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 **VYLERI KEZHEKE SIDDHARTH(1BM21CS247),** 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)
```

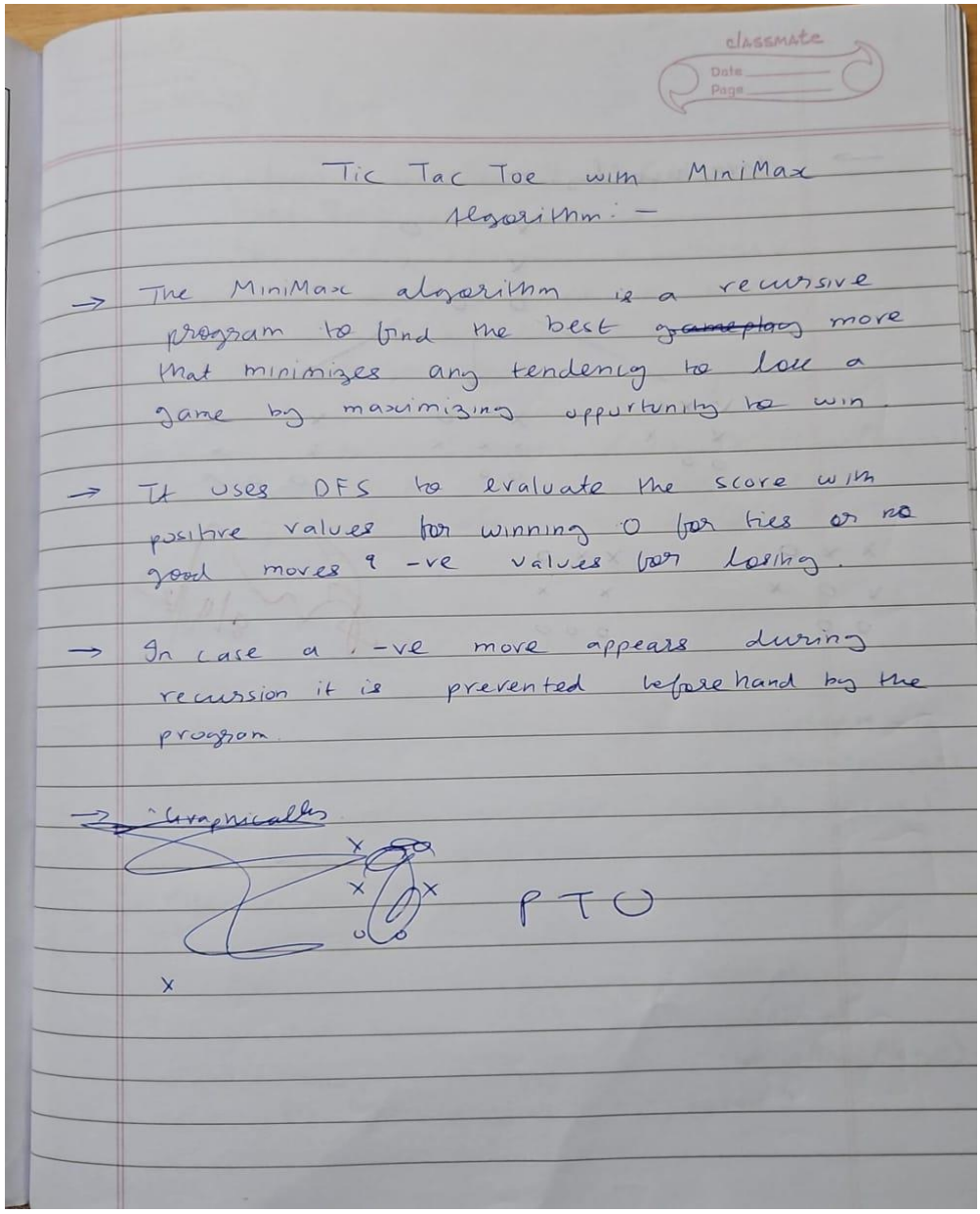
```
        board[computer_move[0]][computer_move[1]] = 'X'
        print("Computer's move:")
        print_board(board)

