VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence

(22CS5PCAIN)

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
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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**" carried out by **Shikha Singh (1BM21CS202),** 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 June-2023 to Sep-2023. 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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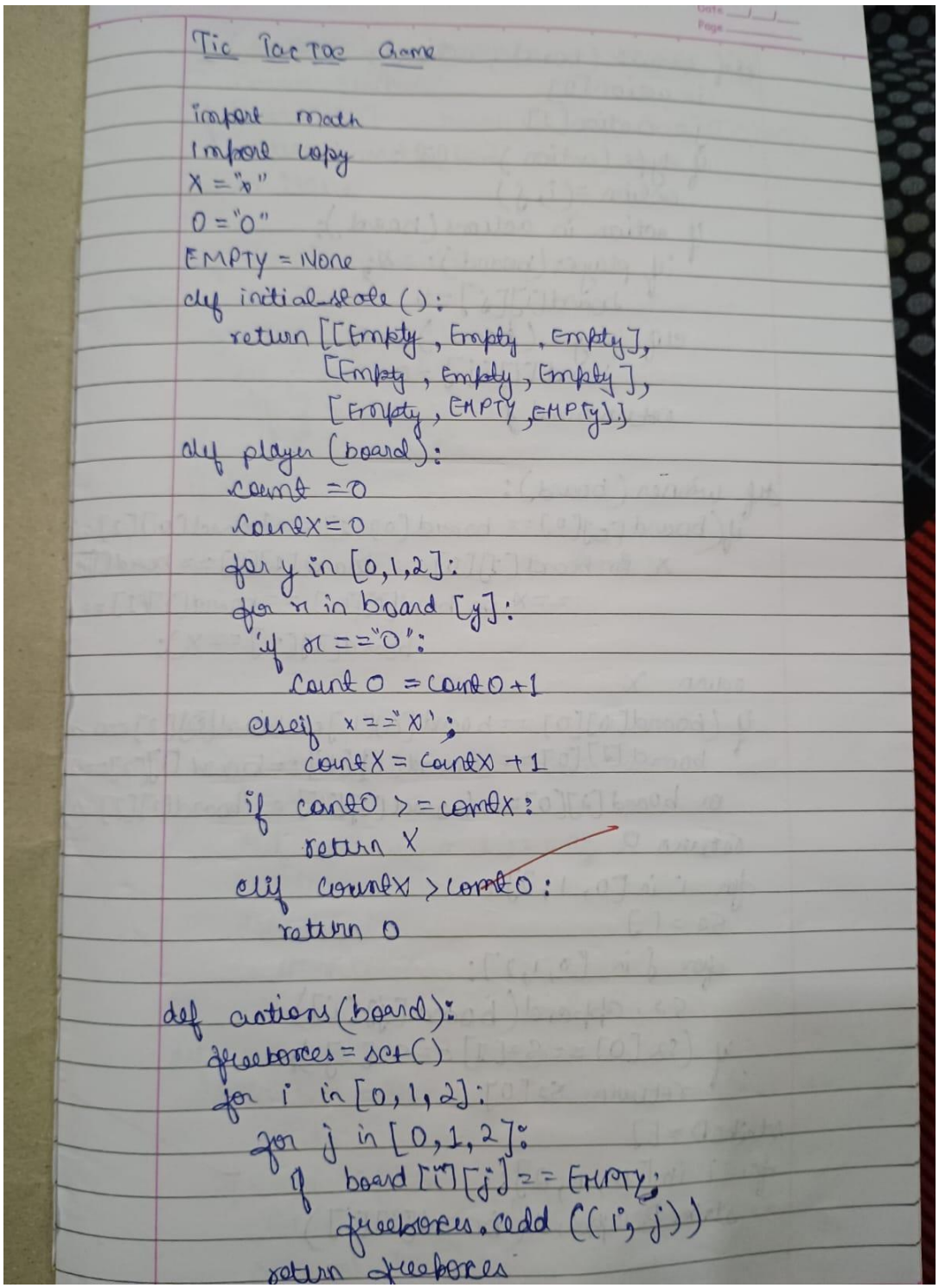
1. Tic Tac Toe



Tic Tac Toe Game

```
import math
import copy
X = "x"
O = "O"
EMPTY = None
def initial_state():
    return [[EMPTY, EMPTY, EMPTY],
            [EMPTY, EMPTY, EMPTY],
            [EMPTY, EMPTY, EMPTY]]
def player(board):
    count = 0
    countX = 0
    for y in [0,1,2]:
    for x in board[y]:
      if x == "O":
        countO = countO + 1
      elseif x == "X":
        countX = countX + 1
    if countO >= countX:
        return X
    elif countX > countO:
        return O

def actions(board):
    freeboxes = set()
    for i in [0,1,2]:
        for j in [0,1,2]:
            if board[i][j] == EMPTY:
                freeboxes.add((i,j))
    return freeboxes
```

```
def result(board, action):
    i = action[0]
    j = action[1]
    if type(action) == list:
        action = (i, j)
    if action in actions(board):
        if player(board) == X:
            board[i][j] = X
        elif player(board) == O:
            board[i][j] = O
    return board

def winner(board):
    if (board[0][0] == board[0][1] == board[0][2] ==
        X or board[1][0] == board[1][1] == board[1][2]
        == X or board[2][0] == board[2][1] ==
                board[2][2] == X):
        return X
    if (board[0][0] == board[0][1] == board[0][2] == O or
        board[1][0] == board[1][1] == board[1][2] == O
        or board[2][0] == board[2][1] == board[2][2] == O):
        return O
    for i in [0, 1, 2]:
        s2 = []
        for j in [0,1,2]:
            s2.append(board[j][i])
        if (s2[0] == s2[1] == s2[2]):
            return s2[0]
    strikeD = []
    for i in [0, 1, 2]:
        strikeD.append(board[i][i])
    if (strikeD[0] == strikeD[1] == strikeD[2]):
        return strikeD[0]
    if (board[0][2] == board[1][1] == board[2][0]):
        return board[2][2]
    return None

def terminal(board):
    Full = True
    for i in [0,1,2]:
        for j in board[i]:
            if j is None:
                Full = False
    if Full:
        return True
    if (winner(board) is not None):
        return True
    return False

def utility(board):
    if (winner(board) == X):
        return 1
    elif winner(board) == O:
        return -1
    else:
        return 0

def minimaxhelper(board):
    isMaxTurn = True if player(board) == X else
        False
    if terminal(board):
        return utility(board)
    scores = []
    for move in actions(board):
        result(board, move)
        scores.append(minimaxhelper(board))
        board[move[0]][move[1]] = EMPTY
    return max(scores) if isMaxTurn else
                min(scores)

def minimax(board):
    isMaxTurn = True if player(board) == X else False
    bestMove = None
    if isMaxTurn:
        bestScore = -math.inf
        for move in actions(board):
            result(board, move)
            score = minimaxhelper(board)
            board[move[0]][move[1]] = EMPTY
            if (score > bestScore):
                bestScore = score
                bestMove = move
    return bestMove
    else:
        bestScore = +math.inf
        for move in actions(board):
            result(board, move)
            score = minimaxhelper(board)
            board[move[0]][move[1]] = EMPTY
            if (score < bestScore):
                bestScore = score
                bestMove = move
        return bestMove

def print_board(board):
    for rows in board:
        print(rows)

game_board = initial_state()
print("Initial Board:")
print_board(game_board)
while not terminal(game_board):
    if player(game_board) == X:
        user_input = input("\n Enter your move(row,col):")
        row, col = map(int, user_input.split(','))
        result(game_board, (row, col))
    else:
        print("\n AI is making a move...")
        move = minimax(copy.deepcopy(game_board))
        result(game_board, move)
    print("\nCurrent Board:")
    print_board(game_board)
if winner(game_board) is not None:
    print(f"\n The winner is: {winner(game_board)}")
else:
    print("\n It's a tie!")
```

