VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence

Submitted by

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in partial fulfillment for the award of the degree of
BACHELOR OF ENGINEERING
in
COMPUTER SCIENCE AND ENGINEERING

B.M.S. COLLEGE OF ENGINEERING
(Autonomous Institution under VTU)
BENGALURU-560019
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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 **ROSHNI R (1BM21CS275),** who is bonafide student of **B.M.S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum during the academic semester Nov-2023 to Feb-2024. The Lab report has been approved as it satisfies the academic requirements in respect of a **Artificial Intelligence (22CS5PCAIN)** work prescribed for the said degree.

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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!")
```

```
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
```

OUTPUT:

Date __/__/____
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Tic Tac Toe (Program-1)

The algorithm used is minmax algorithm
The minmax algorithm is a backtracking algorithm. A numerical value is attached to each possible end result. [0 r s]

```
function minimax(board, depth, ismaxplayer):
if current board state is a terminal state:
return value of the board
if ismax player:
bestVal = -INFINITY
 for each move in board:
     value = minimax(board, depth+1, false)
     bestval = max(bestVal, value);
   return bestVal
else:
best_val = +INFINITY
for each move in board:
   value = minimax(board, depth+1, true)
    bestVal = min(bestVal, value)
return bestVal

function ismovesleft(board):
for each cell in board:
   if current cell is empty:
      return true
return false
```

8/11/2022

```
if maximizer has won:
   return winscrore - depth
else if minimizer has won:
   return loosescore + depth
```

Date __/__/__

Page _____

The maximum depth is 9!

Assume there are two possible ways for X to win:

Move A: X can win in 2 moves

Move B: X can win in 4 moves

Move A is better because it ensures a faster victory. But AI may choose B sometimes. To overcome this problem we subtract the depth value from the evaluated score.

Move A will have a value of 10-2 = 8

Move B will have a value of 10-4 = 6

Since move A has a higher score compared to move B so AI will choose move A over move B.

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]
```

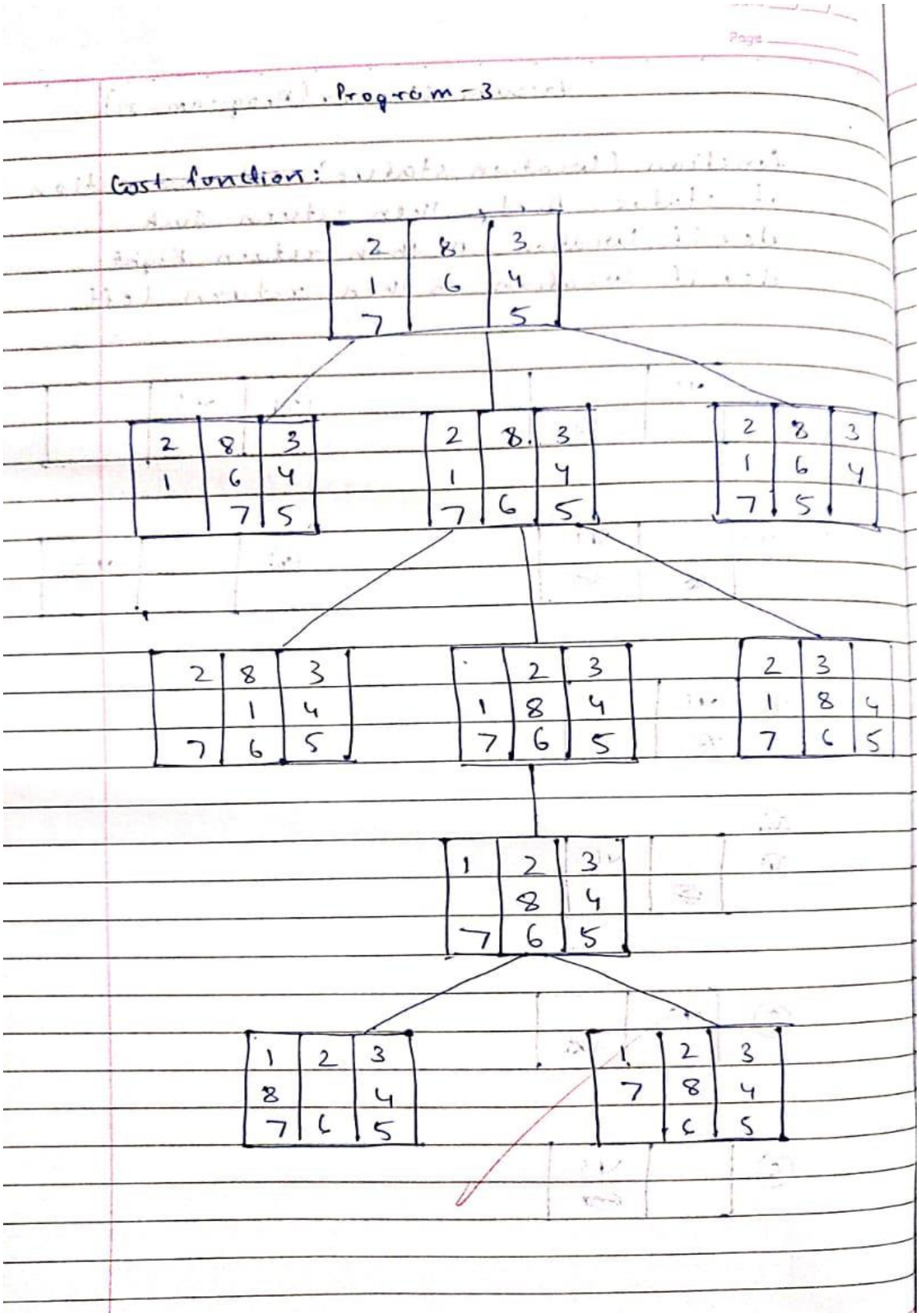
```
    if m=='u':
        temp[b-3],temp[b] = temp[b],temp[b-3]

    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
```

