 as a lambda function (e.g., lambda x: x[0] or x[1] and (x[0] and x[1]): lambda x: (not x[1] or not x[0] or x[2]) and (not x[1] and
Enter Query as a lambda function (e.g., lambda x: x[0] and x[1] and (x[0] or x[1]): lambda x: x[2]
False True
False False
False True
False False
False True
False False
False True
False False
Entails
```

OUTPUT 2

```
Enter Rule 1 as a lambda function (e.g., lambda x: x[0] or x[1] and (x[0] and x[1])): lambda x: (x[0] or x[1]) and (not x[2] or x[0])
Enter Query as a lambda function (e.g., lambda x: x[0] and x[1] and (x[0] or x[1])): lambda x: x[0] and x[2]
True True
True False
Does not entail
```

20/12/22

Propositional Logic.

$(\sim q \vee \sim p \vee r) \wedge (\sim q \wedge p) \wedge q$

(not q and not p and r) or (not q or p) and q

replace p with x[0]
q with x[1]
r with x[2]

(not x[1] and not x[0] and x[2]) or
(not x[1] or x[0]) and x[1]

(not x[1] or not x[0] or x[2]) and
(not x[1] and x[0]) and x[1]

10/10

Program Trace:

for c in combinations → all combs.

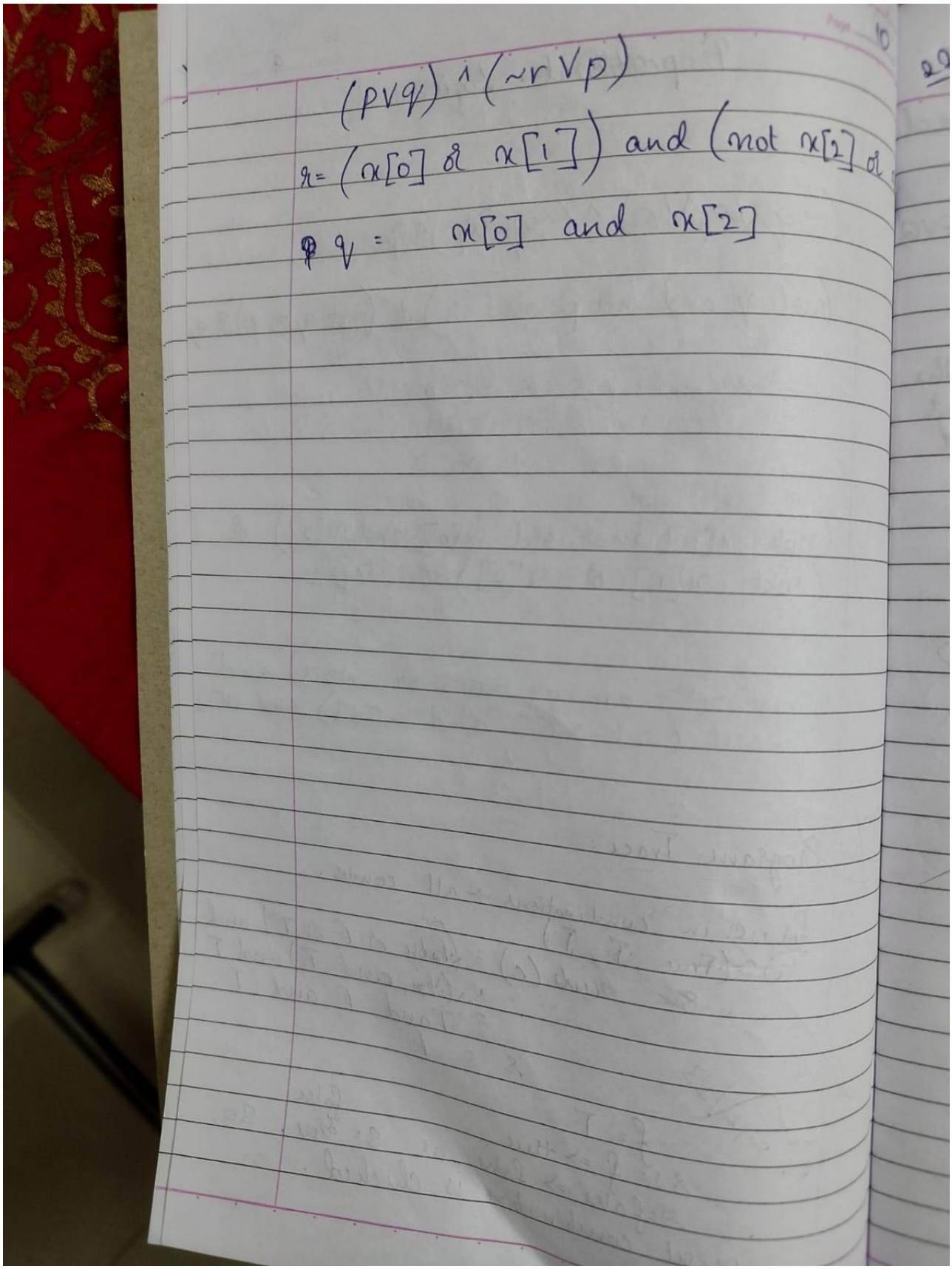
i) c = (True, T, T)

rule(c) = (False or F or T) and
(F and T) and T
= T and F and T
s = F

f = T

s != f => true

s != false => false as s = false. So, next combination is checked.


(p∨q) ∧ (~r∨p)
r = (x[0] or x[1]) and (not x[2] or
p q = x[0] and x[2]

7. Create a knowledge base using prepositional logic and prove the given query using resolution

