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"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence

Submitted by

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in
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CERTIFICATE

This is to certify that the Lab work entitled "**Artificial Intelligence**" carried out by **SANJANA NIRANJAN AMADALLI (1BM22CS418),** 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!")
```

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
```

URBAN EDGE

Sln

Tic Tac Toe

Algorithm used : MiniMax Algorithm

```
function minimax(board, depth, isMaximizingPlayer
    if current board state is a terminal state :
        return value of the board.

    if isMaximizingPlayer :
        bestval = -∞
        for each move in board :
            value = minmax(board, depth+1, false)
            bestval = max(bestvalue, value)
    return bestval

    else :
        bestval = +∞
        for each move in board :
        value = minmax(board, depth+1, fals
        bestval = min(bestvalue, value)

    return bestval
```

Assume that there are 2 possible way for X to win the game

Move A : X can win in 2 move
Move B : X can win in 4 moves

It may happen that it will choose B even though its a slower victo, hence we subtract the depth valu

Move A : 10 - 2 = 8
Move B : 10 - 4 = 6

8/11/2023

absolute maximum is 9! but in case of a win we need not traverse further once a win is encountered

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
```

URBAN EDGE

Program 2 : Vacuum cleaner

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

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
```

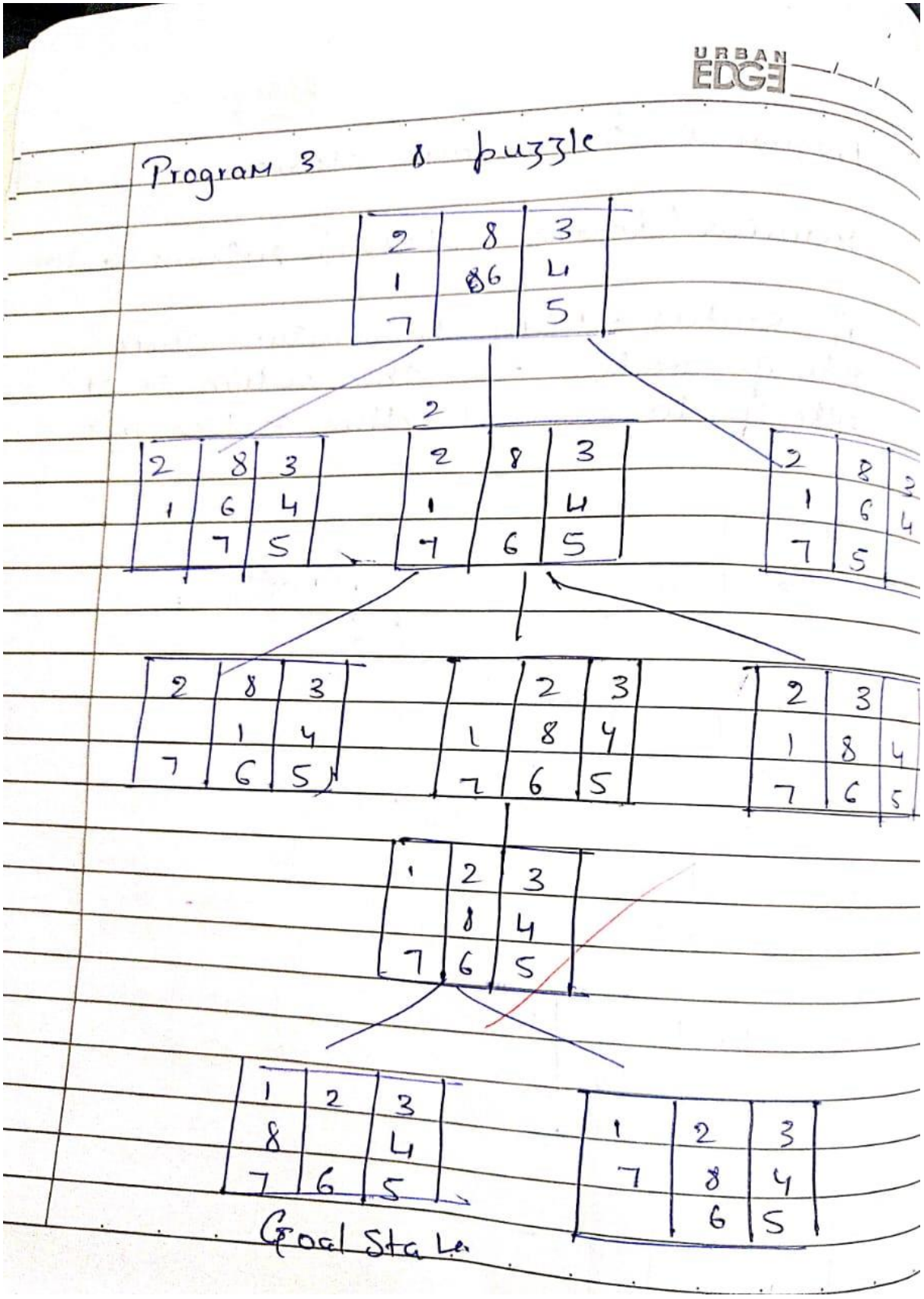
```
1 0 3
4 2 5
6 7 8

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
```