Program - 3

Cost function:



3. Implement Iterative deepening search algorithm.

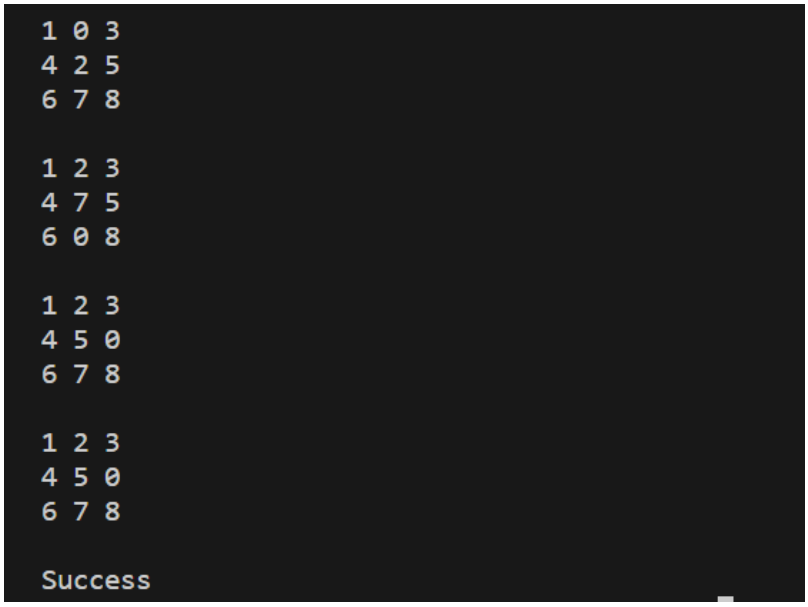
```
def iterative_deepening_search(src, target):
    depth_limit = 0
    while True:
        result = depth_limited_search(src, target, depth_limit, [])
        if result is not None:
            print("Success")
            return
        depth_limit += 1
        if depth_limit > 30:  # Set a reasonable 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

Date / /
Page

Program-4 (IDS)

$$\begin{bmatrix} 1 & 2 & 3 \\ - & 4 & 5 \\ 6 & 7 & 8 \end{bmatrix} = \text{Source}$$

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & - \\ 6 & 7 & 8 \end{bmatrix} = \text{Target}$$

Depth = 0

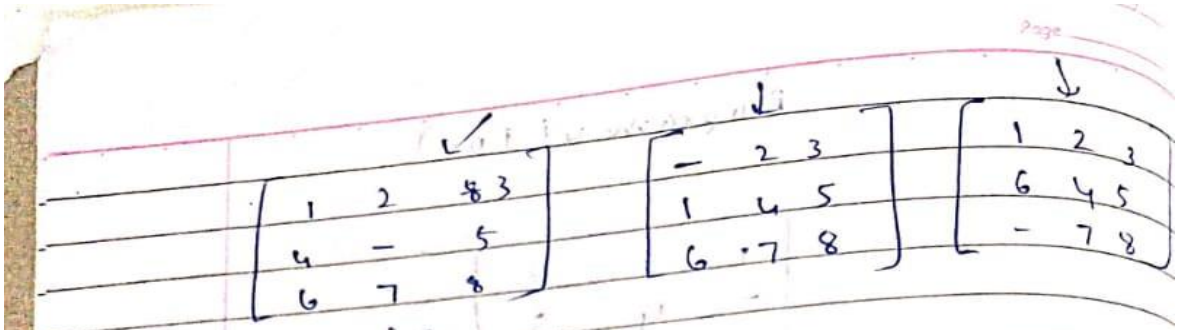
$$\begin{bmatrix} - & 2 & 3 \\ 1 & 4 & 5 \\ 6 & 7 & 8 \end{bmatrix} \quad \begin{bmatrix} 1 & 2 & 3 \\ 4 & - & 5 \\ 6 & 7 & 8 \end{bmatrix} \quad \begin{bmatrix} 1 & 2 & 3 \\ 6 & 4 & 5 \\ - & 7 & 8 \end{bmatrix}$$

False

$$\begin{bmatrix} 1 & 2 & 3 \\ - & 4 & 5 \\ 6 & 7 & 8 \end{bmatrix} = \text{Source}$$

$$\begin{bmatrix} 1 & 2 & 3 \\ 6 & 4 & 5 \\ - & 7 & 8 \end{bmatrix} = \text{Target}$$

Depth = 1



True

```
class EightPuzzle:
def __init__(self, initial_state, goal_state):
    self.initial_state = initial_state
    self.goal_state = goal_state
    self.actions = [(-1,0),(1,0),(0,-1),(0,1)]

def is_goal_state(self, state):
    return state == self.goal_state

def get_successors(self, state):