Output:

```
[1, 1]
[-1, -1, -1]
[1, 1]
[-1, -1, -1]
[1, 1]
```

Computer goes first, Good user positions are as follows

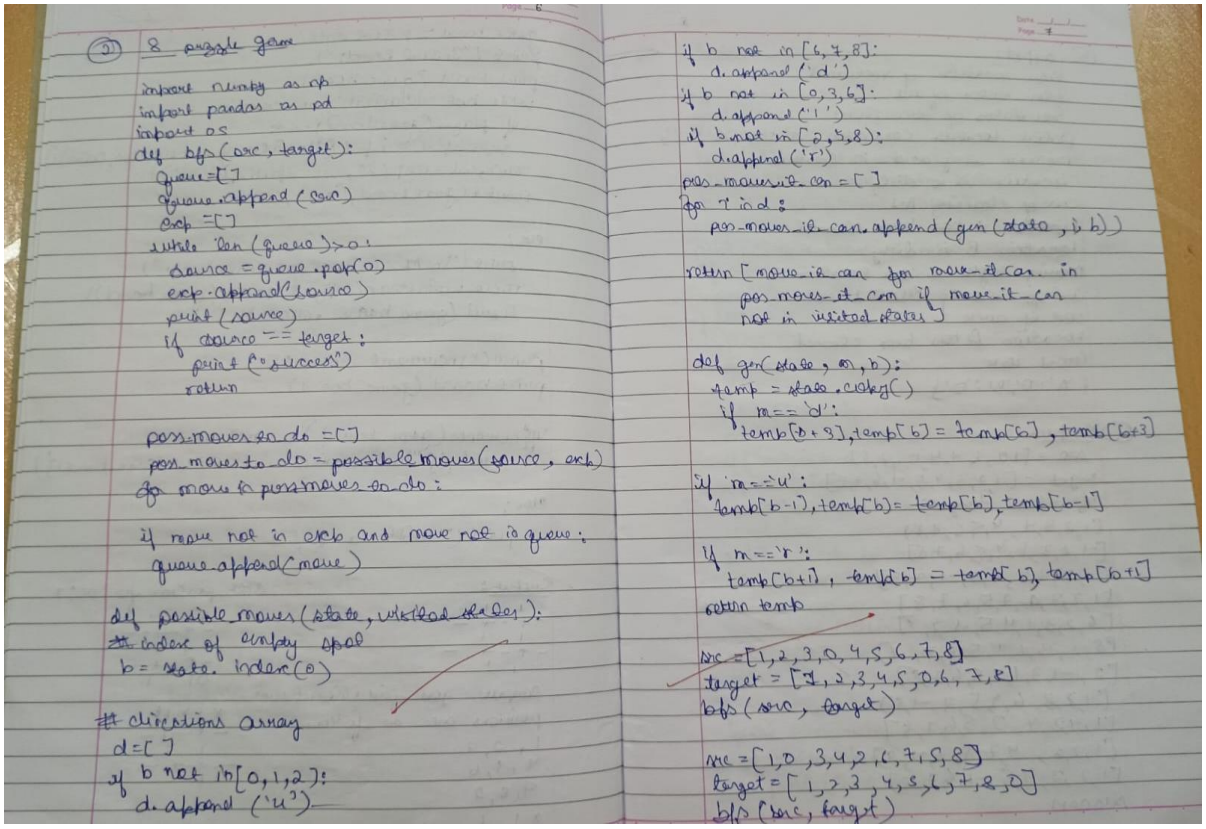
```
1, 2, 3
4, 5, 6
7, 8, 9
```

Enter position for 'O':7

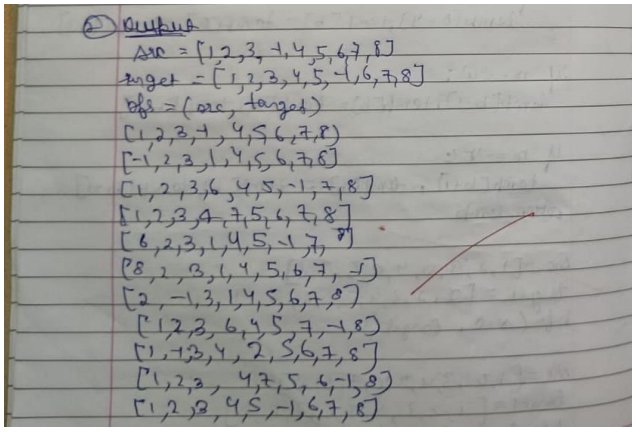
```
[X, 1, 1]
[-1, -1, -1]
[1, 1]
[-1, -1, -1]
[O, 1, 1]
```

```
[X, X, O]
[-1, -1, -1]
[1, 1]
[-1, -1, -1]
[O, 1, 1]
```

2. 8 Puzzle Breadth First Search Algorithm

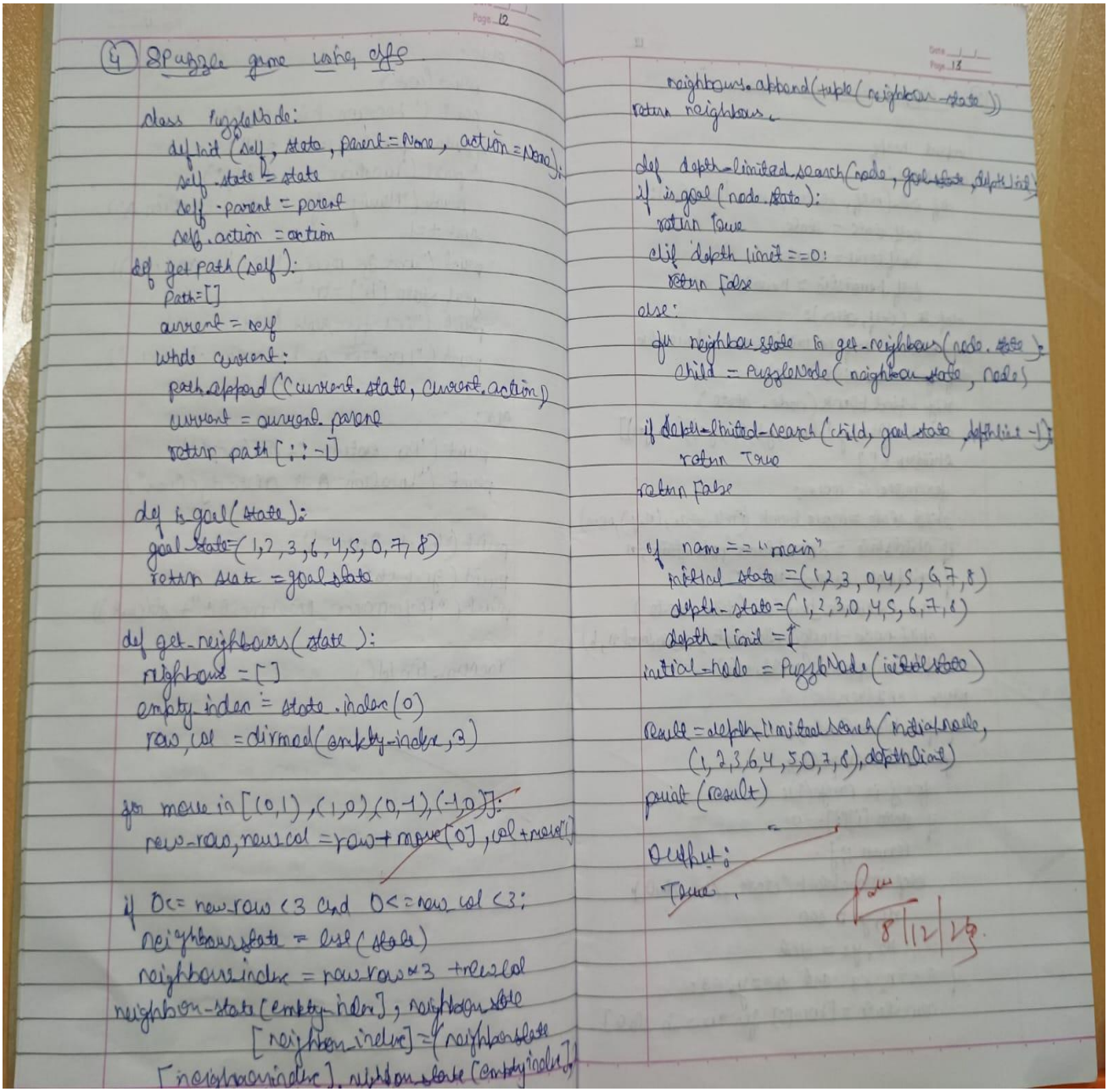


```
(2) 8 puzzle game

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):
    # index of empty spot
    b = state.index(0)

    # directions array
    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=='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)
```



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

3. 8 Puzzle Iterative Deepening Search Algorithm



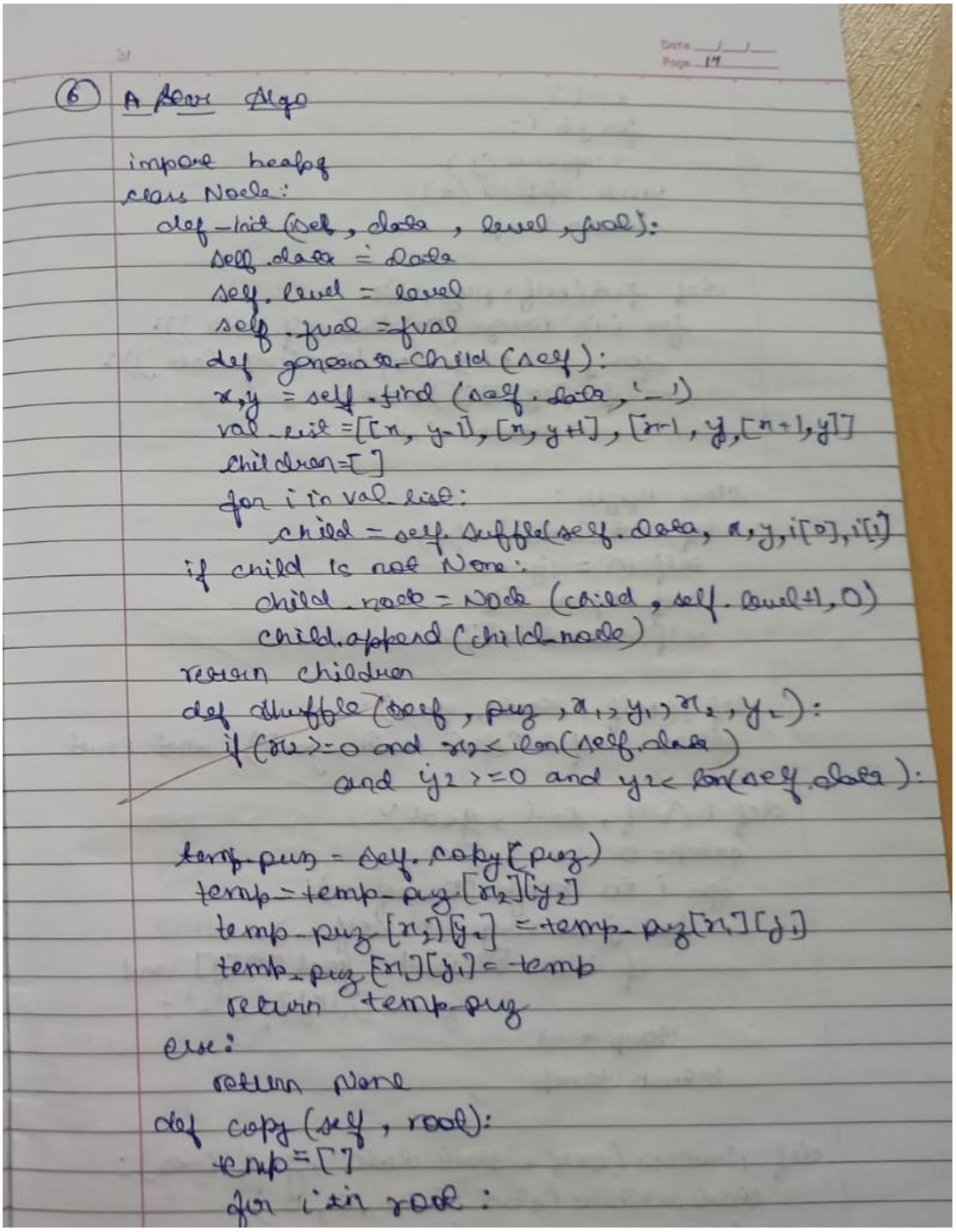
(4) 8 puzzle game using dfs

```
class PuzzleNode:
    def init(self, state, parent=None, action=None):
        self.state = state
        self.parent = parent
        self.action = action
def get_path(self):
    path=[]
    current = self
    while current:
        path.append((current.state, current.action))
        current = current.parent
    return path[::-1]

def is_goal(state):
    goal_state=(1,2,3,6,4,5,0,7,8)
    return state == goal_state

def get_neighbours(state):
    neighbours = []
    empty_index = state.index(0)
    row, col = divmod(empty_index, 3)

for move in [(0,1),(1,0),(0,-1),(-1,0)]:
    new_row, new_col = row + move[0], col + move[1]

if 0<= new_row < 3 and 0<= new_col <3:
    neighbour_state = list(state)
    neighbour_index = new_row * 3 + new_col
neighbour_state[empty_index], neighbour_state
                [neighbour_index] = neighbour_state
[neighbour_index], neighbour_state[empty_index]
    neighbours.append(tuple(neighbour_state))
return neighbours.

def depth_limited_search(node, goal_state, depth_limit):
if is_goal(node.state):
    return True
elif depth_limit == 0:
    return False
else:
    for neighbour_state in get_neighbours(node.state):
        child = PuzzleNode(neighbour_state, node)

    if depth_limited_search(child, goal_state, depth_limit-1):
        return True
return False

if name == "main"
    initial_state = (1,2,3,0,4,5,6,7,8)
    depth_state = (1,2,3,0,4,5,6,7,8)
    depth_limit = 1
initial_node = PuzzleNode(initial_state)

result = depth_limited_search(initial_node,
    (1,2,3,6,4,5,0,7,8), depth_limit)
print(result)
```