    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!
```



Tic Tac Toe with MiniMax algorithm :-

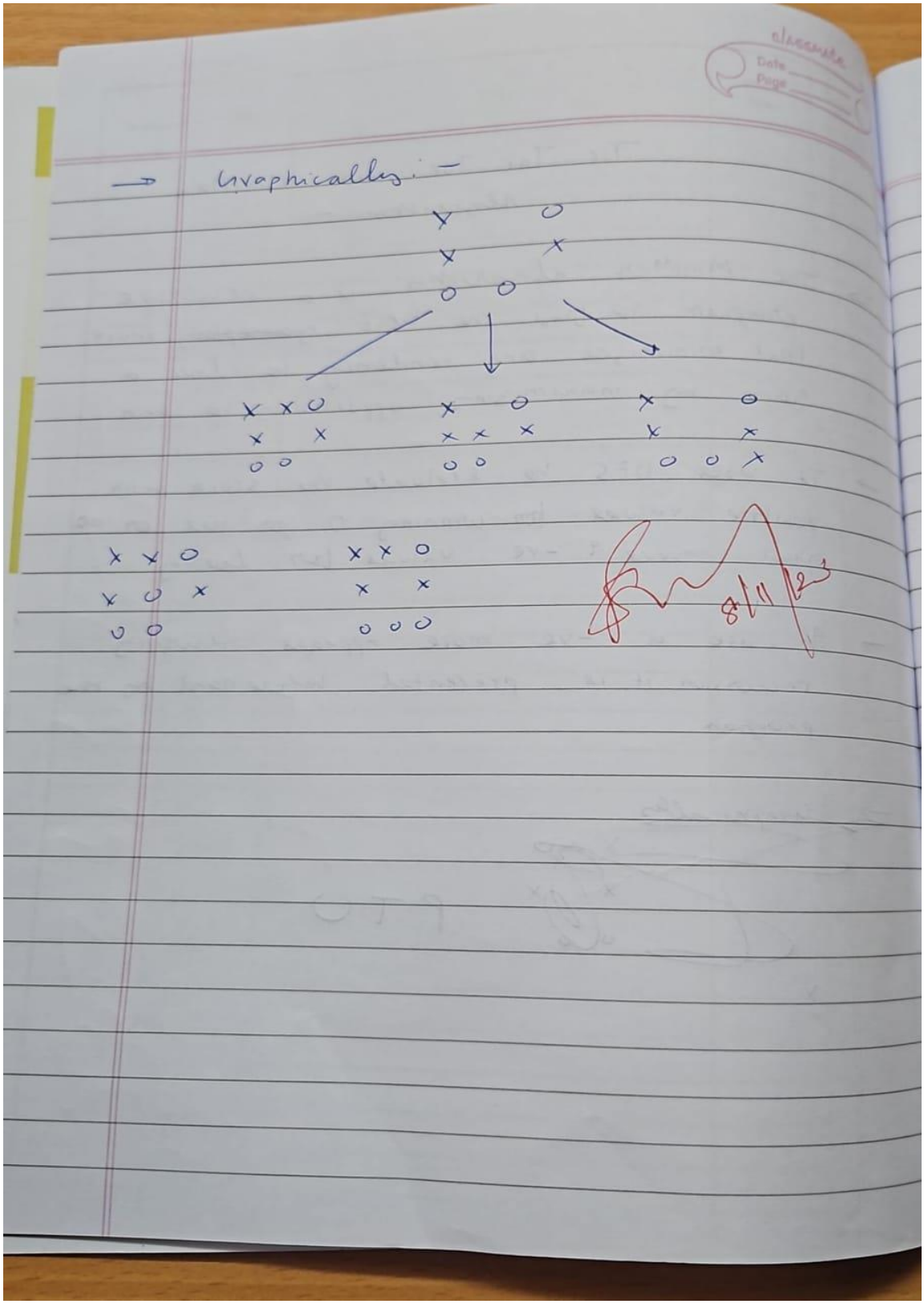
→ The MiniMax algorithm is a recursive program to find the best ~~gameplay~~ move that minimizes any tendency to lose a game by maximizing opportunity to win.

→ 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

PTO


→ Graphically:-
8/11/23

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
```