    successors = []
    empty_tile_index = state.index(0)
    for action in self.actions:
        new_index = empty_tile_index + 3* action[0] +
                    action[1]
        if 0 <= new_index < 9:
            new_state = list(state)
            new_state[empty_tile_index], new_state
            [new_index] = new_state[new_index],
            new_state[empty_tile_index]
            successors.append(new_state)
            return successors

def depth_limited_search(self, state, limit):
    if self.is_goal_state(state):
        return [state]
```

```
    if limit == 0:
        return None
    for successor in self.get_successors(state):
        result = self.depth_limited_search(successor,
                 limit-1)
        if result is not None:
            return [state] + result
    return None

def iterative_deepening_search(self):
    depth_limit = 0
    while True:
        result = self.depth_limited_search(self.
        initial_state, depth_limit)
        if result is not None:
            return result
        depth_limit += 1

initial_state = [1, 2, 3, 4, 5, 6, 0, 7, 8]
goal_state = [1, 2, 3, 4, 5, 6, 7, 8, 0]
puzzle = EightPuzzle(initial_state, goal_state)
solution = puzzle.iterative_deepening_search()
if solution:
    print("Solution found:")
    for step, state in enumerate(solution):
        print(f"Step {step+1}: {state}")
else:
    print("No solution found.")
```

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
```

