B.M.S COLLEGE OF ENGINEERING
BENGALURU Autonomous Institute, Affiliated
to VTU

Lab Record

Artificial Intelligence

(22CS5PCAIN)

Submitted in partial fulfillment for the 5th Semester Laboratory

Bachelor of Technology
in
Computer Science and Engineering

Submitted by:

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B.M.S COLLEGE OF ENGINEERING

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

CERTIFICATE

This is to certify that the Artificial Intelligence (22CS5PCAIN) laboratory has been carried out by Nithin SN (1BM21CS121) during the 5th Semester September-January 2021.

Signature of the Faculty Incharge:

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1.TIC-TAC-TOE

```
def printBoard(board):
print(board[1] + '|' + board[2] + '|' + board[3])
print('-+-+-')
print(board[4] + '|' + board[5] + '|' + board[6])
print('-+-+-')
print(board[7] + '|' + board[8] + '|' + board[9])
print("\n")
def spaceIsFree(position):
if board[position] == ' ':
return True
else:
return False
def insertLetter(letter, position):
if spaceIsFree(position):
board[position] = letter
printBoard(board)
if (checkDraw()):
print("Draw!")
exit()
if checkForWin():
if letter == 'X':
print("Bot wins!")
exit()
else:
```

```
print("Player wins!")
exit()
return
else:
print("Can't insert there!")
position = int(input("Please enter new position: "))
insertLetter(letter, position)
return
def checkForWin():
if (board[1] == board[2] and board[1] == board[3] and board[1] != ' '):
return True
elif (board[4] == board[5] and board[4] == board[6] and board[4] != ' '):
return True
elif (board[7] == board[8] and board[7] == board[9] and board[7] != ' '):
return True
elif (board[1] == board[4] and board[1] == board[7] and board[1] != ' '):
return True
elif (board[2] == board[5] and board[2] == board[8] and board[2] != ' '):
return True
elif (board[3] == board[6] and board[3] == board[9] and board[3] != ' '):
return True
elif (board[1] == board[5] and board[1] == board[9] and board[1] != ' '):
return True
elif (board[7] == board[5] and board[7] == board[3] and board[7] != ' '):
return True
else:
return False
def checkWhichMarkWon(mark):
if board[1] == board[2] and board[1] == board[3] and board[1] == mark:
```

```
return True
elif (board[4] == board[5] and board[4] == board[6] and board[4] == mark):
return True
elif (board[7] == board[8] and board[7] == board[9] and board[7] == mark):
return True
elif (board[1] == board[4] and board[1] == board[7] and board[1] == mark):
return True
elif (board[2] == board[5] and board[2] == board[8] and board[2] == mark):
return True
elif (board[3] == board[6] and board[3] == board[9] and board[3] == mark):
return True
elif (board[1] == board[5] and board[1] == board[9] and board[1] == mark):
return True
elif (board[7] == board[5] and board[7] == board[3] and board[7] == mark):
return True
else:
return False
def checkDraw():
for key in board.keys():
if (board[key] == ' '):
return False
return True
def playerMove():
position = int(input("Enter the position for 'O': "))
insertLetter(player, position)
return
def compMove():
bestScore = -800
bestMove = 0
```

```
for key in board.keys():
if (board[key] == ' '):
board[key] = bot
score = minimax(board, 0, False)
board[key] = ' '
if (score > bestScore):
bestScore = score
bestMove = key
insertLetter(bot, bestMove)
return
def minimax(board, depth, isMaximizing):
if (checkWhichMarkWon(bot)):
return 1
elif (checkWhichMarkWon(player)):
return -1
elif (checkDraw()):
return 0
if (isMaximizing):
bestScore = -800
for key in board.keys():
if (board[key] == ' '):
board[key] = bot
score = minimax(board, depth + 1, False)
board[key] = ' '
if (score > bestScore):
bestScore = score
return bestScore
else:
bestScore = 800
```

```
for key in board.keys():
if (board[key] == ' '):
board[key] = player
score = minimax(board, depth + 1, True)
board[key] = ' '
if (score < bestScore):
bestScore = score
return bestScore
board = {1: ' ', 2: ' ', 3: ' ',
4: ' ', 5: ' ', 6: ' ',
7: ' ', 8: ' ', 9: ' '}
printBoard(board)
print("Computer goes first! Good luck.")
print("Positions are as follow:")
print("1, 2, 3 ")
print("4, 5, 6 ")
print("7, 8, 9 ")
print("\n")
player = 'O'
bot = 'X'
global firstComputerMove
firstComputerMove = True
while not checkForWin():
compMove()
playerMove()
```