WEEK-3

Vaccuum Cleaner

Source code:-

```
def vacuum_world():
    goal_state = {'A': '0', 'B': '0'}
    cost = 0
    location_input = input("Enter location of vacuum")
    status_input = input("Enter status of " + location_input)
    status_input_complement = input("Enter status of other room")
    print("Initial Location condition" + str(goal_state))

    if location_input == 'A':
        print("Vacuum is placed in Location A")
        if status_input == '1':
            print("Location A is dirty.")
            goal_state['A'] = '0'
            cost += 1
            print("cost of cleaning A" + str(cost))
            print("Location A has been cleaned.")
```

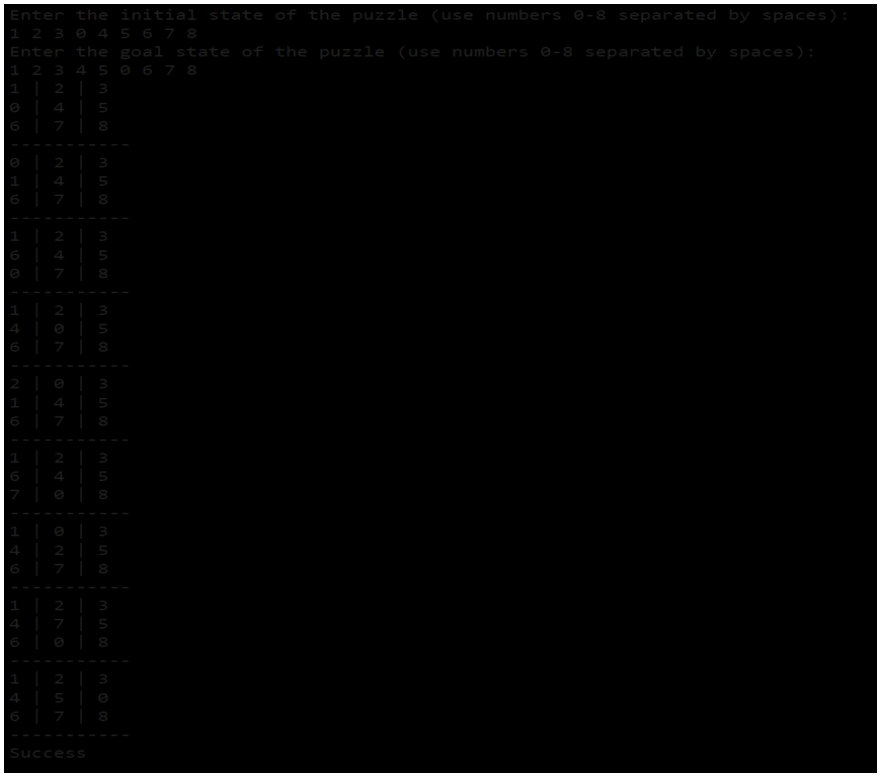
```
else:
    print ( cost)
    print ( "Location B is already clean.")
    if status_input_complement == '1':
        print ("Location A is Dirty")
        print ("Moving Left to Location A.")
        cost += 1
        print ("cost of moving left" + str(cost))
        goal_state['A'] = '0'
        cost += 1
        print ("cost for suck" + str(cost))
        print ("Location A has been
                                cleaned")
    else:
        print ("No action " + str(cost))
        print ("Location A is already clean")

print ("GOAL STATE: ")
print (goal_state)
print ("Performance Measurement: " +
                                str(cost))

Vacuum-world()
```

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

24/11/22

8 - puzzle problem using bfs

WEEK - 2

Source code :-

```
import numpy as np
import pandas as pd
import os

def bfs ( src, target ):
    queue = [ ]
    queue . append ( src )
    exp = [ ]
    while len ( queue ) > 0 :
        source = queue . pop ( 0 )
        exp . append ( source )
        print ( source )
        if source == target :
            print ("success")
            return
        poss_moves_to_do = [ ]
        poss_moves_to_do = possible_moves (source, exp)
        for move in poss_moves_to_do :
            if move not in exp and move
                not in queue :
                queue . append ( move ).
```

```
def possible_moves(state, visited_states):
    b = state.index(0)
    d = []
    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 [move_it_can for move_it_can
            in pos_moves_it_can if
            move_it_can not in
            visited_states]
```