Output:

True.

4. 8 Puzzle A* Search Algorithm



```
(6) A* Algo

import heapq
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 = 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 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, start_data, goal_data):
        start = Node(start_data, 0, 0)
        start.fval = self.f(start, goal_data)
        self.open.append(start)
        print("\n\n")
        while True:
            cur = self.open[0]
            print("\n")
            for i in cur.data:
                for j in i:
                    print(j, end=" ")
                print("")
            if self.h(cur.data, goal_data) == 0:
                break
            for i in cur.generateChild():
                i.fval = self.f(i, goal_data)
                self.open.append(i)
            self.closed.append(cur)
            del self.open[0]
            self.open.sort(key=lambda x: x.fval,
                           reverse=False)

start_state = [[1, 2, 3], [_, 4, 6], [7, 5, 8]]
goal_state = [[1, 2, 3], [4, 5, 6], [7, 8, _]]
puz = Puzzle(3)
puz.process(start_state, goal_state)
```

Output:

```
1 2 3        1 2 3
_ 4 6        4 5 6
7 5 8        7 _ 8

1 2 3        1 2 3
4 _ 6        4 5 6
7 5 8        7 8 _
```

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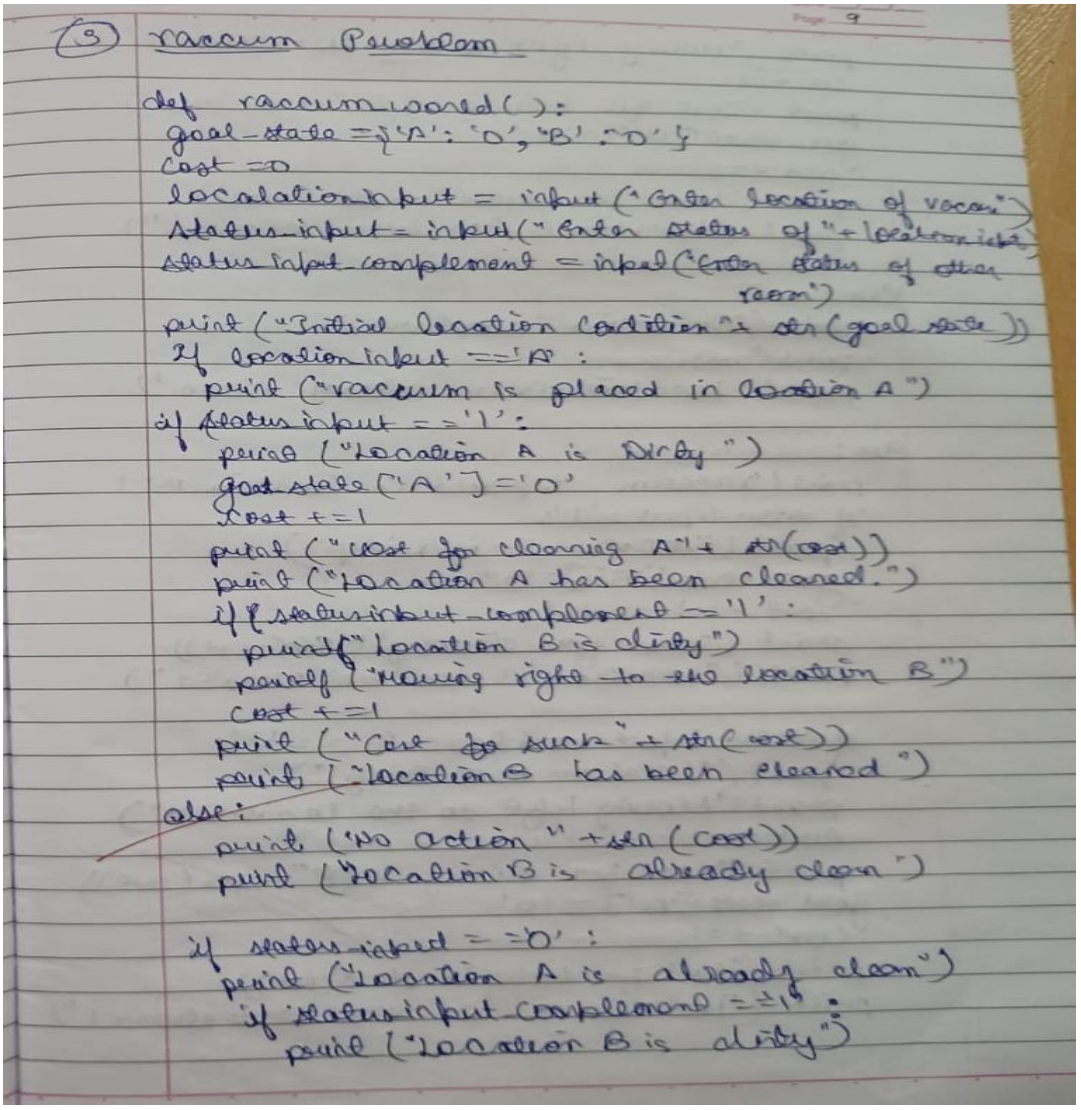
5. Vacuum Cleaner



(3) Vaccum Problem

```
def vaccum_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 for cleaning A" + str(cost))
    print("Location A has been cleaned.")
    if status_input_complement == '1':
        print("Location B is dirty")
        print("Moving right to the location B")
        cost += 1
        print("Cost for such" + str(cost))
        print("Location B has been cleaned")
else:
    print("No action" + str(cost))
    print("Location B is already clean")

if status_input == '0':
    print("Location A is already clean")
    if status_input_complement == '1':
        print("Location B is dirty")
```

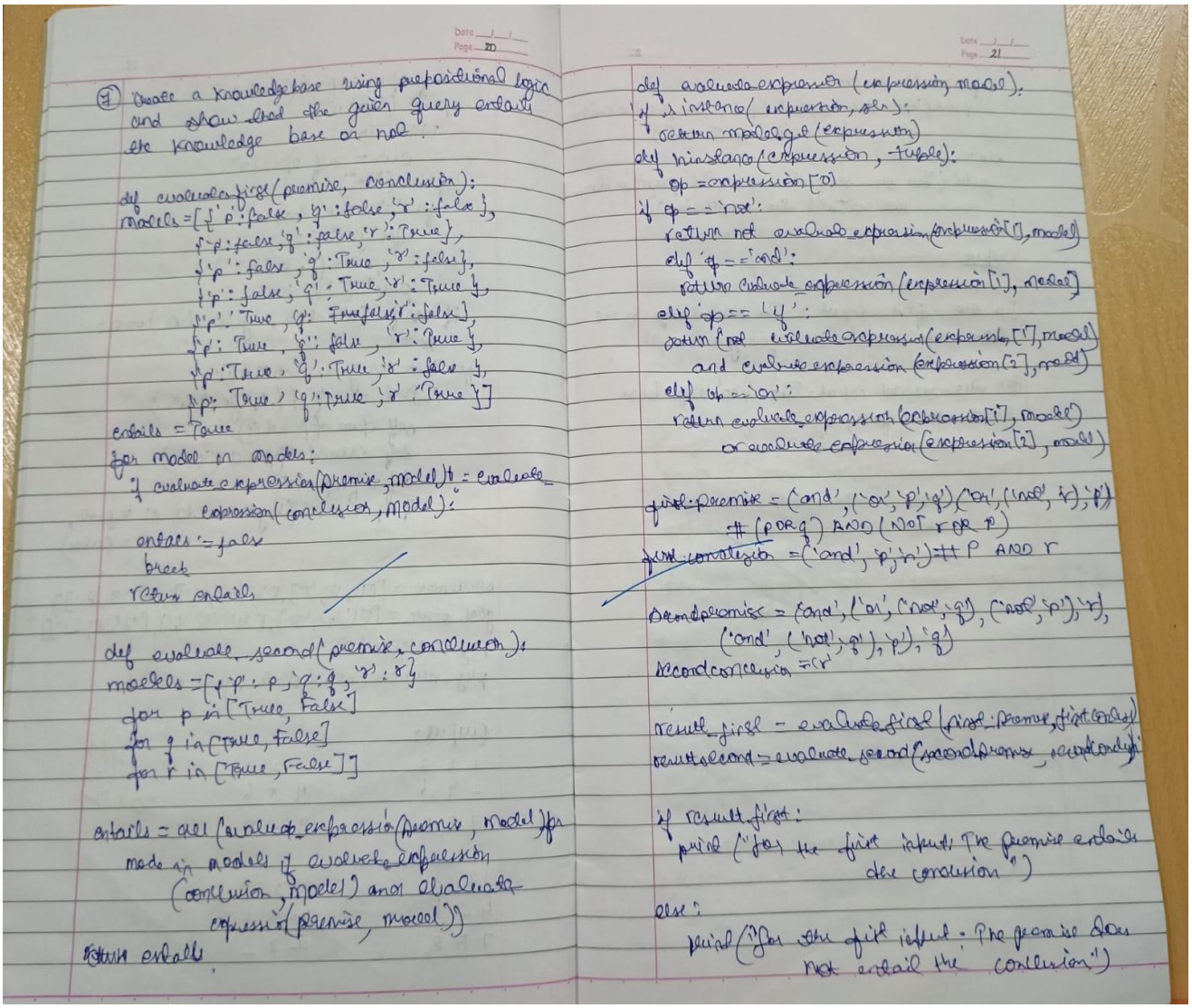
```
print ("Moving right to the location B")
cost +=1
print ("cost for moving right" + str(cost))
goal_state['B'] = '0'
cost +=1
print ("cost for suck" + str(cost))
print ("location B has been cleaned")

else:
print ("No action " + str(cost))
print(cost)
print("location B is already clean")

else:
print("Vacuum is placed in location B")
if status_input == '1':
    print ("location B is Dirty")
    goal_state['B'] = '0'
    cost +=1
    print ("cost for cleaning" + str(cost))
    print ("location B has be cleaned")

if status_input_complement == '1':
    print("location A is Dirty")
    print("Moving left to the location A")
    cost +=1
    print("cost for moving LEFT" + str(cost))
    goal_state['A'] = '0'
    cost +=1
    print("cost for suck" + str(cost))
    print("location A has been cleaned")
```

```
else:
    print(cost)
    print("location B is clean")
    if status_input_complement == '1':
        print("location A is Dirty")
        print("Moving left to the location A")
        cost +=1
        print("cost for moving LEFT" + str(cost))
        goal_state['A'] = '0'
        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()
```

