

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

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in

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CERTIFICATE

This is to certify that the Artificial Intelligence (22CS5PCAIN) laboratory has been carried out by Shashank D K(1BM21CS197) during the 5th Semester September-January 2021.

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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)
```

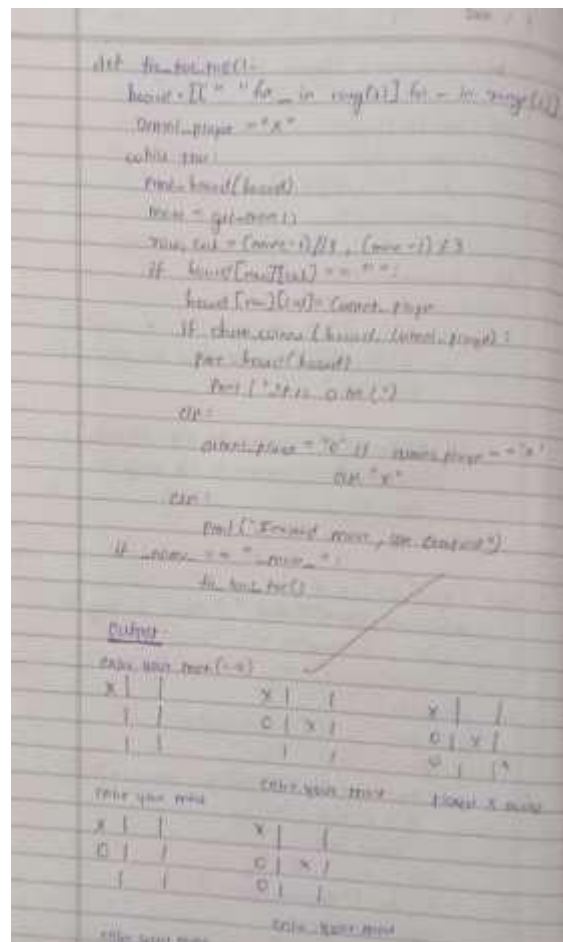
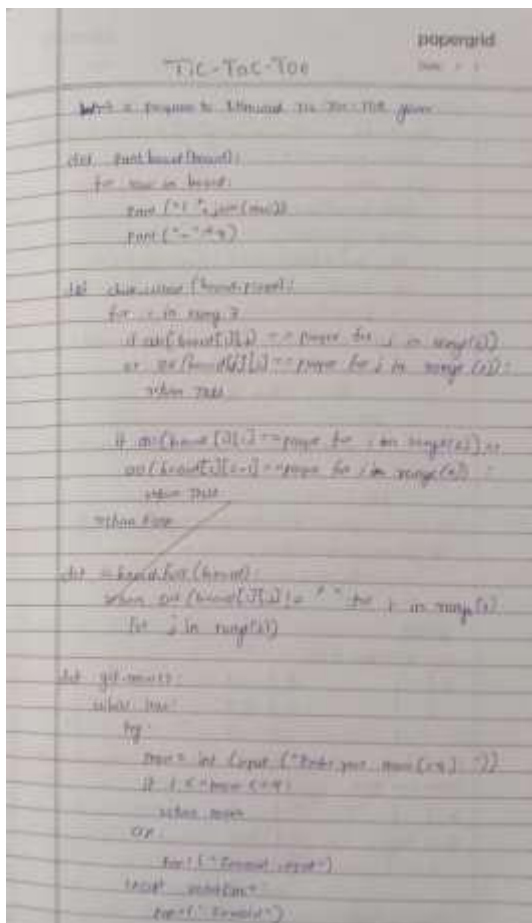
```
# Determine the winner
```

```
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
```

2. Solve 8 puzzle problems.