URBAN EDGE
Program 3 8 puzzle
Goal State

URBAN EDGE

* Move empty space to the left, move blank up, move blank to the right and move blank down

* These moves are modeled by production rules that operates on the state description in the appropriate manner

Initial State

2	8	3
1	6	4
7		5

Goal state

1	2	3
8		4
7	6	5

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
```

URBAN EDGE

Program 4 Iterative Deepening Search

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

depth = 1

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

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

False

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

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

```
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.

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]
```

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```
puzzle = EightPuzzle(initial_state, goal_state)
solution = puzzle.iterative_deepening_search()

if solution:
    print("Solution found")

else
    print("No solution found")
```

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
```

```
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]
    states = [moves[i]]

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('d')
```

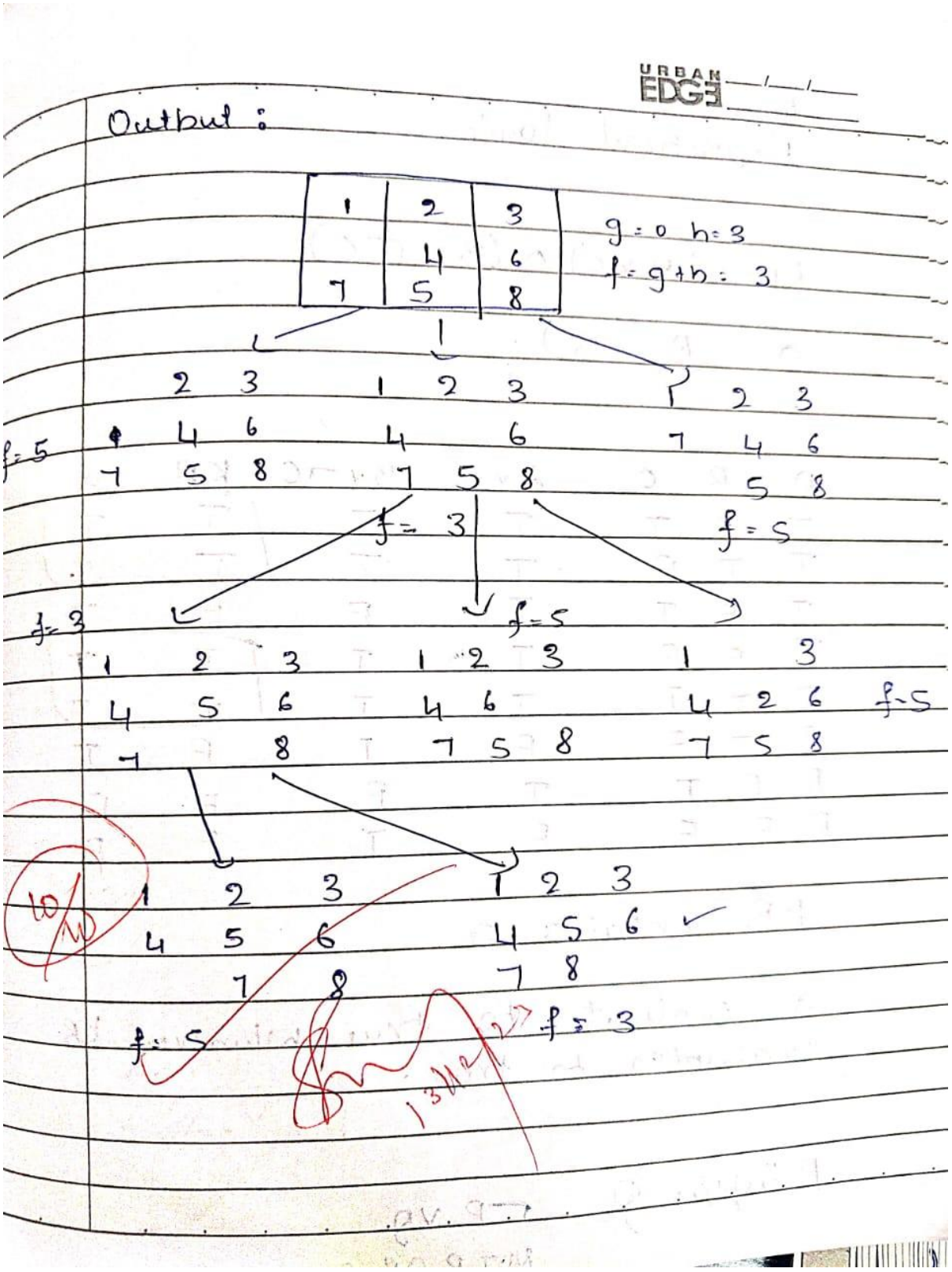
```
def gen(stat, m, b):
    temp = stat.copy()