```
import re

def main():
    rules = input("Enter the rules (space-separated): ")
    goal = input("Enter the goal: ")
    rules = rules.split(' ')
    steps = resolve(rules, goal)
    print('\nStep\t|Clause\t|Derivation\t')
    print('-' * 30)
    i = 1
    for step in steps:
        print(f' {i}.\t| {step}\t| {steps[step]}\t')
        i += 1


def negate(term):
    return f'~{term}' if term[0] != '~' else term[1]


def split_terms(rule):
    exp = '(~*[PQRS])'
    terms = re.findall(exp, rule)
    return terms


def contradiction(goal, clause):
    contradictions = [ f'{goal}v{negate(goal)}',
f'{negate(goal)}v{goal}']
    return clause in contradictions
def resolve(rules, goal):
    temp = rules.copy()
    temp += [negate(goal)]
    steps = dict()
    for rule in temp:
        steps[rule] = 'Given.'
    steps[negate(goal)] = 'Negated conclusion.'
    i = 0
    while i < len(temp):
        n = len(temp)
        j = (i + 1) % n
        clauses = []
        while j != i:
            terms1 = split_terms(temp[i])
            terms2 = split_terms(temp[j])
            for c in terms1:
                if negate(c) in terms2:
                    t1 = [t for t in terms1 if t != c]
```

```
                    t2 = [t for t in terms2 if t != negate(c)]
                    gen = t1 + t2
                    if len(gen) == 2:
                        if gen[0] != negate(gen[1]):
                            clauses += [f'{gen[0]}v{gen[1]}']

                            if
contradiction(goal,f'{gen[0]}v{gen[1]}'):
                                temp.append(f'{gen[0]}v{gen[1]}')
                                steps[''] = f"Resolved {temp[i]} and
{temp[j]} to {temp[-1]}, which is in turn null. \
                                \nA contradiction is found when
{negate(goal)} is assumed as true. Hence, {goal} is true."
                                return steps
                    elif len(gen) == 1:
                        clauses += [f'{gen[0]}']
                    else:
                        if
contradiction(goal,f'{terms1[0]}v{terms2[0]}'):
                            temp.append(f'{terms1[0]}v{terms2[0]}')
                            steps[''] = f"Resolved {temp[i]} and
{temp[j]} to {temp[-1]}, which is in turn null. \
                            \nA contradiction is found when
{negate(goal)} is assumed as true. Hence, {goal} is true."
                            return steps
            for clause in clauses:
                if clause not in temp :
                    temp.append(clause)
                    steps[clause] = f'Resolved from {temp[i]} and
{temp[j]}.'
            j = (j + 1) % n
        i += 1
    return steps
if __name__ == "__main__":
    main()
```

OUTPUT