```
def bfs(src,target):
```

```
    queue = []
```

```
    queue.append(src)
```

```
    exp = []
```

```
    while len(queue) > 0:
```

```
        source = queue.pop(0)
```

```
        exp.append(source)
```

```

print(source)

if source==target:
    print("Success")
    return

poss_moves_to_do = []
poss_moves_to_do = possible_moves(source,exp)

for move in poss_moves_to_do:

    if move not in exp and move not in queue:
        queue.append(move)
def possible_moves(state,visited_states):
    #index of empty spot
    b = state.index(0)

    #directions array
    d = []

    #Add all the possible directions

    if b not in [0,1,2]:
        d.append('u')
    if b not in [6,7,8]:
        d.append('d')
    if b not in [0,3,6]:
        d.append('l')
    if b not in [2,5,8]:
        d.append('r')

```

```

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

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

for i in d:
    pos_moves_it_can.append(gen(state,i,b))

return [move_it_can for move_it_can in pos_moves_it_can if move_it_can not in
visited_states]
def gen(state, m, b):
    temp = state.copy()

    if m=='d':
        temp[b+3],temp[b] = temp[b],temp[b+3]

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

    if m=='l':
        temp[b-1],temp[b] = temp[b],temp[b-1]

    if m=='r':
        temp[b+1],temp[b] = temp[b],temp[b+1]

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

```

```

print("Example 1")

src= [2,0,3,1,8,4,7,6,5]

target=[1,2,3,8,0,4,7,6,5]

print("Source: " , src)

print("Goal State: " , target)

bfs(src, target)

```

```

print("\nExample 2")

src = [1,2,3,0,4,5,6,7,8]

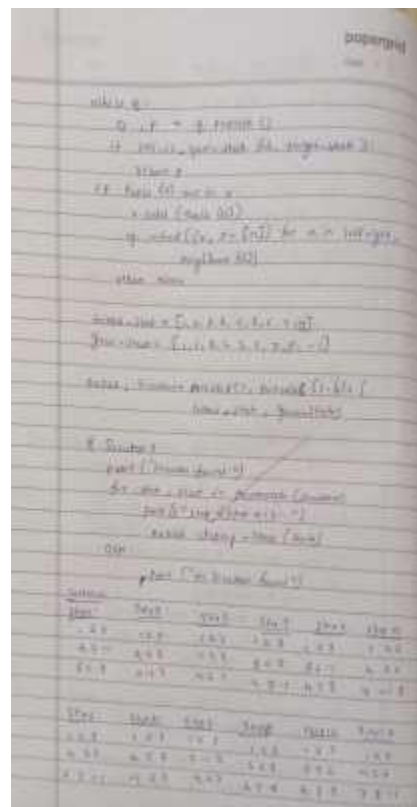
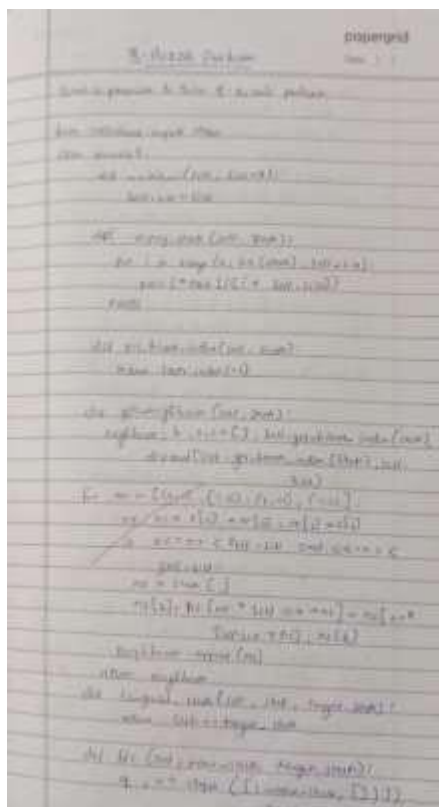
target = [1,2,3,4,5,0,6,7,8]

print("Source: " , src)

print("Goal State: " , target)