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

src = [1, 2, 3, 0, 4, 5, 6, 7, 8]
target = [1, 2, 3, 4, 5, 0, 6, 7, 8]
bfs(src, target)

src = [1, 0, 3, 4, 2, 6, 7, 5, 8]
target = [1, 2, 3, 4, 5, 6, 7, 8, 0]
bfs(src, target)
```

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)
```

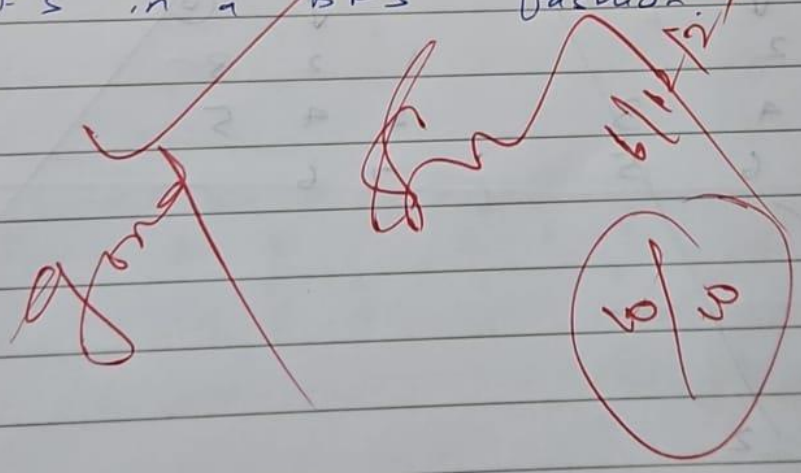
80

8 puzzle using Iterative Deepening DFS

IDDFS combines depth-first search's space-efficiency and breadth-first search's fast search (for nodes closer to root).

How does the IDDFS work?

IDDFS calls DFS for different depths starting from an initial values. In every call, DFS is restricted from going beyond a given depth. So basically, we do DFS in a BFS fashion.