OUTPUT

```
 | |
-+-+-
 | |
-+-+-
 | |


Computer goes first! Good luck.
Positions are as follow:
1, 2, 3
4, 5, 6
7, 8, 9


X| |
-+-+-
 | |
-+-+-
 | |


Enter the position for 'O':  7
X| |
-+-+-
 | |
-+-+-
O| |


X|X|
-+-+-
 | |
-+-+-
O| |
```

```
Enter the position for 'O':  3
X|X|O
-+-+-
 | |
-+-+-
O| |


X|X|O
-+-+-
 |X|
-+-+-
O| |


Enter the position for 'O':  8
X|X|O
-+-+-
 |X|
-+-+-
O|O|


X|X|O
-+-+-
 |X|
-+-+-
O|O|X


Bot wins!
```

2. 8 Puzzle
(bfs)

```
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(-1)

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

    if b not in [-1,1,2]:
        d.append('u')
    if b not in [6,7,8]:
        d.append('d')
    if b not in [-1,3,6]:
        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
```

OUTPUT

```python
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, -1, 5, 6, 7, 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, 4, 7, 5, 6, -1, 8]
[1, 2, 3, 4, 5, -1, 6, 7, 8]
success
```

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

```
[2, -1, 3, 1, 8, 4, 7, 6, 5]
[2, 8, 3, 1, -1, 4, 7, 6, 5]
[-1, 2, 3, 1, 8, 4, 7, 6, 5]
[2, 3, -1, 1, 8, 4, 7, 6, 5]
[2, 8, 3, 1, 6, 4, 7, -1, 5]
[2, 8, 3, -1, 1, 4, 7, 6, 5]
[2, 8, 3, 1, 4, -1, 7, 6, 5]
[7, 2, 3, 1, 8, 4, -1, 6, 5]
[1, 2, 3, -1, 8, 4, 7, 6, 5]
[5, 2, 3, 1, 8, 4, 7, 6, -1]
[2, 3, 4, 1, 8, -1, 7, 6, 5]
[2, 8, 3, 1, 6, 4, -1, 7, 5]
[2, 8, 3, 1, 6, 4, 7, 5, -1]
[-1, 8, 3, 2, 1, 4, 7, 6, 5]
[2, 8, 3, 7, 1, 4, -1, 6, 5]
[2, 8, -1, 1, 4, 3, 7, 6, 5]
[2, 8, 3, 1, 4, 5, 7, 6, -1]
[7, 2, 3, -1, 8, 4, 1, 6, 5]
[7, 2, 3, 1, 8, 4, 6, -1, 5]
[1, 2, 3, 7, 8, 4, -1, 6, 5]
[1, 2, 3, 8, -1, 4, 7, 6, 5]
success
```

3. Implement Iterative deepening search 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
    return False

src = []
target=[]
n = int(input("Enter number of elements : "))
print("Enter source elements")
for i in range(0, n):
    ele = int(input())
    src.append(ele)
print("Enter target elements")
for i in range(0, n):
    ele = int(input())
    target.append(ele)
depth=8
iddfs(src, target,depth)
```

OUTPUT

```
Enter number of elements : 9
Enter source elements
1
2
3
-1
4
5
6
7
8
Enter target elements
1
2
3
4
5
-1
6
7
8
True
```

4. 8 Puzzle A* Search Algorithm