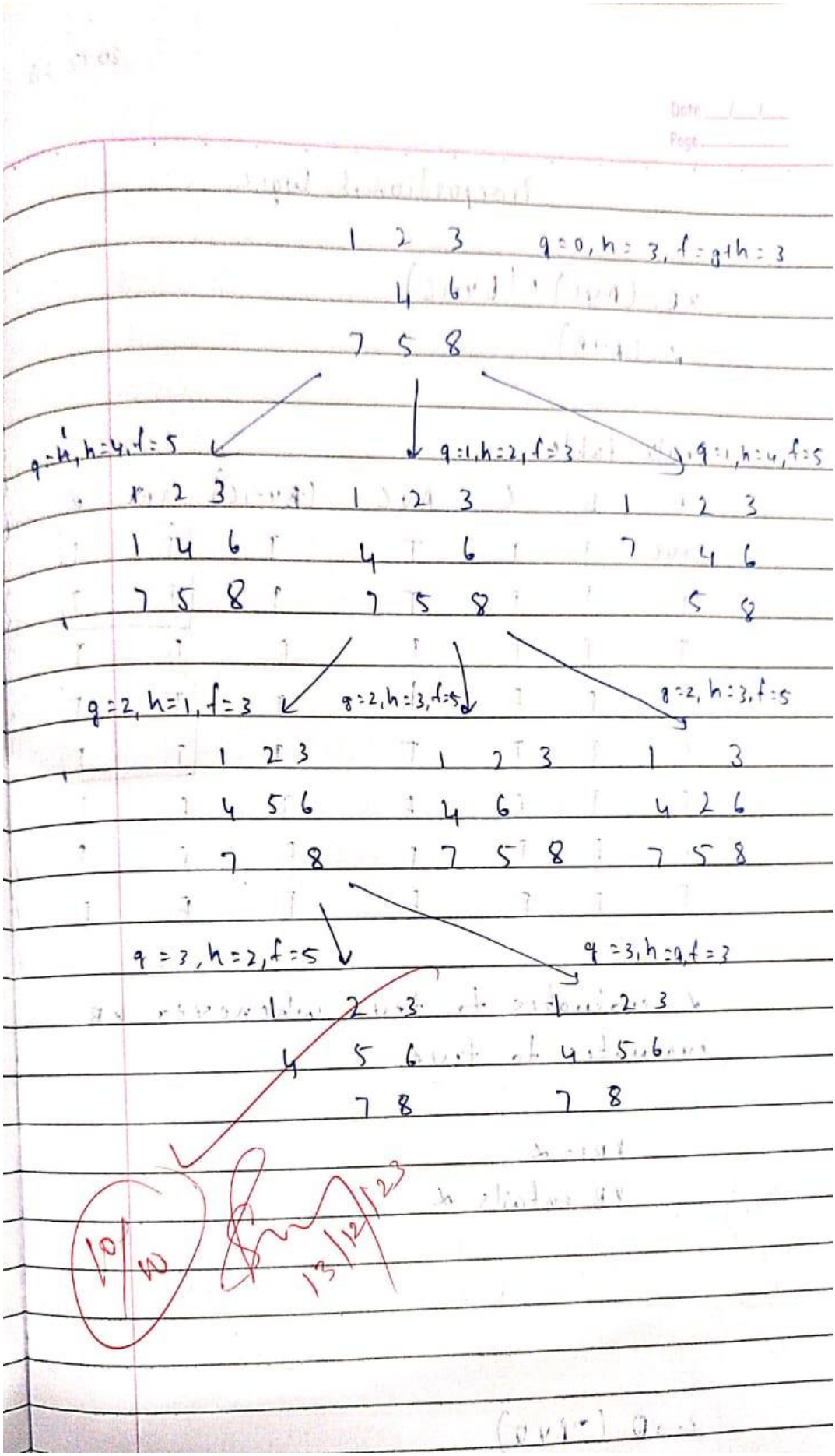
```
7 1 3
4 6 5
  2 8


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
```