5. Implement A* search algorithm

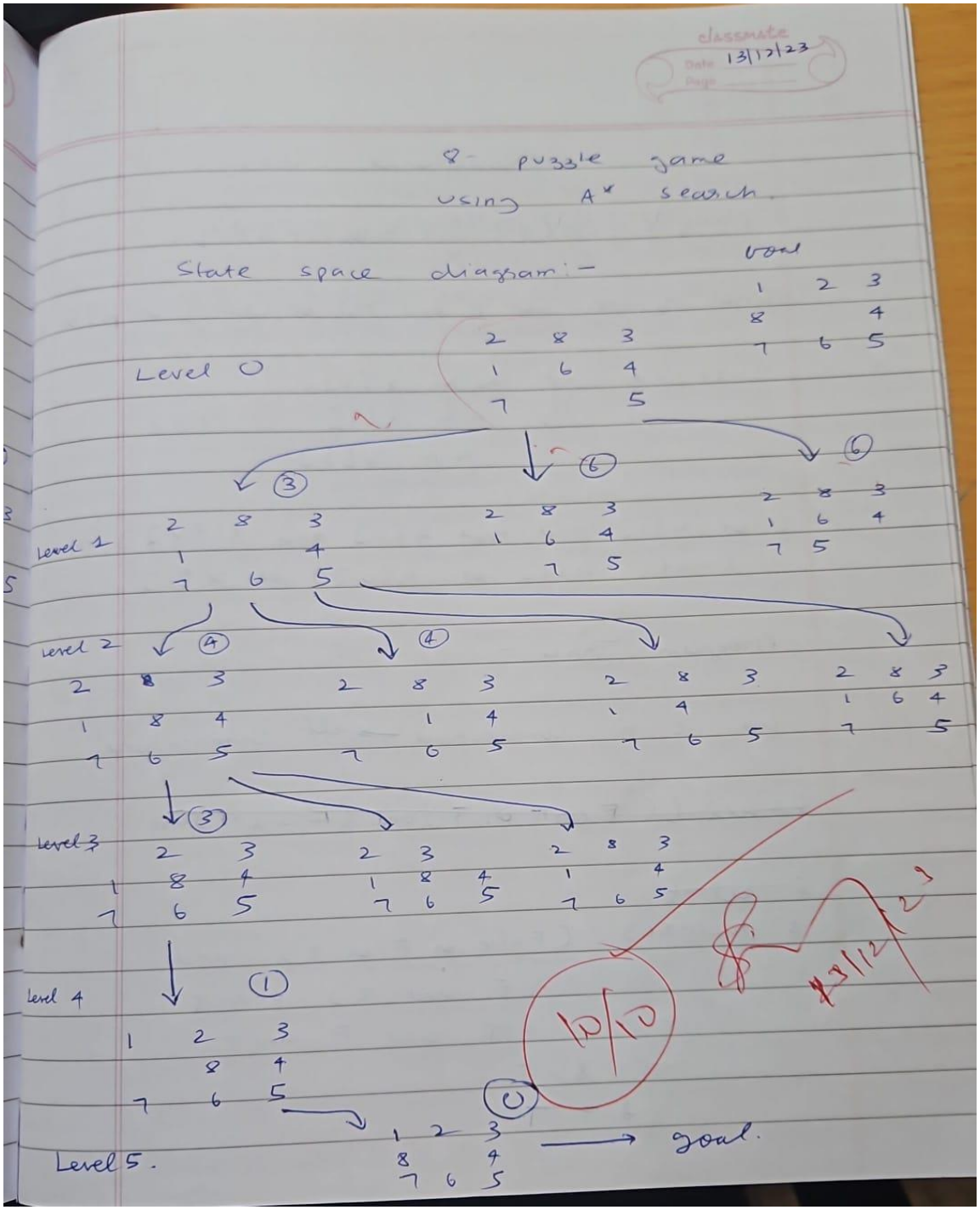
```
class Node:
    def __init__(self,data,level,fval):

        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 game
using A* search.