```
class Node:
    def __init__(self, data, level, fval):
        # Initialize the node with the data ,level of the node and the calculated fvalue
        self.data = data
        self.level = level
        self.fval = fval

    def generate_child(self):
        # Generate hild nodes from the given node by moving the blank space
        # either in the four direction {up,down,left,right}
        x, y = self.find(self.data, '_')
        # val_list contains position values for moving the blank space in either of
        # the 4 direction [up,down,left,right] respectively.
        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):
        # Move the blank space in the given direction and if the position value are out
        # of limits the return None
        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):
        # copy function to create a similar matrix of the given node
        temp = []
        for i in root:
            t = []
            for j in i:
                t.append(j)
            temp.append(t)
        return temp

    def find(self, puz, x):
        # Specifically used to find the position of the blank space
        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):
        # Initialize the puzzle size by the the specified size,open and closed lists to empty
        self.n = size
```

```
        self.open = []
        self.closed = []

    def accept(self):
        # Accepts the puzzle from the user
        puz = []
        for i in range(0, self.n):
            temp = input().split(" ")
            puz.append(temp)
        return puz

    def f(self, start, goal):
        # Heuristic function to calculate Heuristic value f(x) = h(x) + g(x)
        return self.h(start.data, goal) + start.level

    def h(self, start, goal):
        # Calculates the difference between the given puzzles
        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):
        # Accept Start and Goal Puzzle state
        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)
        # put the start node in the open list
        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 the difference between current and goal node is 0 we have reached the goal node
            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]
            # sort the open list based on f value
            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 _
```

5.Vaccum cleaner

```
def vacuum_world():
        # initializing goal_state
        # 0 indicates Clean and 1 indicates Dirty
    goal_state = {'A': '0', 'B': '0'}
    cost = 0

    location_input = input("Enter Location of Vacuum") #user_input of location vacuum is placed
    status_input = input("Enter status of " + location_input) #user_input if location is dirty or clean
    status_input_complement = input("Enter status of other room")
    print("Initial Location Condition" + str(goal_state))

    if location_input == 'A':
        # Location A is Dirty.
        print("Vacuum is placed in Location A")
        if status_input == '1':
            print("Location A is Dirty.")
```

```
    # suck the dirt  and mark it as clean
    goal_state['A'] = '0'
    cost += 1                       #cost for suck
    print("Cost for CLEANING A " + str(cost))
    print("Location A has been Cleaned.")

    if status_input_complement == '1':
        # if B is Dirty
        print("Location B is Dirty.")
        print("Moving right to the Location B. ")
        cost += 1                       #cost for moving right
        print("COST for moving RIGHT" + str(cost))
        # suck the dirt and mark it as clean
        goal_state['B'] = '0'
        cost += 1                       #cost for suck
        print("COST for SUCK " + str(cost))
        print("Location B has been Cleaned. ")
    else:
        print("No action" + str(cost))
        # suck and mark clean
        print("Location B is already clean.")

if status_input == '0':
    print("Location A is already clean ")
    if status_input_complement == '1':# if B is Dirty
        print("Location B is Dirty.")
        print("Moving RIGHT to the Location B. ")
        cost += 1                       #cost for moving right
        print("COST for moving RIGHT " + str(cost))
```

```
            # suck the dirt and mark it as clean
            goal_state['B'] = '0'
            cost += 1                       #cost for suck
            print("Cost for SUCK" + str(cost))
            print("Location B has been Cleaned. ")
        else:
            print("No action " + str(cost))
            print(cost)
            # suck and mark clean
            print("Location B is already clean.")

else:
    print("Vacuum is placed in location B")
    # Location B is Dirty.
    if status_input == '1':
        print("Location B is Dirty.")
        # suck the dirt  and mark it as clean
        goal_state['B'] = '0'
        cost += 1  # cost for suck
        print("COST for CLEANING " + str(cost))
        print("Location B has been Cleaned.")