```
Enter the rules (space-separated): Rv~P Rv~Q ~RvP ~RvQ
Enter the goal: R

Step     |Clause |Derivation
------------------------------
 1.      | Rv~P  | Given.
 2.      | Rv~Q  | Given.
 3.      | ~RvP  | Given.
 4.      | ~RvQ  | Given.
 5.      | ~R    | Negated conclusion.
 6.      |       | Resolved Rv~P and ~RvP to Rv~R, which is in turn null.
A contradiction is found when ~R is assumed as true. Hence, R is true.
```

22/12/23

Date / /
Page 11

Solving Propositional Logic Using Resolution

Rules

Input:
i) $(P \Rightarrow Q) \Rightarrow Q$ ~~(not P or Q)~~
ii) $(P \Rightarrow P) \Rightarrow R$
iii) $(R \Rightarrow S) \Rightarrow \sim(S \Rightarrow Q)$

Implies can be represented as,
not x[i] or x[j]

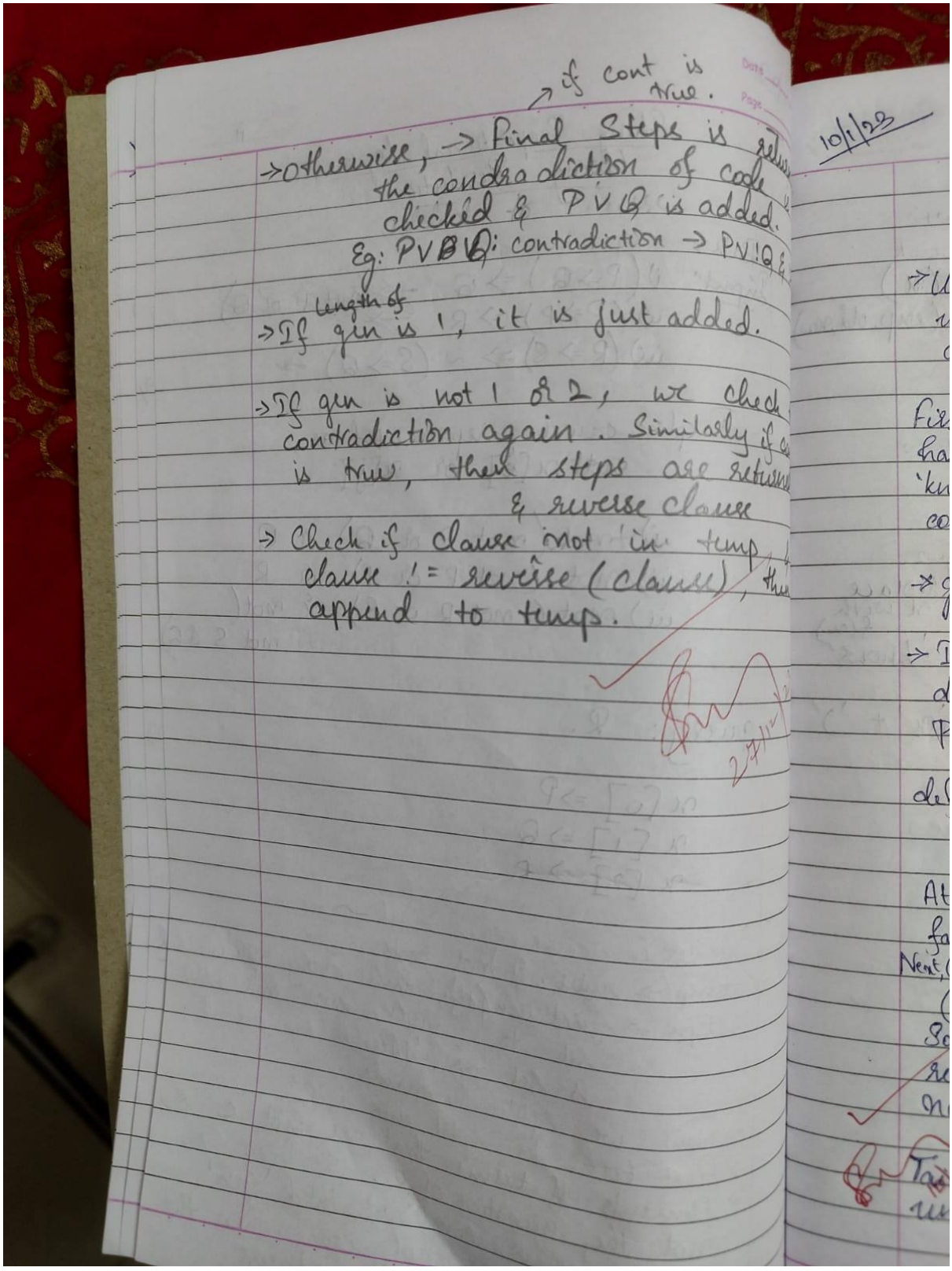
i) not (not P or Q) or Q
ii) not (not P or P) or R
iii) not (not R or S) or not (not S & Q)

query: R.

x[0] => P
x[1] => Q
x[2] => R

10/12

resolve:
temp -> rules & not rules
steps -> first empty, then every rule is set to given, ever not rule is set as 'Negated'
-> Now we split the terms.
-> First term is split into a 'c'.
-> Elements of term1 that are not c & not the negation of c.
-> This is then combined into 'gen'
-> If t1 & t2 are not equal then the


if cont is true.
→otherwise, → Final Steps is ret
the contradiction of cod
checked & P V Q is added.
Eg: P V R V Q: contradiction → P V !Q &
→ If length of gen is 1, it is just added.
→ If gen is not 1 or 2, we check
contradiction again. Similarly if
is true, then steps are return
& reverse clause
→ Check if clause not in temp
clause != reverse (clause), th
append to temp.
10/1/23

8. Implement unification in first order logic