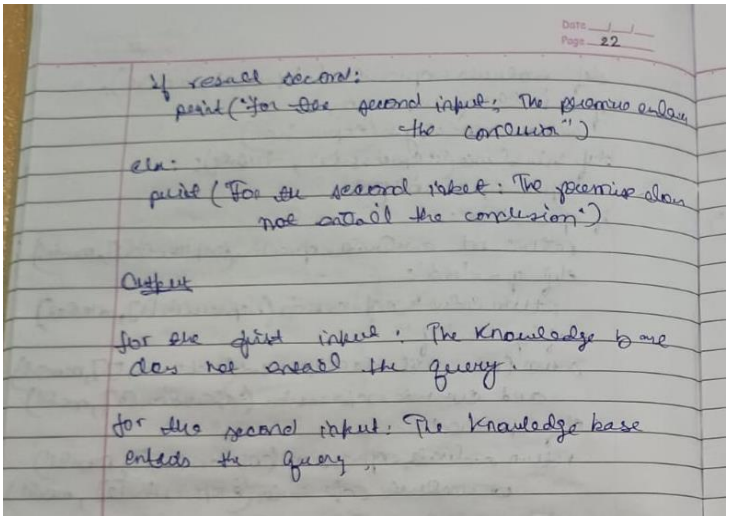
(3) output:

```
Enter location of vacuum A
enter status of A
Enter status of other rooms
Initial location condition {'A':'0','B':'0'}
vacuum is placed in location A
location A is dirty
cost of cleaning A 1
Location A has been cleaned
location B is dirty
moving right to the location B
cost for moving RIGHT 2
cost of suck 3
Location B has been cleaned
Goal state
{'A':'0','B':'0'}
```

6. Knowledge Base Entailment



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

def evaluate_first(premise, conclusion):
models = [{'p': false, 'q': false, 'r': false},
          {'p': false, 'q': false, 'r': True},
          {'p': false, 'q': True, 'r': false},
          {'p': false, 'q': True, 'r': True},
          {'p': True, 'q': false, 'r': false},
          {'p': True, 'q': false, 'r': True},
          {'p': True, 'q': True, 'r': false},
          {'p': True, 'q': True, 'r': True}]
entails = True
for model in models:
    if evaluate_expression(premise, model) != evaluate_expression(conclusion, model):
        entails = false
        break
return entails

def evaluate_second(premise, conclusion):
models = [{'p': p, 'q': q, 'r': r}
    for p in [True, False]
    for q in [True, False]
    for r in [True, False]]

entails = all(evaluate_expression(premise, model) for model in models if evaluate_expression(conclusion, model) and evaluate_expression(premise, model))
return entails

def evaluate_expression(expression, model):
if isinstance(expression, str):
    return model.get(expression)
def isinstance(expression, tuple):
    op = expression[0]
if op == 'not':
    return not evaluate_expression(expression[1], model)
elif op == 'and':
    return evaluate_expression(expression[1], model)
elif op == 'if':
    return (not evaluate_expression(expression[1], model)
        and evaluate_expression(expression[2], model))
elif op == 'or':
    return evaluate_expression(expression[1], model)
        or evaluate_expression(expression[2], model)

first_premise = ('and', ('or', 'p', 'q'), ('or', ('not', 'r'), 'p'))
    # (p OR q) AND (NOT r OR p)
first_conclusion = ('and', 'p', 'r') # p AND r

second_premise = ('and', ('or', ('not', 'q'), ('not', 'p')), 'r'),
        ('and', ('not', 'q'), 'p'), 'q')
second_conclusion = 'r'

result_first = evaluate_first(first_premise, first_conclusion)
result_second = evaluate_second(second_premise, second_conclusion)

if result_first:
    print("for the first input, The premise entails the conclusion")
else:
    print("for the first input, The premise does not entail the conclusion")
```



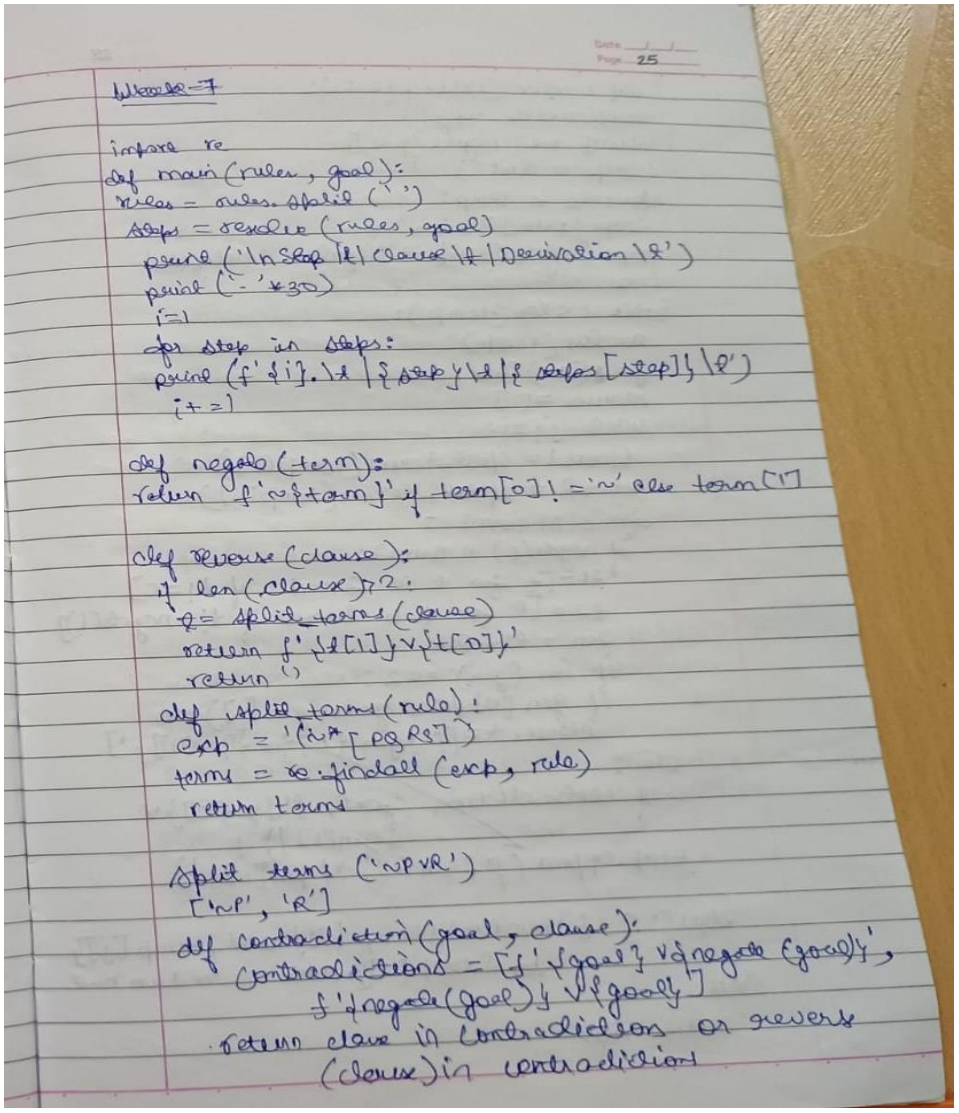
```
if result_second:
    print("for the second input, The premise entails the conclusion")
else:
    print("for the second input, The premise does not entail the conclusion")
```

Output

for the first input, The Knowledge base does not entail the query.

for the second input, The Knowledge base entails the query.
```
```

7. Knowledge Base Resolution



```
Program-7

import re
def main(rules, 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 reverse(clause):
if len(clause)>2:
t= split_terms(clause)
return f'{t[1]}v{t[0]}'
return ''
def split_terms(rule):
exp = '(~*[PQRS])'
terms = re.findall(exp, rule)
return terms

Split terms ('~PvR')
['~P', 'R']
def contradiction(goal, clause):
contradictions = [f'{goal}v{negate(goal)}',
f'{negate(goal)}v{goal}']
return clause in contradictions or reverse
(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]}']
                    else:
                        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'
                            return steps
            for clause in clauses:
                if clause not in temp and clause != Rev(clause) and reverse(clause) not in temp:
                    temp.append(clause)
                    steps[clause] = f'Resolved {temp[i]} and {temp[j]} to {temp[-1]}'
            j = (j+1) % n
        i += 1
    return steps
```