        if status_input_complement == '1':
            # if A is Dirty
            print("Location A is Dirty.")
            print("Moving LEFT to the Location A. ")
            cost += 1  # cost for moving right
            print("COST for moving LEFT" + str(cost))
            # suck the dirt and mark it as clean
```

```
            goal_state['A'] = '0'
            cost += 1  # cost for suck
            print("COST for SUCK " + str(cost))
            print("Location A has been Cleaned.")

    else:
        print(cost)
        # suck and mark clean
        print("Location B is already clean.")

        if status_input_complement == '1':  # if A is Dirty
            print("Location A is Dirty.")
            print("Moving LEFT to the Location A. ")
            cost += 1  # cost for moving right
            print("COST for moving LEFT " + str(cost))
            # suck the dirt and mark it as clean
            goal_state['A'] = '0'
            cost += 1  # cost for suck
            print("Cost for SUCK " + str(cost))
            print("Location A has been Cleaned. ")
        else:
            print("No action " + str(cost))
            # suck and mark clean
            print("Location A is already clean.")

# done cleaning
print("GOAL STATE: ")
print(goal_state)
print("Performance Measurement: " + str(cost))
```

vacuum_world()

OUTPUT

```
Enter Location of VacuumA
Enter status of A1
Enter status of other room1
Initial Location Condition{'A': '0', 'B': '0'}
Vacuum is placed in Location A
Location A is Dirty.
Cost for CLEANING A 1
Location A has been Cleaned.
Location B is Dirty.
Moving right to the Location B.
COST for moving RIGHT2
COST for SUCK 3
Location B has been Cleaned.
GOAL STATE:
{'A': '0', 'B': '0'}
Performance Measurement: 3
```

```
vacuum_world()
```

```
Enter Location of VacuumA
Enter status of A0
Enter status of other room0
Initial Location Condition{'A': '0', 'B': '0'}
Vacuum is placed in Location A
Location A is already clean
No action 0
0
Location B is already clean.
GOAL STATE:
{'A': '0', 'B': '0'}
Performance Measurement: 0
```

```
Enter Location of VacuumB
Enter status of B0
Enter status of other room1
Initial Location Condition{'A': '0', 'B': '0'}
Vacuum is placed in location B
0
Location B is already clean.
Location A is Dirty.
Moving LEFT to the Location A.
COST for moving LEFT 1
Cost for SUCK 2
Location A has been Cleaned.
GOAL STATE:
{'A': '0', 'B': '0'}
Performance Measurement: 2
```

6. Knowledge Base Entailment

```
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 = all(rule(c) for rule in kb)
        f = q(c)
        print(s, f)
        if s != f and s != False:
            return 'Does not entail'
    return 'Entails'


kb = []

# Get user input for Rule 1
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)

# Get user input for Rule 2
#rule_str = input("Enter Rule 2 as a lambda function (e.g., lambda x: (x[0] or x[1]) and x[2]): ")
#r2 = eval(rule_str)
#tell(kb, r2)

# Get user input for Query
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)
```

Ask KB Query

result = ask(kb, q)

print(result)

OUTPUT

```
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
```

7. Knowledge Base 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

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'
main(rules, goal)
 rules = 'PvQ ~PvR ~QvR' #P=vQ, P=>Q : ~PvQ, Q=>R, ~QvR
goal = 'R'
main(rules, goal)
```

OUTPUT

```
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.

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.
```

8. Unification

```
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)
```

```python
    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 = "knows(A,x)"
exp2 = "knows(y,mother(y))"
substitutions = unify(exp1, exp2)
print("Substitutions:")
print(substitutions)
```

OUTPUT

```
Substitutions:
[('A', 'y'), ('mother(y)', 'x')]
```

9. FOL to 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 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


def fol_to_cnf(fol):
    statement = fol.replace("=>", "-")
    expr = '\[([^]]+)\]'
    statements = re.findall(expr, statement)
    print(statements)
    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)]"))
```

OUTPUT

```
~bird(x)|~fly(x)
[~bird(A)|~fly(A)]
```

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

OUTPUT

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