```
import re

def getAttributes(expression):
    expression = expression.split("(")[1:]
    expression = "(".join(expression)
    expression = expression[:-1]
    expression = re.split("(?<!\(.),(?!.\))", expression)
    return expression

def getInitialPredicate(expression):
    return expression.split("(")[0]

def isConstant(char):
    return char.isupper() and len(char) == 1

def isVariable(char):
    return char.islower() and len(char) == 1

def replaceAttributes(exp, old, new):
    attributes = getAttributes(exp)
    for index, val in enumerate(attributes):
        if val == old:
            attributes[index] = new
    predicate = getInitialPredicate(exp)
    return predicate + "(" + ",".join(attributes) + ")"

def apply(exp, substitutions):
    for substitution in substitutions:
        new, old = substitution
        exp = replaceAttributes(exp, old, new)
    return exp

def checkOccurs(var, exp):
    if exp.find(var) == -1:
        return False
    return True


def getFirstPart(expression):
    attributes = getAttributes(expression)
    return attributes[0]


def getRemainingPart(expression):
    predicate = getInitialPredicate(expression)
    attributes = getAttributes(expression)
    newExpression = predicate + "(" + ",".join(attributes[1:]) + ")"
```

```
    return newExpression

def unify(exp1, exp2):
    if exp1 == exp2:
        return []

    if isConstant(exp1) and isConstant(exp2):
        if exp1 != exp2:
            return False

    if isConstant(exp1):
        return [(exp1, exp2)]

    if isConstant(exp2):
        return [(exp2, exp1)]

    if isVariable(exp1):
        if checkOccurs(exp1, exp2):
            return False
        else:
            return [(exp2, exp1)]

    if isVariable(exp2):
        if checkOccurs(exp2, exp1):
            return False
        else:
            return [(exp1, exp2)]

    if getInitialPredicate(exp1) != getInitialPredicate(exp2):
        print("Predicates do not match. Cannot be unified")
        return False

    attributeCount1 = len(getAttributes(exp1))
    attributeCount2 = len(getAttributes(exp2))
    if attributeCount1 != attributeCount2:
        return False

    head1 = getFirstPart(exp1)
    head2 = getFirstPart(exp2)
    initialSubstitution = unify(head1, head2)
    if not initialSubstitution:
        return False
    if attributeCount1 == 1:
        return initialSubstitution

    tail1 = getRemainingPart(exp1)
    tail2 = getRemainingPart(exp2)
```

```
    if initialSubstitution != []:
        tail1 = apply(tail1, initialSubstitution)
        tail2 = apply(tail2, initialSubstitution)

    remainingSubstitution = unify(tail1, tail2)
    if not remainingSubstitution:
        return False

    initialSubstitution.extend(remainingSubstitution)
    return initialSubstitution


exp1 = input("Enter the first expression: ")
exp2 = input("Enter the second expression: ")


substitutions = unify(exp1, exp2)


print("Substitutions:")
print(substitutions)
```

OUTPUT

```
Enter the first expression: knows(f(x),y)
Enter the second expression: knows(J,John)
Substitutions:
[('J', 'f(x)'), ('John', 'y')]
```

10/1/23

Date / /
Page

Unification & First order Logic

→ Unification is when the agent tries to unify the knowledge/information it has and come to conclusions.

First call of the function unify has all expressions be stripped of their 'knows' & become just the variables or constants.

→ ~~getAttributes counts the number of~~

→ If the number of expressions/attributes don't match, then a sol is not possible.