```
rules = 'RV~P RV~Q, ~RVP ~QVR' #(P=>Q)^(Q=>R):
    (RV~P)^(RV~Q)^(~PVR)^(~QVR)
goal = 'R'
main(rules, goal)
rules = 'PVQ ~PVR ~QVR' #P=>Q, Q=>R, ~R:
    PVQ, Q=>R, ~R
goal = 'R'
main(rules, goal)
rules = 'PVQ PVR ~PVR ~QVR RV~Q ~PV~Q
    #(P=>Q)=>Q, (P=>R)=>R, (R=>Q)=>~(Q=
main(rules, 'R')
```

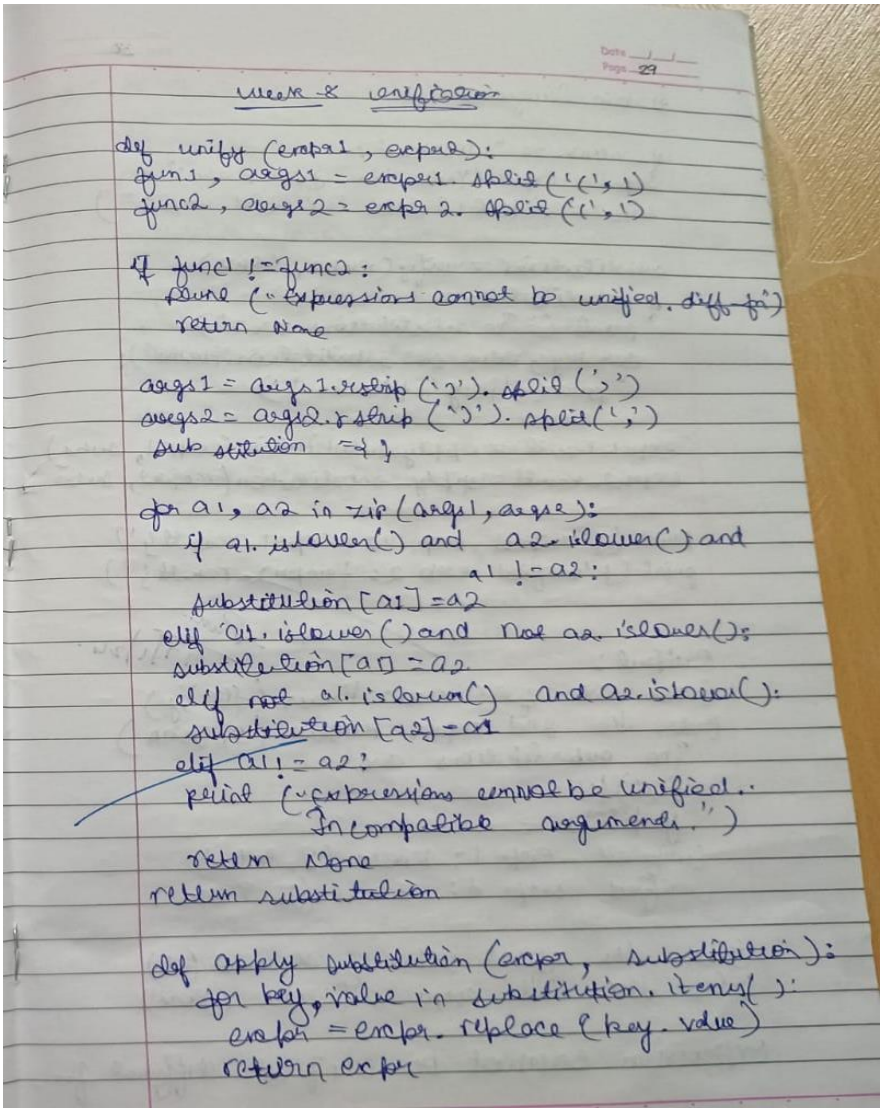
Output:

Step	Clause	Derivation
1.	RV~P	Given
2.	RV~Q	Given
3.	~RVP	Given
4.	~RV~Q	Given
5.	~R	Negated Conclusion

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.

8. Unification



```
Date
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Week 8 unification

def unify(expr1, expr2):
    fun1, args1 = expr1.split('(', 1)
    fun2, args2 = expr2.split('(', 1)

    if fun1 != fun2:
        print("Expressions cannot be unified. Different functions.")
        return None

    args1 = args1.rstrip(')').split(',')
    args2 = args2.rstrip(')').split(',')
    substitution = {}

    for a1, a2 in zip(args1, args2):
        if a1.islower() and a2.islower() and
                                    a1 != a2:
            substitution[a1] = a2
        elif a1.islower() and not a2.islower():
            substitution[a1] = a2
        elif not a1.islower() and a2.islower():
            substitution[a2] = a1
        elif a1 != a2:
            print("Expressions cannot be unified.
                    Incompatible arguments.")
            return None
    return substitution

def apply_substitution(expr, substitution):
    for key, value in substitution.items():
        expr = expr.replace(key, value)
    return expr
```

Date / /
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Main Program

```
if __name__ == "__main__":
    expr1 = input("Enter the first expr:")
    expr2 = input("Enter the 2nd expr:")

    substitution = unify(expr1, expr2)
    if substitution:
        print("The substitutions are:")
        for key, value in substitution.items():
            print(f'{key} | {value}')

    expr1_result = apply_substitution(expr1, subs)
    expr2_result = apply_substitution(expr2, subs)

    print(f'Unified exp 1: {expr1_result}')
    print(f'Unified exp 2: {expr2_result}')
```

Pass
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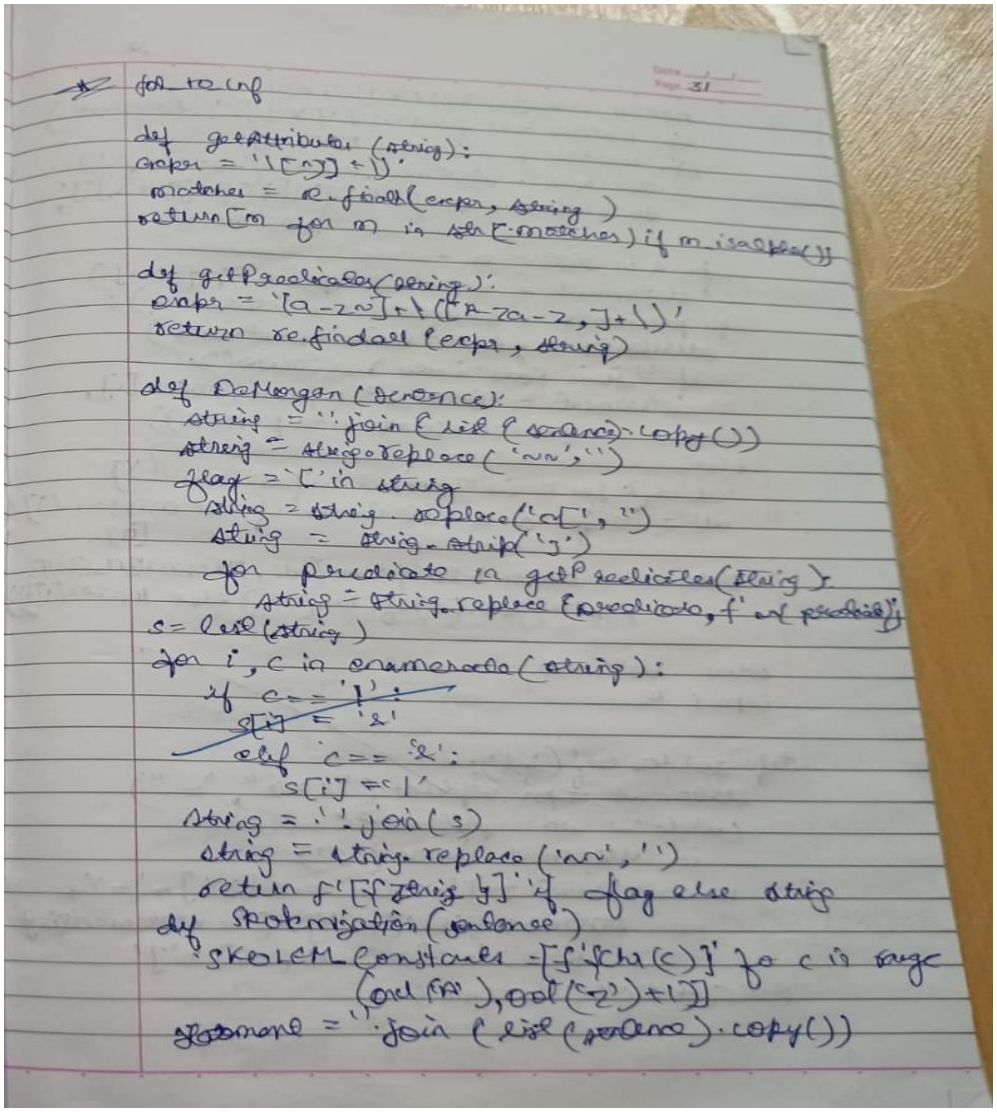
Output:

Enter the first expr: knows(f(x),y)
Enter the 2nd expr: knows(J, John)
The substitutions are
f(x) | J
y | John
Unified exp 1: knows(J, John)
Unified exp 2: knows(J, John)

Enter the first expr: student(x)
Enter the 2nd expr: teacher(Rose)

Expression cannot be unified. Different fn.

9. FOL to CNF



```
FOL to CNF

def getAttributes(string):
    expr = '([a-zA-Z]+\([A-Za-z,]+\))'
    matches = re.findall(expr, string)
    return [m for m in str[:matches] if m.isalpha()]

def getPredicates(string):
    expr = '[a-zA-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())
```

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```
matches = re.findall('[∀∃].', statement)
for 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.lower()]
    aU = [a for a in attributes if not a.islower()]
                                            [0].
statement = statement.replace(aU, f'{SKOLEM_CONST.
        pop(0)}({aL[0] if len(aL) else match[1]})')

return statement
import re

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
```