    if (m == 'U'):
        temp[b-3], temp[b] = temp[b], temp[b
    if m == 'L':
        temp[b-1], temp[b] = temp[b], temp[b
    if m == 'R':
        temp[b+1], temp[b] = temp[b], temp[b
```

f = 5

```
# Test
src = [2, 8, 3, 1, 6, 4, 7, -1, 5]
target: [1, 2, 3, 8, -1, 4, 7, 6, 5]

astar(src, target)
```

Output &

Pseudo

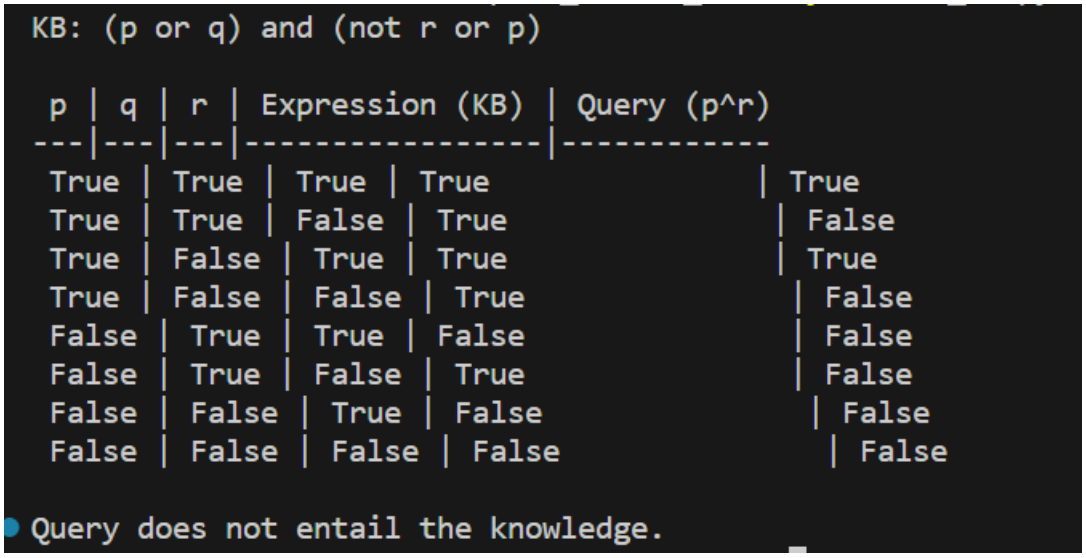

Output :
g = 0 h = 3
f = g + h = 3
f = 5
f = 3
f = 5
f = 5
f = 3

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:



Program 6
Propositional logic

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

$\alpha = (A \vee B)$

A	B	C	A ∨ C	B ∨ ¬C	KB	α
T	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

KB entails α

α evaluates to true whenever KB evaluates to true.

P implies Q : $\neg P \vee Q$

NOT P OR Q

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.
```

Program 7

Resolution

Prove R

① P ∨ Q

② P → R

③ Q → R

	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.

```
!pip install Z3-Solver
from Z3 import Implies, Not, Bool, Solver
p, q, r = Bool('p'), Bool('q'), Bool(
kb = Implies(p, q) & Implies(q, r) &
query = r

def prove-query-with-rus (knol_base, qu
    S = Solver()
    S.add(Not(knowledge_base), query
    result = S.check()
    return result == sat

proof-result = prove-query-with-rus (kb, qu

if proof_query:
    print("The Query is proved to be true
else
    print("The Query is not proved to b

O/P:
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
```