```
def unify( ):
    ↓ ignore first time till line 78
```

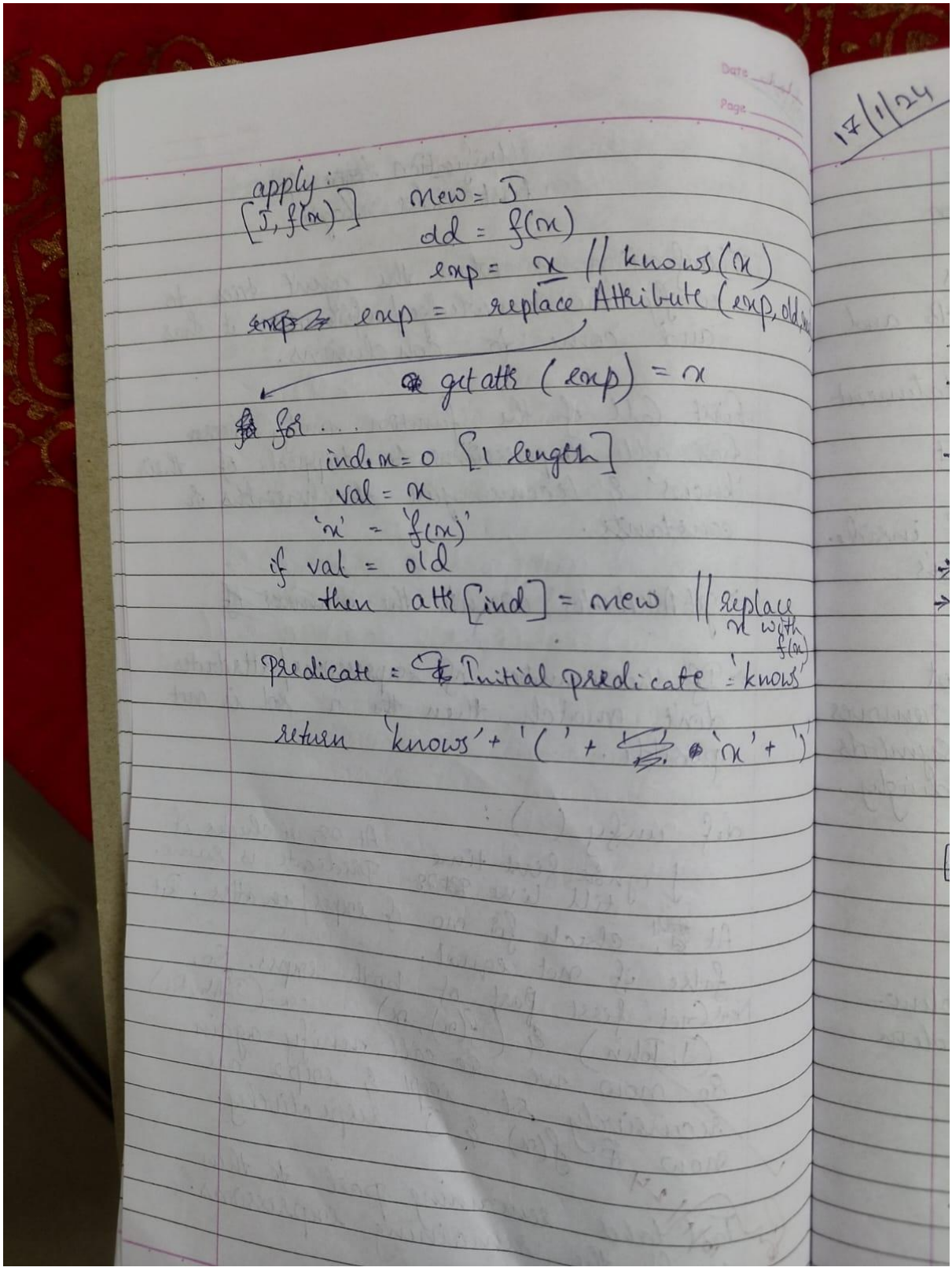
At 78, it checks if predicate is same.

At 81, check for no. of expres/attrs. Ret false if not equal.

Next, Get first part of both expss. So, (J, John) & (f(x), x) ex: (J, Ah, Ri)

So, now we call unify again recursively s.t, exp1 & exp2 are now f(x) & J respectively.

Tail takes remaining part to then unify the remaining expressions.


17/1/24
apply:
[5, f(x)]
new = 5
old = f(x)
exp = x // knows(x)
exp = replace Attribute (exp, old, new)
get attr (exp) = x
for ...
index = 0 [1 length]
val = x
'x' = 'f(x)'
if val = old
then attr[ind] = new // replace x with f(x)
predicate = Initial predicate : 'knows'
return 'knows' + '(' + 'x' + ')'

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