Program-5 (A*)

```
def print_b(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):
    count=0
    i=0
    for j in state:
        if state[i] != target[i]:
            count=count+1
        return count

def astar(state, target):
    states=[src]
    g=0
    visited_states=[]
    while len(states):
        print(f"Level: {g}")
        moves=[]
        for state in states:
            visited_states.append(state)
            print_b(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
            cost[i] == min(costs)]
    g += 1
print("Fail")

def possible_moves(state, visited_state):
    b = state.index(-1)
    d = []
    if b -3 in range(9):
        d.append('u')
    if b not in [0,3,6]:
        d.append('l')
    if b not in [2,5,8]:
        d.append('r')
    if b +3 in range(9):
        d.append('d')
    pos_moves = []
    for m in d:
        pos_moves.append(gen(state, m, b))
    return [move for move in pos_moves if move
            not in visited_state]

def gen(state, m, b):
    temp = state.copy()
    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]
    if m == 'd':
        temp[b+3], temp[b] = temp[b], temp[b+3]
    return temp

src = [2, 8, 3, 1, 6, 4, 7, -1, 5]
target = [1, 2, 3, 8, -1, 4, 7, 6, 5]

astar(src, target)
```


1 2 3
4 6
7 5 8
g=0, h=3, f=g+h=3
g=1, h=4, f=5
g=1, h=2, f=3
g=1, h=4, f=5
1 2 3
1 4 6
7 5 8
1 2 3
4 6
7 5 8
1 2 3
7 4 6
5 8
g=2, h=1, f=3
g=2, h=3, f=5
g=2, h=3, f=5
1 2 3
4 5 6
7 8
1 2 3
4 6
7 5 8
1 3
4 2 6
7 5 8
g=3, h=2, f=5
g=3, h=1, f=4
1 2 3
4 5 6
7 8
1 2 3
4 5 6
7 8
10
11
13
12
23

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
```

Date __/__/__
Page _____

Vaccum cleaner (Program-2)

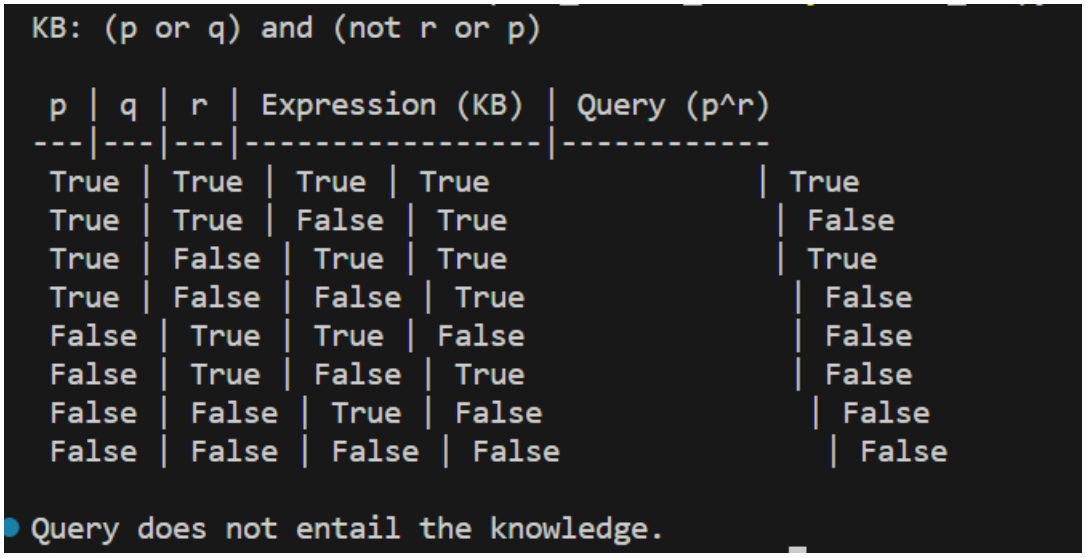
function (location, status) returns action
if status : Dirty then return Suck
else if location : A then return Right
else if location : B then return Left

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:



Propositional logic

KB: $(A \vee C) \wedge (B \vee \neg C)$

$\alpha = (A \vee B)$

Truth table:

A	B	C	$A \vee C$	$(B \vee \neg C)$	KB	α
True	T	T	T	T	T	T
T	T	F	T	T	T	T
T	F	T	T	F	F	T
T	F	F	T	T	T	T
F	T	T	T	T	T	T
F	T	F	F	T	F	T
F	F	T	T	F	F	F
F	F	F	F	T	F	F

α evaluates to true whenever KB evaluates to true.

$KB \models \alpha$

KB entails α

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$P \rightarrow Q \quad (\neg P \vee Q)$

P	Q	$\neg P \vee Q$	~~$\neg \alpha$~~
T	T	T	~~F~~
T	F	F	~~F~~
F	T	T	~~F~~
F	F	T	~~T~~

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.
```