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```
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:
    ~~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, DeMorgan(s))
```

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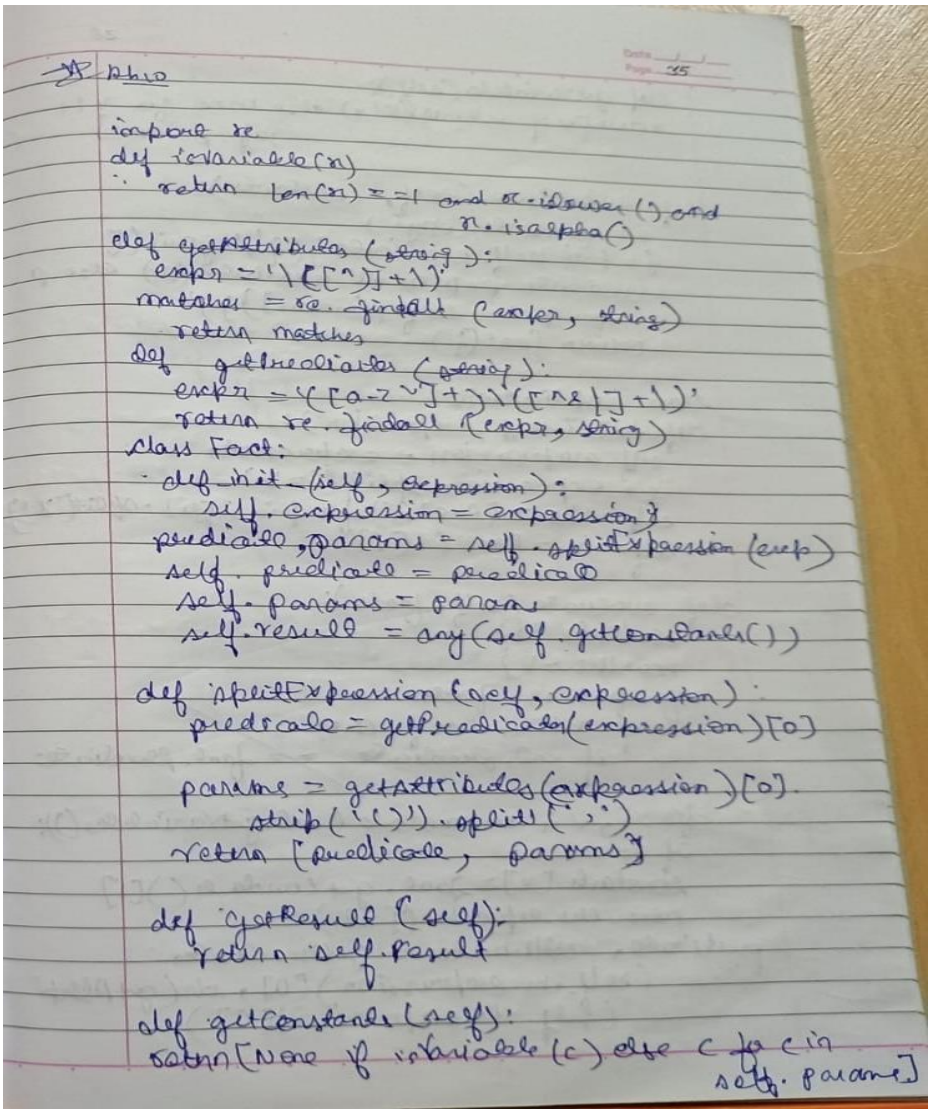
```
return statement
print(skolemization(fol_to_cnf("∀x food(x)
            => likes(John, x)")))
print(skolemization(fol_to_cnf("~∀x[∃z
            [loves(x, z)]]")))
print(fol_to_cnf("[american(x) & weapon(y)
            & sells(x,y,z) & hostile(z)]
            => criminal(x)"))
```

Output:

```
~food(A) | likes(John, A)
[loves(x, B(x)))
[~american(x) | ~weapon(y) | ~sells(x,y,z)
    | ~hostile(z)] | criminal(x)
```

10. Forward reasoning



```
Ans

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(exp)
    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]

def substitute(self, constants):
    c = constants.copy()
    f = f"{self.predicate}({','.join([
        constants.pop(0) if isVariable(p) else p
        for p in self.params])})"
    return Fact(f)

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:
        if hl 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('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()
kb = KB()
kb.tell('king(x) & greedy(x) => evil(x)')
kb.tell('king(John)')
kb.tell('greedy(John)')
kb.tell('king(Richard)')
kb.query('evil(x)')
```

Output:

```
Query: criminal(x):
    criminal(West)

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

25/11/24

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
import copy

X = "X"
O = "O"
EMPTY = None

def initial_state():
    return [[EMPTY, EMPTY, EMPTY],
            [EMPTY, EMPTY, EMPTY],
            [EMPTY, EMPTY, EMPTY]]

def player(board):
    countO = 0
    countX = 0
    for y in [0, 1, 2]:
        for x in board[y]:
            if x == "O":
                countO = countO + 1
            elif x == "X":
                countX = countX + 1
    if countO >= countX:
        return X
    elif countX > countO:
        return O


def actions(board):
```

```
    freeboxes = set()
    for i in [0, 1, 2]:
        for j in [0, 1, 2]:
            if board[i][j] == EMPTY:
                freeboxes.add((i, j))
    return freeboxes


def result(board, action):
    i = action[0]
    j = action[1]
    if type(action) == list:
        action = (i, j)
    if action in actions(board):
        if player(board) == X:
            board[i][j] = X
        elif player(board) == O:
            board[i][j] = O
    return board


def winner(board):
    if (board[0][0] == board[0][1] == board[0][2] == X or board[1][0] == board[1][1] ==
board[1][2] == X or board[2][0] == board[2][1] == board[2][2] == X):
        return X
    if (board[0][0] == board[0][1] == board[0][2] == O or board[1][0] == board[1][1] ==
board[1][2] == O or board[2][0] == board[2][1] == board[2][2] == O):
        return O
    for i in [0, 1, 2]:
        s2 = []
        for j in [0, 1, 2]:
```

```
            s2.append(board[j][i])
        if (s2[0] == s2[1] == s2[2]):
            return s2[0]
    strikeD = []
    for i in [0, 1, 2]:
        strikeD.append(board[i][i])
    if (strikeD[0] == strikeD[1] == strikeD[2]):
        return strikeD[0]
    if (board[0][2] == board[1][1] == board[2][0]):
        return board[0][2]
    return None


def terminal(board):
    Full = True
    for i in [0, 1, 2]:
        for j in board[i]:
            if j is None:
                Full = False
    if Full:
        return True
    if (winner(board) is not None):
        return True
    return False


def utility(board):
    if (winner(board) == X):
        return 1
    elif winner(board) == O:
```

```
        return -1
    else:
        return 0


def minimax_helper(board):
    isMaxTurn = True if player(board) == X else False
    if terminal(board):
        return utility(board)

    scores = []
    for move in actions(board):
        result(board, move)
        scores.append(minimax_helper(board))
        board[move[0]][move[1]] = EMPTY
    return max(scores) if isMaxTurn else min(scores)


def minimax(board):
    isMaxTurn = True if player(board) == X else False
    bestMove = None
    if  isMaxTurn:
        bestScore = -math.inf
        for move in actions(board):
            result(board, move)
            score = minimax_helper(board)
            board[move[0]][move[1]] = EMPTY
            if (score > bestScore):
                bestScore = score
                bestMove = move
```

```
        return bestMove
    else:
        bestScore = +math.inf
        for move in actions(board):
            result(board, move)
            score = minimax_helper(board)
            board[move[0]][move[1]] = EMPTY
            if (score < bestScore):
                bestScore = score
                bestMove = move
        return bestMove


def print_board(board):
    for row in board:
        print(row)


# Example usage:
game_board = initial_state()
print("Initial Board:")
print_board(game_board)

while not terminal(game_board):
    if player(game_board) == X:
        user_input = input("\nEnter your move (row, column): ")
        row, col = map(int, user_input.split(','))
        result(game_board, (row, col))
    else:
        print("\nAI is making a move...")
```

```
        move = minimax(copy.deepcopy(game_board))
        result(game_board, move)

    print("\nCurrent Board:")
    print_board(game_board)

# Determine the winner
if winner(game_board) is not None:
    print(f"\nThe winner is: {winner(game_board)}")
else:
    print("\nIt's a tie!")
```

OUTPUT:

```
Initial Board:
[None, None, None]
[None, None, None]
[None, None, None]

Enter your move (row, column): 1,2

Current Board:
[None, None, None]
[None, None, 'X']
[None, None, None]

AI is making a move...

Current Board:
[None, None, None]
[None, 'O', 'X']
[None, None, None]

Enter your move (row, column): 0,0

Current Board:
['X', None, None]
[None, 'O', 'X']
[None, None, None]

AI is making a move...

Current Board:
['X', 'O', None]
[None, 'O', 'X']
[None, None, None]

Enter your move (row, column): 2,1
```

```
Current Board:
['X', 'O', None]
[None, 'O', 'X']
[None, 'X', None]

AI is making a move...

Current Board:
['X', 'O', None]
[None, 'O', 'X']
['O', 'X', None]

Enter your move (row, column): 1,0

Current Board:
['X', 'O', None]
['X', 'O', 'X']
['O', 'X', None]

AI is making a move...

Current Board:
['X', 'O', 'O']
['X', 'O', 'X']
['O', 'X', None]

The winner is: O
```

2. Solve 8 puzzle problems.