State space diagram:-
Goal
Level 0
Level 1
Level 2
Level 3
Level 4
Level 5.
goal.

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

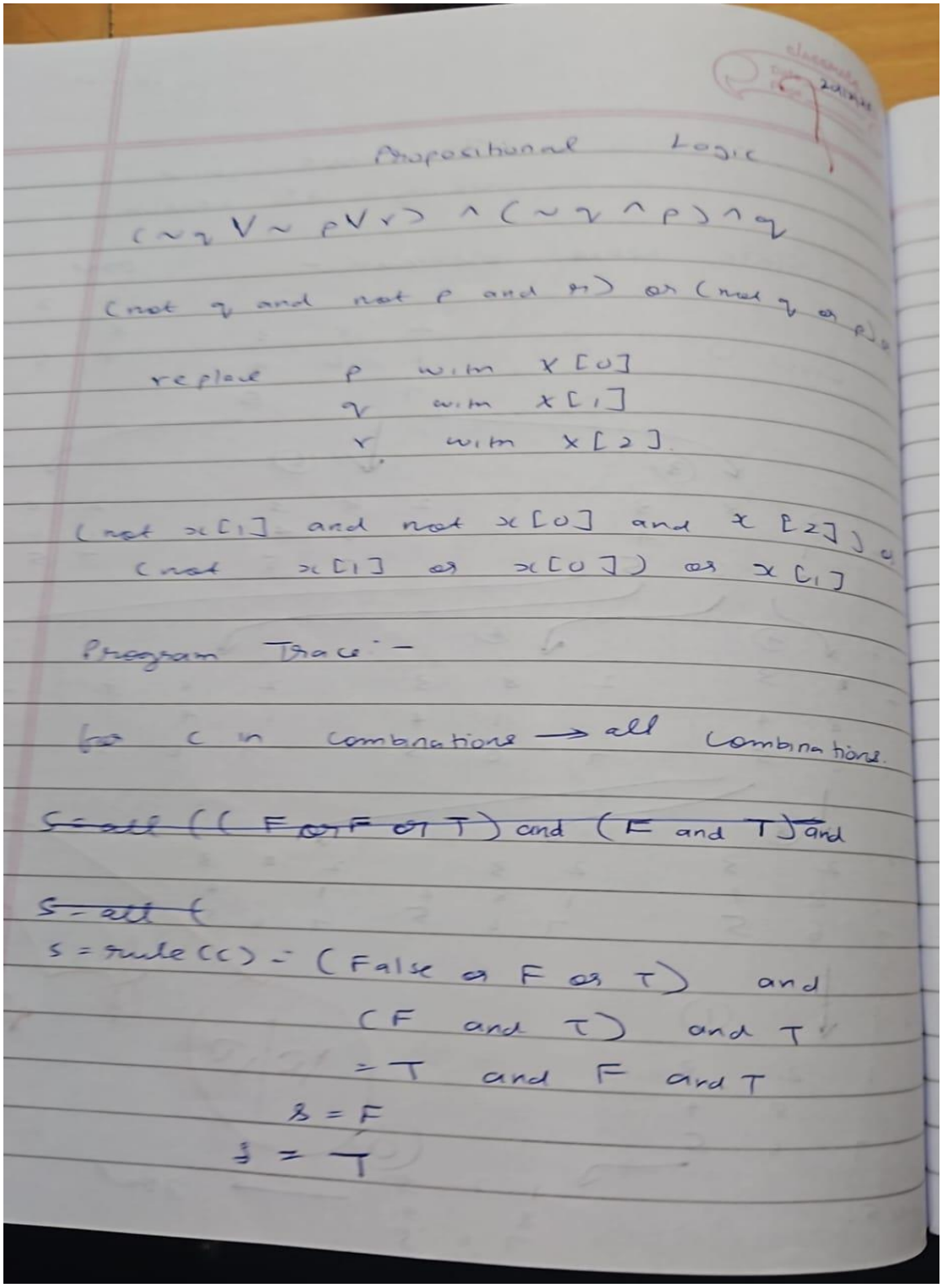
```
def tell(kb, rule):
    kb.append(rule)