bfs(src, target)

```



OUTPUT:

Example 1

Source: [2, 0, 3, 1, 8, 4, 7, 6, 5]

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

[2, 0, 3, 1, 8, 4, 7, 6, 5]

[2, 8, 3, 1, 0, 4, 7, 6, 5]

[0, 2, 3, 1, 8, 4, 7, 6, 5]

[2, 3, 0, 1, 8, 4, 7, 6, 5]

[2, 8, 3, 1, 6, 4, 7, 0, 5]

[2, 8, 3, 0, 1, 4, 7, 6, 5]

[2, 8, 3, 1, 4, 0, 7, 6, 5]

[1, 2, 3, 0, 8, 4, 7, 6, 5]

[2, 3, 4, 1, 8, 0, 7, 6, 5]

[2, 8, 3, 1, 6, 4, 0, 7, 5]

[2, 8, 3, 1, 6, 4, 7, 5, 0]

[0, 8, 3, 2, 1, 4, 7, 6, 5]

[2, 8, 3, 7, 1, 4, 0, 6, 5]

[2, 8, 0, 1, 4, 3, 7, 6, 5]

[2, 8, 3, 1, 4, 5, 7, 6, 0]

[1, 2, 3, 7, 8, 4, 0, 6, 5]

[1, 2, 3, 8, 0, 4, 7, 6, 5]

Success

Example 2

Source: [1, 2, 3, 0, 4, 5, 6, 7, 8]

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

[1, 2, 3, 0, 4, 5, 6, 7, 8]

[0, 2, 3, 1, 4, 5, 6, 7, 8]

[1, 2, 3, 6, 4, 5, 0, 7, 8]

[1, 2, 3, 4, 0, 5, 6, 7, 8]

[2, 0, 3, 1, 4, 5, 6, 7, 8]

[1, 2, 3, 6, 4, 5, 7, 0, 8]

[1, 0, 3, 4, 2, 5, 6, 7, 8]

[1, 2, 3, 4, 7, 5, 6, 0, 8]

[1, 2, 3, 4, 5, 0, 6, 7, 8]

Success

3. Implement Iterative deepening search algorithm.

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



```

        return result

    return None

def possible_moves(state, visited_states):
    b = state.index(0)
    d = []

    if b not in [0, 1, 2]:
        d.append('u')
    if b not in [6, 7, 8]:
        d.append('d')
    if b not in [0, 3, 6]:
        d.append('l')
    if b not in [2, 5, 8]:
        d.append('r')

    pos_moves_it_can = []

    for i in d:
        pos_moves_it_can.append(gen(state, i, b))

    return [move_it_can for move_it_can in pos_moves_it_can if move_it_can not in
visited_states]

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

    if m == 'd':
        temp[b + 3], temp[b] = temp[b], temp[b + 3]
    elif m == 'u':

```

```

    temp[b - 3], temp[b] = temp[b], temp[b - 3]

elif m == 'l':

    temp[b - 1], temp[b] = temp[b], temp[b - 1]

elif m == 'r':

    temp[b + 1], temp[b] = temp[b], temp[b + 1]

return temp

def print_state(state):

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

print("Example 1")

src = [1,2,3,0,4,5,6,7,8]

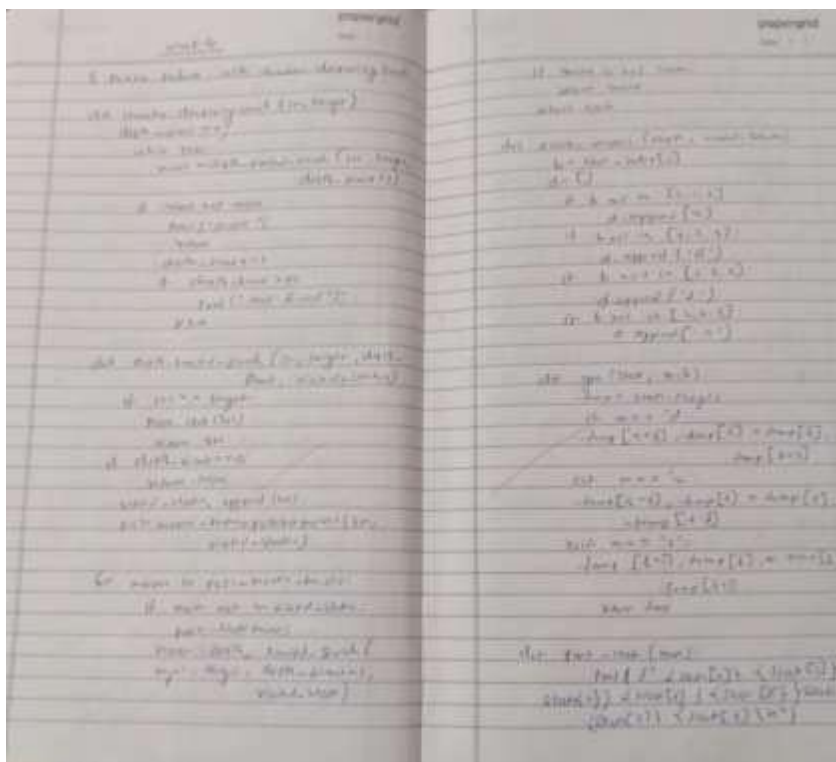
target = [1,2,3,4,5,0,6,7,8]