```
import re

def getAttributes(string):
    expr = '\([^)]+\)'
    matches = re.findall(expr, string)
    return [m for m in str(matches) if m.isalpha()]

def getPredicates(string):
    expr = '[a-z~]+\([A-Za-z,]+\)'
    return re.findall(expr, string)

def DeMorgan(sentence):
    string = ''.join(list(sentence).copy())
    string = string.replace('~~','')
    flag = '[' in string
    string = string.replace('~[','')
    string = string.strip(']')
    for predicate in getPredicates(string):
        string = string.replace(predicate, f'~{predicate}')
    s = list(string)
    for i, c in enumerate(string):
        if c == '|':
            s[i] = '&'
        elif c == '&':
            s[i] = '|'
    string = ''.join(s)
    string = string.replace('~~','')
    return f'[{string}]' if flag else string

def Skolemization(sentence):
    SKOLEM_CONSTANTS = [f'{chr(c)}' for c in range(ord('A'),
ord('Z')+1)]
    statement = ''.join(list(sentence).copy())
    matches = re.findall('[∀∃].', statement)
    for match in matches[::-1]:
        statement = statement.replace(match, '')
        statements = re.findall('\[\[^]]+\]]', statement)
        for s in statements:
            statement = statement.replace(s, s[1:-1])
        for predicate in getPredicates(statement):
            attributes = getAttributes(predicate)
            if ''.join(attributes).islower():
                statement =
statement.replace(match[1],SKOLEM_CONSTANTS.pop(0))
            else:
                aL = [a for a in attributes if a.islower()]
```

```
                aU = [a for a in attributes if not a.islower()][0]
                statement = statement.replace(aU,
f'{SKOLEM_CONSTANTS.pop(0)}({aL[0] if len(aL) else match[1]})')
    return statement

def fol_to_cnf(fol):
    statement = fol.replace("<=>", "_")
    while '_' in statement:
        i = statement.index('_')
        new_statement = '[' + statement[:i] + '=>' + statement[i+1:] +
']&['+ statement[i+1:] + '=>' + statement[:i] + ']'
        statement = new_statement
    statement = statement.replace("=>", "-")
    expr = '\[([^]]+)\]'
    statements = re.findall(expr, statement)
    for i, s in enumerate(statements):
        if '[' in s and ']' not in s:
            statements[i] += ']'
    for s in statements:
        statement = statement.replace(s, fol_to_cnf(s))
    while '-' in statement:
        i = statement.index('-')
        br = statement.index('[') if '[' in statement else 0
        new_statement = '~' + statement[br:i] + '|' + statement[i+1:]
        statement = statement[:br] + new_statement if br > 0 else
new_statement
    while '~∀' in statement:
        i = statement.index('~∀')
        statement = list(statement)
        statement[i], statement[i+1], statement[i+2] = '∃',
statement[i+2], '~'
        statement = ''.join(statement)
    while '~∃' in statement:
        i = statement.index('~∃')
        s = list(statement)
        s[i], s[i+1], s[i+2] = '∀', s[i+2], '~'
        statement = ''.join(s)
    statement = statement.replace('~[∀','[~∀')
    statement = statement.replace('~[∃','[~∃')
    expr = '(~[∀|∃].)'
    statements = re.findall(expr, statement)
    for s in statements:
        statement = statement.replace(s, fol_to_cnf(s))
    expr = '~\[[^]]+\]'
    statements = re.findall(expr, statement)
    for s in statements:
        statement = statement.replace(s, DeMorgan(s))
    return statement
```

```
print(Skolemization(fol_to_cnf("animal(y)<=>loves(x,y)")))
print(Skolemization(fol_to_cnf("∀x[∀y[animal(y)=>loves(x,y)]]=>[∃z[loves(z,x)]]")))
print(fol_to_cnf("[american(x)&weapon(y)&sells(x,y,z)&hostile(z)]=>criminal(x)"))
```

OUTPUT

```
[~animal(y)|loves(x,y)]&[~loves(x,y)|animal(y)]
[animal(G(x))&~loves(x,G(x))]|[loves(F(x),x)]
[~american(x)|~weapon(y)|~sells(x,y,z)|~hostile(z)]|criminal(x)
```

17/1/24

Date __/__/__
Page

First Order Logic to CNF conversion.

For CNF:
→ No implication
→ No variable repetition
→ Move negation, so that, brackets are not considered. Eg: ¬(A & B) = ¬A and ¬B
→ Elimate Existential instance with constant & then with a function. ∃ → Existential
Eg: ∃y Rich(y) => Rich(G1)
→ Drop Universal Quantifier. Eg: ∀x Person(x) ↳ Person(x)
→ And * Keep V as is
* Change a sentence with '∧' into two & more depending on the number of literals.
* Basically distribute it.

Eg:
[American(x) ∧ Weapon(y) ∧ Sells(x,y,z) ∧ Hostile(z)] → Criminal(x)

Step 1: Remove Implication.

¬[American(x) ∧ Weapon(y) ∧ Sells(x,y,z) ∧ Hostile(z)] V Criminal(x)

Step 2: Remove ¬ & Parenthesis.

¬American(x) V ¬Weapons(y) V ¬Sells(x,y,z) V ¬Hostile(z) V Criminal(x)

24/1/24

In Code:
→ We first go to fol_to_cnf function
→ Here, <=> or double implication is removed & converted to A⇒B and B⇒A
→ Next, ⇒ is removed & the statement is converted to ¬A ∨ B
→ Replace ¬∀ with ∃
→ Replace ¬∃ with ∀
→ Both places have ¬ transferred inside
→ Finally, we apply Demorgan's Law on the Statement.

→ This is the final cnf if not for Skolemization. Skolemization removes Existential & Universal quantifier symbols & changes the statement accordingly

* Skolem_Constants → all capital letters.
* Find all instances of ∀ or ∃
* Remove both ∀ & ∃.
* Remove 1 letter after either.
* With ∃, replace with Skolem Constants & then with Skolem Functions.

24/1/24

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