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)
```

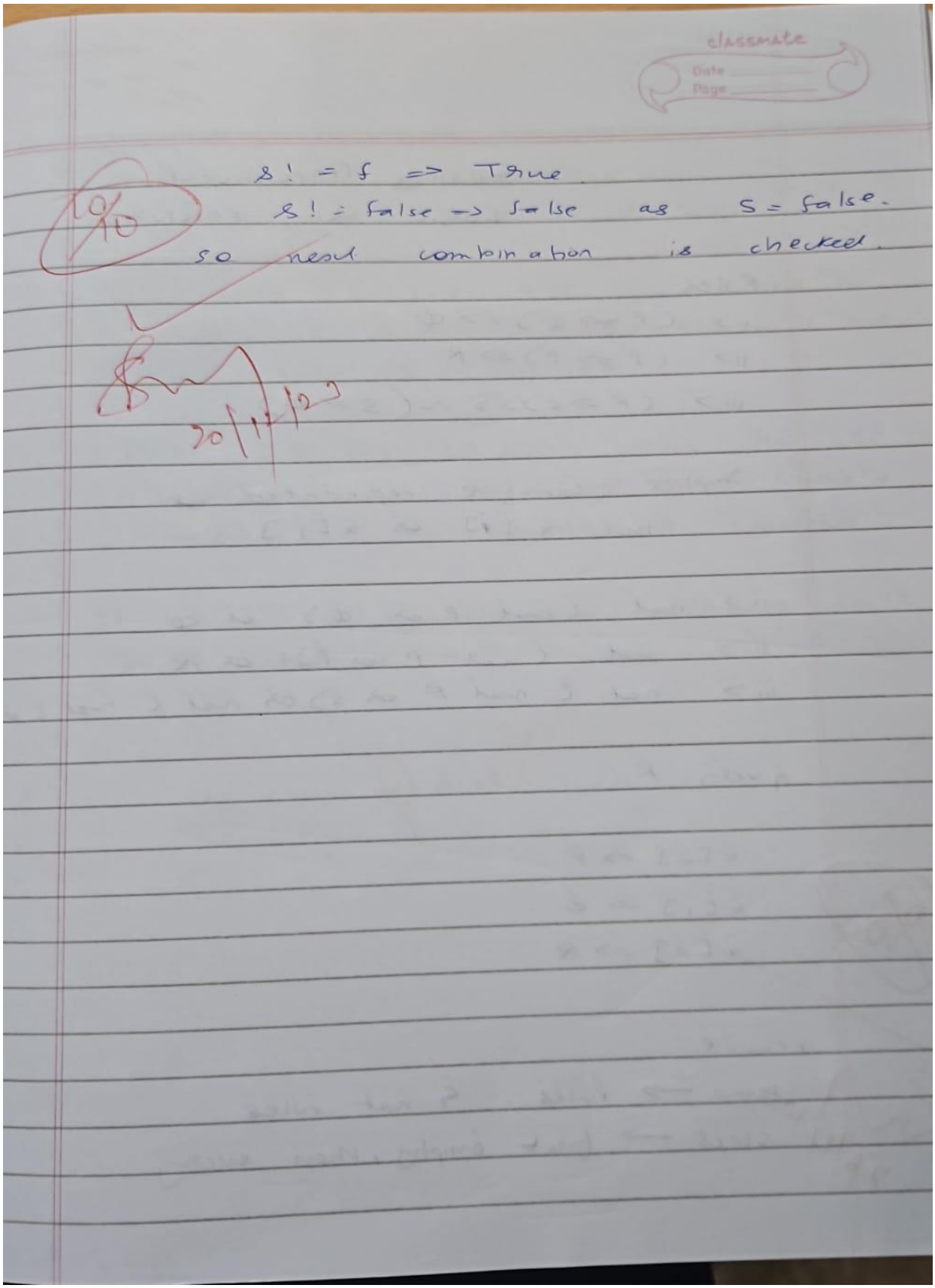
OUTPUT 1