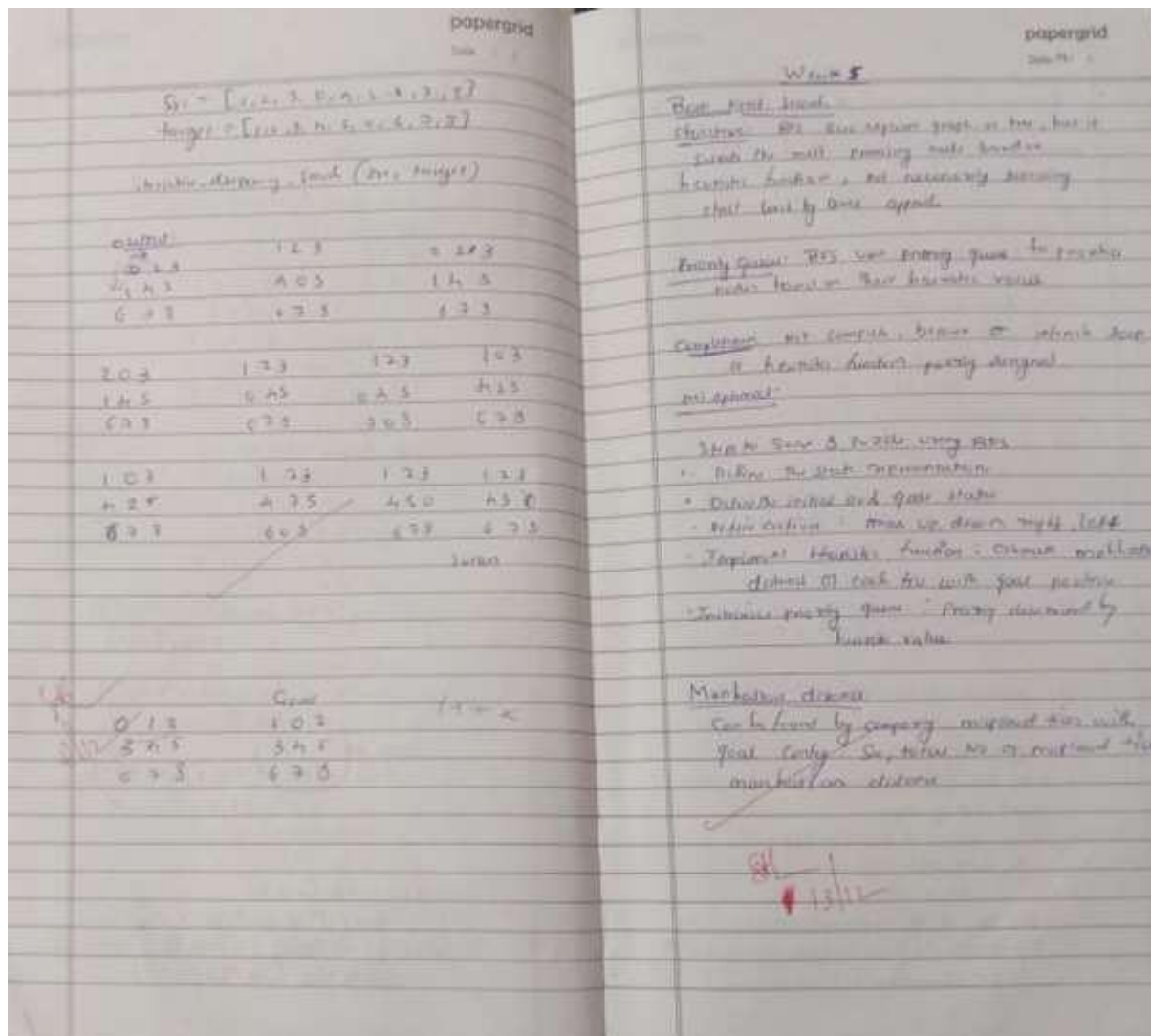
print("Source: " , src)