```
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):
    #index of empty spot
    b = state.index(0)

    #directions array
```

```
    d = []
    #Add all the possible directions

    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')



    # If direction is possible then add state to move
    pos_moves_it_can = []

    # for all possible directions find the state if that move is played
    ### Jump to gen function to generate all possible moves in the given directions

    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 new state with tested move to later check if "src == target"
    return temp

print("Example 1")
src= [2,0,3,1,8,4,7,6,5]
target=[1,2,3,8,0,4,7,6,5]
print("Source: " , src)
print("Goal State: " , target)
bfs(src, target)

print("\nExample 2")
src = [1,2,3,0,4,5,6,7,8]
target = [1,2,3,4,5,0,6,7,8]
print("Source: " , src)
print("Goal State: " , target)
bfs(src, target)
```

OUTPUT:

```
Example 1
Source:  [2, 0, 3, 1, 8, 4, 7, 6, 5]
Goal State:  [1, 2, 3, 8, 0, 4, 7, 6, 5]
[2, 0, 3, 1, 8, 4, 7, 6, 5]
[2, 8, 3, 1, 0, 4, 7, 6, 5]
[0, 2, 3, 1, 8, 4, 7, 6, 5]
[2, 3, 0, 1, 8, 4, 7, 6, 5]
[2, 8, 3, 1, 6, 4, 7, 0, 5]
[2, 8, 3, 0, 1, 4, 7, 6, 5]
[2, 8, 3, 1, 4, 0, 7, 6, 5]
[1, 2, 3, 0, 8, 4, 7, 6, 5]
[2, 3, 4, 1, 8, 0, 7, 6, 5]
[2, 8, 3, 1, 6, 4, 0, 7, 5]
[2, 8, 3, 1, 6, 4, 7, 5, 0]
[0, 8, 3, 2, 1, 4, 7, 6, 5]
[2, 8, 3, 7, 1, 4, 0, 6, 5]
[2, 8, 0, 1, 4, 3, 7, 6, 5]
[2, 8, 3, 1, 4, 5, 7, 6, 0]
[1, 2, 3, 7, 8, 4, 0, 6, 5]
[1, 2, 3, 8, 0, 4, 7, 6, 5]
Success

Example 2
Source:  [1, 2, 3, 0, 4, 5, 6, 7, 8]
Goal State:  [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
```

3. Implement Iterative deepening search algorithm.

```
def iterative_deepening_search(src, target):
    depth_limit = 0
    while True:
        result = depth_limited_search(src, target, depth_limit, [])
        if result is not None:
            print("Success")
            return
        depth_limit += 1
        if depth_limit > 30: # Set a reasonable depth limit to avoid an infinite loop
            print("Solution not found within depth limit.")
            return

def depth_limited_search(src, target, depth_limit, visited_states):
    if src == target:
        print_state(src)
        return src

    if depth_limit == 0:
        return None

    visited_states.append(src)
    poss_moves_to_do = possible_moves(src, visited_states)

    for move in poss_moves_to_do:
        if move not in visited_states:
            print_state(move)
            result = depth_limited_search(move, target, depth_limit - 1, visited_states)
            if result is not None:
```

```
            return result

    return None

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]
    elif m == 'u':
```

```
        temp[b - 3], temp[b] = temp[b], temp[b - 3]
    elif m == 'l':
        temp[b - 1], temp[b] = temp[b], temp[b - 1]
    elif m == 'r':
        temp[b + 1], temp[b] = temp[b], temp[b + 1]

    return temp

def print_state(state):
    print(f"{state[0]} {state[1]} {state[2]}\n{state[3]} {state[4]} {state[5]}\n{state[6]} {state[7]} {state[8]}\n")

print("Example 1")
src = [1,2,3,0,4,5,6,7,8]
target = [1,2,3,4,5,0,6,7,8]
print("Source: " , src)
print("Goal State: " , target)
iterative_deepening_search(src, target)
```

OUTPUT:

```
Example 1
Source:  [1, 2, 3, 0, 4, 5, 6, 7, 8]
Goal State:  [1, 2, 3, 4, 5, 0, 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

0 2 3
1 4 5
6 7 8

2 0 3
1 4 5
6 7 8

1 2 3
6 4 5
0 7 8

1 2 3
6 4 5
7 0 8

1 2 3
4 0 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
6 7 8

1 2 3
4 5 0
6 7 8

Success
```

4. Implement A* search algorithm.

```
def print_grid(src):
    state = src.copy()
    state[state.index(-1)] = ' '
    print(
        f"""
{state[0]} {state[1]} {state[2]}
{state[3]} {state[4]} {state[5]}
{state[6]} {state[7]} {state[8]}
        """
    )

def h(state, target):
    #Manhattan distance
    dist = 0
    for i in state:
        d1, d2 = state.index(i), target.index(i)
        x1, y1 = d1 % 3, d1 // 3
        x2, y2 = d2 % 3, d2 // 3
        dist += abs(x1-x2) + abs(y1-y2)
    return dist

def astar(src, target):
    states = [src]
    g = 0
    visited_states = set()
    while len(states):
        moves = []
        for state in states:
```

```
            visited_states.add(tuple(state))
            print_grid(state)
            if state == target:
                print("Success")
                return
            moves += [move for move in possible_moves(state, visited_states) if move not in
moves]
        costs = [g + h(move, target) for move in moves]
        states = [moves[i] for i in range(len(moves)) if costs[i] == min(costs)]
        g += 1
    print("Fail")


def possible_moves(state, visited_states):
    b = state.index(-1)
    d = []
    if 9 > b - 3 >= 0:
        d += 'u'
    if 9 > b + 3 >= 0:
        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 tuple(move) not in visited_states]


def gen(state, direction, b):
    temp = state.copy()
    if direction == 'u':
```

```
        temp[b-3], temp[b] = temp[b], temp[b-3]
    if direction == 'd':
        temp[b+3], temp[b] = temp[b], temp[b+3]
    if direction == 'r':
        temp[b+1], temp[b] = temp[b], temp[b+1]
    if direction == 'l':
        temp[b-1], temp[b] = temp[b], temp[b-1]
    return temp

#Test 1
print("Example 1")
src = [1,2,3,-1,4,5,6,7,8]
target = [1,2,3,4,5,-1,6,7,8]
print("Source: " , src)
print("Goal State: " , target)
astar(src, target)


# Test 2
print("Example 2")
src = [1,2,3,-1,4,5,6,7,8]
target=[1,2,3,6,4,5,-1,7,8]
print("Source: " , src)
print("Goal State: " , target)
astar(src, target)


# Test 3
print("Example 3")
src = [1,2,3,7,4,5,6,-1,8]
```

```
target=[1,2,3,6,4,5,-1,7,8]
print("Source: " , src)
print("Goal State: " , target)
astar(src, target)
```

OUTPUT:

```
Example 1
Source:  [1, 2, 3, -1, 4, 5, 6, 7, 8]
Goal State:  [1, 2, 3, 4, 5, -1, 6, 7, 8]

1 2 3
  4 5
6 7 8


1 2 3
4   5
6 7 8


1 2 3
4 5
6 7 8

Success
Example 2
Source:  [1, 2, 3, -1, 4, 5, 6, 7, 8]
Goal State:  [1, 2, 3, 6, 4, 5, -1, 7, 8]

1 2 3
  4 5
6 7 8


1 2 3
6 4 5
  7 8

Success
```

```
Example 3
Source:  [1, 2, 3, 7, 4, 5, 6, -1, 8]
Goal State:  [1, 2, 3, 6, 4, 5, -1, 7, 8]

1 2 3
7 4 5
6   8


1 2 3
7 4 5
  6 8


1 2 3
  4 5
7 6 8


  2 3
1 4 5
7 6 8


1 2 3
4   5
7 6 8


1 2 3
4 6 5
7   8
```

```
1 2 3
  6 5
4 7 8


1 2 3
6   5
4 7 8


1 2 3
6 7 5
4   8


1 2 3
6 7 5
  4 8


1 2 3
  7 5
6 4 8


  2 3
1 7 5
6 4 8


1 2 3
7   5
6 4 8
```

```
7 1 3
4 6 5
  2 8


7 1 3
4 6 5
2   8


7 1 3
4   5
2 6 8


7 1 3
4 6 5
2 8


7 1 3
  4 5
2 6 8


7 1 3
2 4 5
  6 8

Fail
```

5. Implement vacuum cleaner agent.

```
def clean(floor, row, col):
    i, j, m, n = row, col, len(floor), len(floor[0])
    goRight = goDown = True
    cleaned = [not any(f) for f in floor]
    while not all(cleaned):
        while any(floor[i]):
            print_floor(floor, i, j)
            if floor[i][j]:
                floor[i][j] = 0
                print_floor(floor, i, j)
            if not any(floor[i]):
                cleaned[i] = True
                break
            if j == n - 1:
                j -= 1
                goRight = False
            elif j == 0:
                j += 1
                goRight = True
            else:
                j += 1 if goRight else -1
        if all(cleaned):
            break
        if i == m - 1:
            i -= 1
            goDown = False
        elif i == 0:
            i += 1
```

```
            goDown = True
        else:
            i += 1 if goDown else -1
        if cleaned[i]:
            print_floor(floor, i, j)

def print_floor(floor, row, col): # row, col represent the current vacuum cleaner position
    for r in range(len(floor)):
        for c in range(len(floor[r])):
            if r == row and c == col:
                print(f" >{floor[r][c]}< ", end = '')
            else:
                print(f" {floor[r][c]} ", end = '')
        print(end = '\n')
    print(end = '\n')

# Test 1
floor = [[1, 0, 0, 0],
         [0, 1, 0, 1],
         [1, 0, 1, 1]]

print("Room Condition: ")
for row in floor:
    print(row)
print("\n")
clean(floor, 1, 2)
```

OUTPUT:

```
Room Condition:
[1, 0, 0, 0]
[0, 1, 0, 1]
[1, 0, 1, 1]