Program 8

Unification in FOL

```
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(theta[x], var, theta)
    elif isinstance(var, variable):
        theta[x] = var
        return theta
    elif isinstance(x, variable):
        theta[var] = x
        return theta
    elif isinstance(var, Atom) and isinstance(x,
        if var.predicate != x.predicate
            return None
```

```
        for arg1, arg2 in zip(var.arguments, x.
            theta = unify(arg1, arg2, theta)
            if theta is None:
                return None
        return theta
    else:
        return None

def print_sub(sub):
    for key, value in substitution.items():
        print(f"{key.name} -> {value.name}

X = Variable('X')
Y = Variable('Y')
Z = Variable('Z')

atom1 = Atom('knows', [X, Y])
atom2 = Atom('knows', [i, 'John'])

theta = unify(atom1, atom2, {})
if theta is Not None:
    print("unification successful").
else:
    print("unification failed")
```

Output:

Unification successful
i -> 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)
```

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Program 9

Convert FOL into CNF

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

```
def getPredicates(string):
    expr = '[a-zn]+\([
```

Steps

1) Eliminate implication '→'

$a \rightarrow b = \neg a \vee b$

$\neg(a \wedge b) = \neg a \vee \neg b$ (DeMorgan)

2) Eliminate Existential Quantifier ∃

To eliminate ∃, replace the variable by Skolem constant

$\exists x : \exists y . President(x)$

Replace y

President(GeorgeBush)

3) Eliminate Universal Quantifier ∀
To eliminate ∀, drop the prefix
i.e just drop the ∀

4) ~~Existential~~ ~~Elimination~~

Example 1

Ravi likes all kind of food

$\forall x : food(x) \rightarrow likes(Ravi, x)$

$\neg food(x) \vee likes(Ravi, x)$

Example 2

Apples and chicken are food

$food(Apple) \wedge food(chicken)$

$food(Apple)$

$food(chicken)$

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$\neg \forall x\ p$ becaus $\exists x\ \neg p$

$\neg \exists x$ $\forall x$

URBAN EDGE

Program 7

```
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.strip('[]')
    for predicate in getPredicates(string):
    string = string.replace(predicate, fs)
    s = list(string)
    for i, c in enumerate(string):
        if c == '|':
            s[i] = '&'
        elif c == '&':
            s[i] = '|'
```

```
string = ' '.join(s)
String = string.replace('s', 's')
return f'[{string}]' if flag else

def skolemization(Sentence):
    skolem_constants = ['{chr(c)}' for
c in range(ord('A'), ord('Z')+1,
    Statement = ''.join(list(Sentence).
    matches = re.findall('[∀∃]..'
    Statement = ''.re.findall('|[[
    +|]]', Statement)
    for s in Statements:
        Statement = Statement.replace(s,
    for predicate in getPredicate(State
        attributes = getAttributes(predic
    if ''.join(Attribute).islower():
        Statement = Statement.replace(match[i],
        skolem_constant.pop(0))
    else:
        aL = [a for a in attributes
a.islower()]
        aU = [a for a in attributes
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.replace

while 'n∀' in statement:
    i = statement.index('n∀')
    statement = list(statement)
    statement[i], statement[i+1]
    statement = statement[:br] +
    new_statement if br > 0 else new_st

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)]]')))
```

URBAN EDGE

Output

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

[animal(C(x)) & ∀x loves(x, C(x))] | loves(F(x), x)]

[∀x american(x) | ∀x weapon(y) | ∀x sell(x, y, z) | ∀x hostile(z)] | criminal(x)

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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)
```

Program 10

Create a knowledge base consisting of FOL & 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, ...

american (x) & weapon (y) & sells (x, y, z) => criminal (x)

Missile (M1)

missile (M1) => weapon (M1)

enemy (nono, America)

enemy (nono, America) => hostile (nono)

hostile (nono)

missile(M1) & owns(nono, M1) => sells(West, M1, nono)

~~x e) end~~

american(West)

america(West) & Weapon(M1) & Sells(West, M1, nono) => criminal(West)

Query: criminal(x)

criminal(West)

Query true.

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-zA-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 isVariable(v) else None for
v in self.params]


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

def evaluate(self, facts):
    constants = {}
    new_lhs = []
    for fact in facts:
        for val in self.lhs:
            if val.predicate == fact.predicate:
```

```
        if v:
            constants[v] = fact.getConstants()[i]
        new_lhs.append(fact)
    predicate, attributes = getPredicates(self.expression)[0], str(getAttributes(self.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 {i}:')

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('enemy(Nono, America)')
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:

criminal (west)

All facts

1) missile (M1)
2) sells (West, M1, None)
3) hostile (None)
4) owns (None, M1)
5) Weapon (M1)
6) criminal (West)
7) american (West)
8) enemy (None, America)

(W)