```
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
```




classmate
Date
Page
s ! = f => True
s ! = false -> false as s = false.
so next combination is checked.
10/10
20/12/23

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.
```

Solving propositional Logic using Resolution

Rules

i) $(P \rightarrow Q) \Rightarrow Q$

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 or

query: R

x[0] => P

x[1] => Q

x[2] => R

10/10

resolve:

temp → rules & not rules

steps → first empty, then every

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')]
```

classmate
Date 10/1/23
Page

Unification
First order logic

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

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

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

10/1/24

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

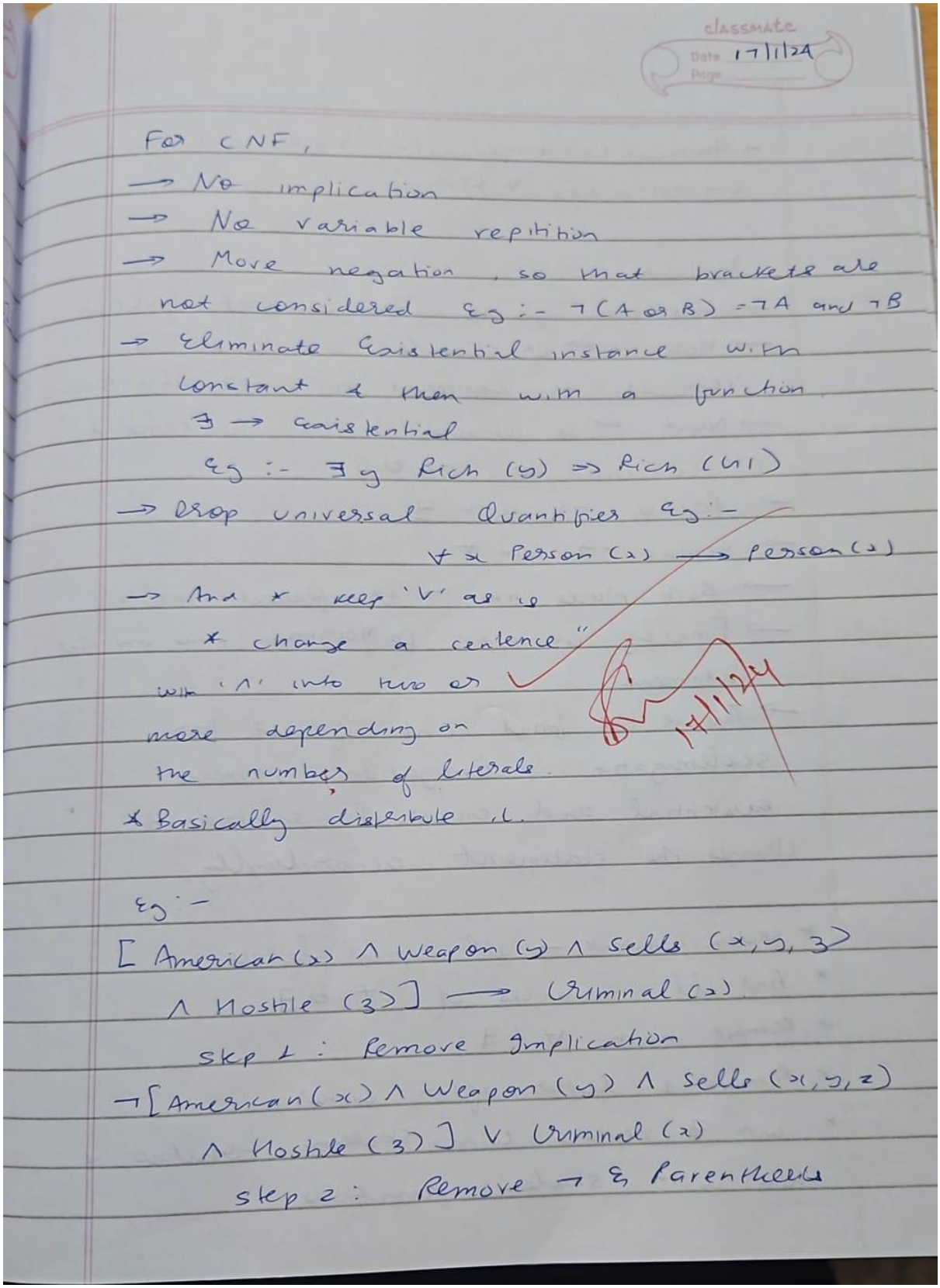
```
import re

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[love
s(z,x)]]")))
print(fol_to_cnf("[american(x)&weapon(y)&sells(x,y,z)&hostile(z)]=>crim
inal(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)
```


classmate
Date 17/11/24
Page
For CNF,
→ No implication
→ No variable repitition
→ Move negation, so that brackets are not considered Eg :- ¬(A or B) = ¬A and ¬B
→ Eliminate Existential instance with Constant & then with a function
∃ → Existential
Eg :- ∃y Rich(y) ⇒ Rich(H1)
→ Drop universal Quantifiers Eg :-
∀x Person(x) ⟶ person(x)
→ And x keep 'V' as is
* change a sentence with '∧' into two or more depending on the numbers of literals
* Basically distribute it.
Eg :-
[American(x) ∧ Weapon(y) ∧ Sells(x, y, z) ∧ Hostile(z)] ⟶ Criminal(x)
Skp 1 : Remove Implication
¬[American(x) ∧ Weapon(y) ∧ Sells(x, y, z) ∧ Hostile(z)] ∨ Criminal(x)
step 2 : Remove → & Parenthesis
17/11/24

→ American (x) ∨ Weapon (y) ∨ Sells (x, y, z)
∨ → Hostile (z) ∨ Criminal (x)

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 or B
→ Replace ¬∀ with ∃
→ Replace ¬∃ with ∀
→ Both places have ¬ transferred inside
→ Finally, we apply De Morgans Law on the statement
→ This is the final cnf if not for skolemization. Skolemization removes existential and universal 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

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)
```

prove the given query using forward reasoning.

1. is Variable (x):
   → Role:- Determines whether a given string represents a variable.
   → Purpose:- checks if the input string 'x' is a single lowercase alphabetical character.

2. get Attributes (string):
   → Role: Extracts attributes (arguments) from a string that represents a logical expression.
   → Purpose: Uses regular expressions to find substrings within parentheses in the given string and returns them.

3. get Predicates (string):
   → Role: Extracts predicates from a string that represents a L.F.
   → Purpose:- Uses regular expressions to find predicates (logical symbols) in the given string and returns them.