```
import re

def isVariable(x):
    return len(x) == 1 and x.islower() and x.isalpha()

def getAttributes(string):
    expr = '\([^)]+\)'
    matches = re.findall(expr, string)
    return matches

def getPredicates(string):
    expr = '([a-z~]+)\([^&|]+\)'
    return re.findall(expr, string)

class Fact:
    def __init__(self, expression):
        self.expression = expression
        predicate, params = self.splitExpression(expression)
        self.predicate = predicate
        self.params = params
        self.result = any(self.getConstants())

    def splitExpression(self, expression):
        predicate = getPredicates(expression)[0]
        params = getAttributes(expression)[0].strip('()').split(',')
        return [predicate, params]

    def getResult(self):
        return self.result

    def getConstants(self):
        return [None if isVariable(c) else c for c in self.params]

    def getVariables(self):
        return [v if isVariable(v) else None for v in self.params]

class Implication:
    def __init__(self, expression):
        self.expression = expression
        l = expression.split('=>')
        self.lhs = [Fact(f) for f in l[0].split('&')]
        self.rhs = Fact(l[1])

    def evaluate(self, facts):
        constants = {}
        new_lhs = []
```

```
        for fact in facts:
            for val in self.lhs:
                if val.predicate == fact.predicate:
                    for i, v in enumerate(val.getVariables()):
                        if v:
                            constants[v] = fact.getConstants()[i]
                    new_lhs.append(fact)
        predicate, attributes = getPredicates(self.rhs.expression)[0],
str(getAttributes(self.rhs.expression)[0])
        for key in constants:
            if constants[key]:
                attributes = attributes.replace(key, constants[key])
        expr = f'{predicate}{attributes}'
        return Fact(expr) if len(new_lhs) and all([f.getResult() for f
in new_lhs]) else None

class KB:
    def __init__(self):
        self.facts = set()
        self.implications = set()

    def tell(self, e):
        if '=>' in e:
            self.implications.add(Implication(e))
        else:
            self.facts.add(Fact(e))
        for i in self.implications:
            res = i.evaluate(self.facts)
            if res:
                self.facts.add(res)

    def query(self, e):
        facts = set([f.expression for f in self.facts])
        i = 1
        print(f'Querying {e}:')
        for f in facts:
            if Fact(f).predicate == Fact(e).predicate:
                print(f'\t{i}. {f}')
                i += 1

    def display(self):
        print("All facts: ")
        for i, f in enumerate(set([f.expression for f in self.facts])):
            print(f'\t{i+1}. {f}')
kb = KB()
kb.tell('missile(x)=>weapon(x)')
kb.tell('missile(M1)')
kb.tell('enemy(x,America)=>hostile(x)')
```