Resolution

Prove R

P ∨ Q

P → R

Q → R

P → R ⇒ ¬P ∨ R

Q → R ⇒ ¬Q ∨ R

Step	Formula	Derivation
1	P ∨ Q	Given
2	¬P ∨ R	Given
3	¬Q ∨ R	Given
4	¬R	Negated conclusion
5	Q ∨ R	1, 2
6	¬P	2, 4
7	¬Q	3, 4
8	R	5, 7
9		4, 8

A contradiction is found when ¬R is assumed as true. Hence, R is true.

Code:

```
!pip install z3-solver
from z3 import Implies, Not, Bool, Solver, sat
p,q,r = Bool('p'), Bool('q'), Bool('r')
kb: Implies(p, q) & Implies(q, r) & Not (p)
query = r
def prove-query-with-resolution (knowledge-
                                 base, query):
```

```
s = Solver()
s.add(Not(knowledge_base), query)
result = s.check
return result == sat
proof_result = prove_query_with_
                resolution(kb, query)
if proof_result:
  print("The query is proved to be true.")
else:
  print("The query is not proved to be
                                  true.")
```

The query is proved to be 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
```

Unification in FOL

Code:

```
class Variable:
def __init__(self, name):
    self.name = name

class Atom:
def __init__(self, predicate, arguments):
    self.predicate = predicate
    self.arguments = arguments

def unify(var, x, theta):
    if var in theta:
        return unify(theta[var], x, theta)
    elif x in theta:
        return unify(var, theta[x], theta)
    elif isinstance(var, Variable):
        theta[var] = x
        return theta
    elif isinstance(x, Variable):
        theta[x] = var
        return theta
    elif isinstance(var, Atom) and
                        isinstance(x, Atom):
        if var.predicate != x.predicate or
        len(var.arguments) != len(x.arguments):
            return None
        for arg1, arg2 in zip(var.arguments,
                              x.arguments):
            theta = unify(arg1, arg2, theta)
            if theta is None:
                return None
```

```
        return None
    else:
        return None

def print_substitution(substitution):
    for key, value in substitution.items():
        print(f"{key.name} → {value.name}")

x = Variable('x')
y = Variable('y')
z = Variable('z')
j = Variable('j')
john = Variable('john')

atom1 = Atom('knows', [j, john])
atom2 = Atom('knows', [x, y])
theta = unify(atom1, atom2, {})
if theta is not None:
    print("Unification successful. Substitution theta:")
    print_substitution(theta)
else:
    print("Unification failed.")
```

output:

Unification successful. Substitution theta:

j → x

john → y

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)
```

FOL to CNF

Code:

```
def getAttributes(string):
    expr = '\([^)]+\)'
    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)
```

Steps:

1) Eliminate implications:

$a \rightarrow b = \sim a \vee b$

$\sim(a \wedge b) = \sim a \vee \sim b$ (De-Morgan's)

$\sim(a \vee b) = \sim a \wedge \sim b$

$\sim(\sim a) = a$

2) Eliminate Existential Quantifier '∃'

To eliminate f, replace the variable by skolem constant.

Ex: ∃y, President(y)

replace y

President(George Bush)

3) Eliminate universal quantifier, ∀

3) Eliminate universal quantifier ∀

Eliminate ∀, drop the pretix i.e just drop the ∀.