  1    0    0    0
  0    1   >0<   1
  1    0    1    1

  1    0    0    0
  0    1    0   >1<
  1    0    1    1

  1    0    0    0
  0    1    0   >0<
  1    0    1    1

  1    0    0    0
  0    1   >0<   0
  1    0    1    1

  1    0    0    0
  0   >1<   0    0
  1    0    1    1

  1    0    0    0
  0   >0<   0    0
  1    0    1    1

  1    0    0    0
  0    0    0    0
  1   >0<   1    1
```

```
 1    0    0    0
 0    0    0    0
>1<   0    1    1

 1    0    0    0
 0    0    0    0
>0<   0    1    1

 1    0    0    0
 0    0    0    0
 0   >0<   1    1

 1    0    0    0
 0    0    0    0
 0    0   >1<   1

 1    0    0    0
 0    0    0    0
 0    0   >0<   1

 1    0    0    0
 0    0    0    0
 0    0    0   >1<

 1    0    0    0
 0    0    0    0
 0    0    0   >0<

 1    0    0    0
 0    0    0   >0<
 0    0    0    0

 1    0    0   >0<
 0    0    0    0
 0    0    0    0
```

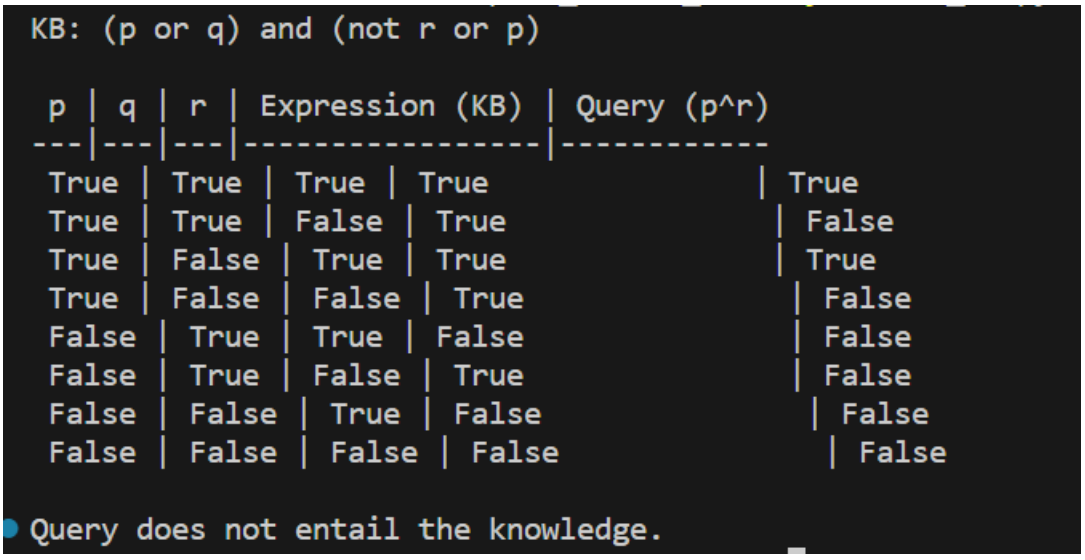
```
 1    0   >0<   0
 0    0    0    0
 0    0    0    0

 1   >0<   0    0
 0    0    0    0
 0    0    0    0

>1<   0    0    0
 0    0    0    0
 0    0    0    0

>0<   0    0    0
 0    0    0    0
 0    0    0    0
```

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

```
def evaluate_expression(p, q, r):
    expression_result = (p or q) and (not r or p)
    return expression_result

def generate_truth_table():
    print(" p | q | r | Expression (KB) | Query (p^r)")
    print("...|...|...|.....|.....")

    for p in [True, False]:
        for q in [True, False]:
            for r in [True, False]:
                expression_result = evaluate_expression(p, q, r)
                query_result = p and r

                print(f" {p} | {q} | {r} | {expression_result}              | {query_result}")

def query_entails_knowledge():
    for p in [True, False]:
        for q in [True, False]:
            for r in [True, False]:
                expression_result = evaluate_expression(p, q, r)
                query_result = p and r

                if expression_result and not query_result:
                    return False

    return True
```

```
def main():
    generate_truth_table()

    if query_entails_knowledge():
        print("\nQuery entails the knowledge.")
    else:
        print("\nQuery does not entail the knowledge.")

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

OUTPUT:



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

```
import re


def main(rules, 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 reverse(clause):
    if len(clause) > 2:
        t = split_terms(clause)
        return f'{t[1]}v{t[0]}'
    return ''
def split_terms(rule):
    exp = '(~*[PQRS])'
    terms = re.findall(exp, rule)
    return terms


split_terms('~PvR')
def contradiction(goal, clause):
    contradictions = [ f'{goal}v{negate(goal)}', f'{negate(goal)}v{goal}']
    return clause in contradictions or reverse(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]}']
                        else:
                            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 and clause != reverse(clause) and reverse(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
rules = 'Rv~P Rv~Q ~RvP ~RvQ' #(P^Q)<=>R : (Rv~P)v(Rv~Q)^(~RvP)^(~RvQ)
goal = 'R'
print('Rules: ',rules)
print("Goal:  ",goal)
main(rules, goal)

rules = 'PvQ ~PvR ~QvR' #P=vQ, P=>Q : ~PvQ, Q=>R, ~QvR
goal = 'R'
print('Rules: ',rules)
print("Goal:  ",goal)
main(rules, goal)

rules = 'PvQ PvR ~PvR RvS Rv~Q ~Sv~Q' # (P=>Q)=>Q, (P=>P)=>R, (R=>S)=>~(S=>Q)
goal = 'R'
print('Rules: ',rules)
```

print("Goal: ",goal)

main(rules, goal)

OUTPUT:

```
Example 1
Rules:  Rv~P Rv~Q ~RvP ~RvQ
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.

Example 2
Rules:  PvQ ~PvR ~QvR
Goal:  R

Step    |Clause |Derivation
------------------------------
 1.     | PvQ   | Given.
 2.     | ~PvR  | Given.
 3.     | ~QvR  | Given.
 4.     | ~R    | Negated conclusion.
 5.     | QvR   | Resolved from PvQ and ~PvR.
 6.     | PvR   | Resolved from PvQ and ~QvR.
 7.     | ~P    | Resolved from ~PvR and ~R.
 8.     | ~Q    | Resolved from ~QvR and ~R.
 9.     | Q     | Resolved from ~R and QvR.
 10.    | P     | Resolved from ~R and PvR.
 11.    | R     | Resolved from QvR and ~Q.
 12.    |       | Resolved R and ~R to Rv~R, which is in turn null.
A contradiction is found when ~R is assumed as true. Hence, R is true.
```

```
Example 3
Rules:  PvQ PvR ~PvR RvS Rv~Q ~Sv~Q
Goal:  R

Step    |Clause |Derivation
-----------------------------
 1.     | PvQ   | Given.
 2.     | PvR   | Given.
 3.     | ~PvR  | Given.
 4.     | RvS   | Given.
 5.     | Rv~Q  | Given.
 6.     | ~Sv~Q | Given.
 7.     | ~R    | Negated conclusion.
 8.     | QvR   | Resolved from PvQ and ~PvR.
 9.     | Pv~S  | Resolved from PvQ and ~Sv~Q.
 10.    | P     | Resolved from PvR and ~R.
 11.    | ~P    | Resolved from ~PvR and ~R.
 12.    | Rv~S  | Resolved from ~PvR and Pv~S.
 13.    | R     | Resolved from ~PvR and P.
 14.    | S     | Resolved from RvS and ~R.
 15.    | ~Q    | Resolved from Rv~Q and ~R.
 16.    | Q     | Resolved from ~R and QvR.
 17.    | ~S    | Resolved from ~R and Rv~S.
 18.    |       | Resolved ~R and R to ~RvR, which is in turn null.
A contradiction is found when ~R is assumed as true. Hence, R is true.
```

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

print("\nExample 1")
exp1 = "knows(f(x),y)"
exp2 = "knows(J,John)"
print("Expression 1: ",exp1)
print("Expression 2: ",exp2)

substitutions = unify(exp1, exp2)
print("Substitutions:")
print(substitutions)

print("\nExample 2")
exp1 = "knows(John,x)"
```

```
exp2 = "knows(y,mother(y))"
print("Expression 1: ",exp1)
print("Expression 2: ",exp2)

substitutions = unify(exp1, exp2)
print("Substitutions:")
print(substitutions)


print("\nExample 3")
exp1 = "Student(x)"
exp2 = "Teacher(Rose)"
print("Expression 1: ",exp1)
print("Expression 2: ",exp2)

substitutions = unify(exp1, exp2)
print("Substitutions:")
print(substitutions)
```

OUTPUT:

```
Example 1
Expression 1:  knows(f(x),y)
Expression 2:  knows(J,John)
Substitutions:
[('J', 'f(x)'), ('John', 'y')]

Example 2
Expression 1:  knows(John,x)
Expression 2:  knows(y,mother(y))
Substitutions:
[('John', 'y'), ('mother(y)', 'x')]

Example 3
Expression 1:  Student(x)
Expression 2:  Teacher(Rose)
Predicates do not match. Cannot be unified
Substitutions:
False
```

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

```
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 Skolemization(statement):
    SKOLEM_CONSTANTS = [f'{chr(c)}' for c in range(ord('A'), ord('Z')+1)]
    matches = re.findall('[∃].', statement)
    for match in matches[::-1]:
        statement = statement.replace(match, '')
        for predicate in getPredicates(statement):
            attributes = getAttributes(predicate)
            if ''.join(attributes).islower():
                statement = statement.replace(match[1],SKOLEM_CONSTANTS.pop(0))
    return statement
import re

def fol_to_cnf(fol):
    statement = fol.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
    return Skolemization(statement)


print(fol_to_cnf("bird(x)=>~fly(x)"))
print(fol_to_cnf("∃x[bird(x)=>~fly(x)]"))


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:

```
Example 1
FOL: bird(x)=>~fly(x)
CNF:  ~bird(x)|~fly(x)

Example 2
FOL: ∃x[bird(x)=>~fly(x)]
CNF:  [~bird(A)|~fly(A)]

Example 3
FOL: animal(y)<=>loves(x,y)
CNF:  ~animal(y)<|loves(x,y)

Example 4
FOL: ∀x[∀y[animal(y)=>loves(x,y)]]=>[∃z[loves(z,x)]]
CNF:  ∀x~[∀y[~animal(y)|loves(x,y)]]|[[loves(A,x)]]

Example 5
FOL: [american(x)&weapon(y)&sells(x,y,z)&hostile(z)]=>criminal(x)
CNF:  ~[american(x)&weapon(y)&sells(x,y,z)&hostile(z)]|criminal(x)
```

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]

    def substitute(self, constants):
        c = constants.copy()
        f = f"{self.predicate}({','.join([constants.pop(0) if isVariable(p) else p for p in self.params])})"
        return Fact(f)

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()

kb_ = KB()
kb_.tell('king(x)&greedy(x)=>evil(x)')
kb_.tell('king(John)')
kb_.tell('greedy(John)')
kb_.tell('king(Richard)')
kb_.query('evil(x)')
```

OUTPUT:

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

Example 2
Querying evil(x):
        1. evil(John)
```