```
kb.tell('american(West)')
kb.tell('enemy(Nono,America)')
kb.tell('owns(Nono,M1)')
kb.tell('missile(x)&owns(Nono,x)=>sells(West,x,Nono)')
kb.tell('american(x)&weapon(y)&sells(x,y,z)&hostile(z)=>criminal(x)')
kb.query('criminal(x)')
kb.display()
```

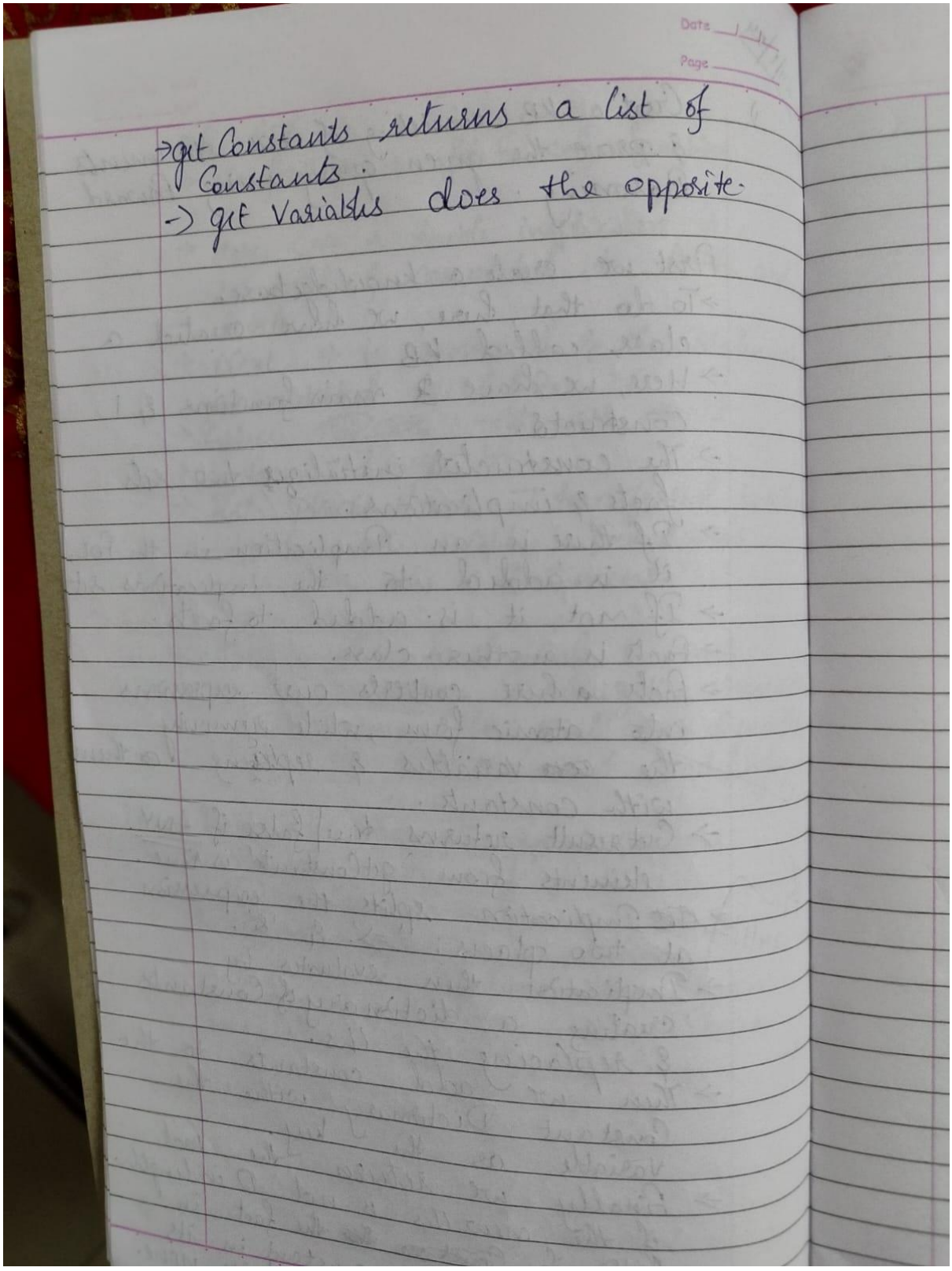
OUTPUT

```
Querying criminal(x):
        1. criminal(West)
All facts:
        1. enemy(Nono,America)
        2. weapon(M1)
        3. owns(Nono,M1)
        4. missile(M1)
        5. criminal(West)
        6. hostile(Nono)
        7. sells(West,M1,Nono)
        8. american(West)
```

24/11

1) Create a KB consisting of FOL statements & prove the given query using Forward Reasoning.

First we create a knowledge base.
→ To do that here, we have created a class called KB
→ Here, we have 3 main functions & 1 constructor.
→ The constructor initializes two sets facts & implications.
→ If there is an Implication in the FOL, it is added to the implications set
→ If not, it is added to facts.
→ Facts is another class.
→ Facts class converts our expressions into atomic form, while removing the variables & replacing them with constants.
→ Get result returns true/false if ANY elements from 'getConstant' is true.
→ Implication splits the expression at two places: '=>' & '&'.
→ Implication then evaluates by creating a dictionary of Constants & replacing the lhs.
→ Then we add constants to the Constant Dictionary with the variable as the key.
→ Finally we return the fact if the new lhs is not 0 in length. AND if the fact in new LHS has a constant in its Constant list. Else we return none.


Date
Page
->get Constants returns a list of Constants.
-> get Variables does the opposite.