Ex:

a) ∀x: food(x) ⟹ likes(John, x)

b) food(Apple) ∧ food(vegetables)

1) Eliminate all implications

a) ∀x ¬food(x) ∨ likes(John, x)

b) food(Apple) ∧ food(Vegetables)

2) Move negation (¬) inwards

a) ∀x ¬food(x) ∨ likes(John, x)

b) food(Apple) ∧ food(Vegetables)

c)

3) Rename variable

Ex:

¬∀x p becomes ∃x ¬p

¬∃x p becomes ∀x ¬p.

Program 9:

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

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

def DeMorgan(sentence):
    string = ''.join(list(sentence).copy())
    string = string.replace(expr, string)
    flag = '[' in string
    string = string.strip(']')
    for predicate in getPredicates(string):
    string = string.strip(']')
    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 stolemization(sentence):
    stolem_constants = [f'{chr(c)}' for
c in range(ord('A'), ord('Z')+1)
    statement = ''.join(list(sdence).copy())
```

```
matches = re.findall('[∀]', statement)
statement = ''.join(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():
        skolem_constant.pop(0))
    else:
        a = [a for a in attributes if
             a.islower()]
        aU = [a for a in attributes if
              not a.islower()][0]
    return statement

def fol_to_cnf(fol):
    statement = fol.replace("<=>", "_")
while '_' in statement:
    i = statement.index('_')
    new_statement = '[' + statement[i] + '⇒'
        + statement[i+1:]
    for i,s in enumerate(statements):
        if '[' in s and ']' not in s
            statements[i] += ']'
        for s in statements:
            statement = statement[:br] +
            new_statement if br > 0 else result

print(skolemization(fol_to_cnf
    (animal(Y) <=> (over(x,Y))))
print(skolemization(fol_to_cnf(∀x[
∀y[animal(Y) ⇒ lover(x,Y)]] ⇒
```

[∃ z [loves(z,x)]]

output:

[~animal(y) | loves(x,y)] & [~loves(x,y) | animal(y)]

[animal(G(x)) & ~loves(x, G(x))]
loves(F(x), x)]

[~american(x) | ~weapon(y) | ~sells(x,y,z) | ~hostile(z)] | criminal(x)]

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)
```

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

missile(x) ⇒ weapon(x)

missile(M1)

enemy(x, America) ⇒ hostile(x)

american(West)

enemy(Nono, America)

owns(Nono, M1)

missile(x) & owns(Nono, x) ⇒ sells(West, x, Nono)

american(x) & weapon(y) & sells(x, y, z) & hostile(z) ⇒ criminal(x)

Query:

criminal(x)

Missile(M1)

missile(M1) ⇒ Weapon(M1)

x / M1

enemy(Nono, America) ⇒ hostile(Nono)

x / Nono

hostile(Nono)

missile(M1) & owns(Nono, M1) ⇒ sells (West, M1, Nono)

x / M1

american(West) & weapon(M1) & sells (West, M1, Nono) & hostile(Nono) ⇒ criminal(West)

∴ Query proved

Program 10:

```
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(
  self.predicate = predicate
  self.params = params
  self.result = any(self.getConstants())

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 is_variable(v) else None for v in self.params]

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

    def evaluate(self, facts):
        constants = {}
        new_lhs = []
        for fact in facts:
            for val in self.lhs:
                if val.predicate == fact.predicate:
                    for v, f in zip(val.getConstants(), fact.getConstants()):
                        if v:
                            constants[v] = f
                        new_lhs.append(fact)
        predicate, attributes = getPredicates(self.rhs.expression)[0], str(getAttributes(self.rhs.expression)[0])

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

    def tell(self, e):
        if '=>' in e:
            self.implication.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}:')

    def display(self):
        print("All facts:")

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('American(x) & Weapon(y) & sells
    (x,y,z) & hostile(z) => criminal(x)')
kb.query('criminal(x)')
kb.display()
```

Output:

All facts

1) Missile(M1)
2) Sells(West, M1, Nono)
3) Hostile(Nono)
4) Owns(Nono, M1)
5) Weapon(M1)

6) Criminal (West)
7) American (West)
8) enemy (Nono, America)
Criminal (West)