print("Goal State: " , target)

iterative_deepening_search(src, target)

```





OUTPUT:

Example 1

Source: [1, 2, 3, 0, 4, 5, 6, 7, 8]

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

0 2 3

1 4 5

6 7 8

1 2 3

6 4 5

0 7 8

1 2 3

4 0 5

6 7 8

0 2 3

1 4 5

6 7 8

2 0 3

1 4 5

6 7 8

1 2 3

6 4 5

0 7 8

1 2 3

6 4 5

7 0 8

1 2 3

4 0 5

6 7 8

1 0 3

4 2 5

6 7 8

1 2 3

4 7 5

6 0 8

1 2 3

4 5 0

6 7 8

1 2 3

4 5 0

6 7 8

Success

4. Implement A* search algorithm.

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

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

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

```

        visited_states.add(tuple(state))

        print_grid(state)

        if state == target:
            print("Success")
            return

        moves += [move for move in possible_moves(state, visited_states) if move not in
moves]

        costs = [g + h(move, target) for move in moves]
        states = [moves[i] for i in range(len(moves)) if costs[i] == min(costs)]
        g += 1
        print("Fail")

```

```

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

```

```

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

```

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

#Test 1

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

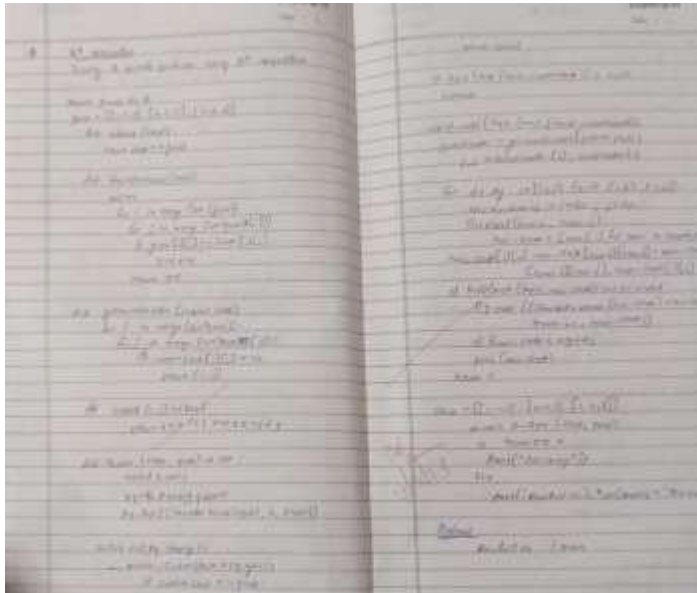
Test 2

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

Test 3

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

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



OUTPUT:

Example 1

Source: [1, 2, 3, -1, 4, 5, 6, 7, 8]

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

1 2 3

4 5

6 7 8

1 2 3

4 5

6 7 8

1 2 3

4 5

6 7 8

Success

Example 2

Source: [1, 2, 3, -1, 4, 5, 6, 7, 8]

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

1 2 3

4 5

6 7 8

1 2 3

6 4 5

7 8

Success

Example 3

Source: [1, 2, 3, 7, 4, 5, 6, -1, 8]

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Fail

5. Implement vacuum cleaner agent.

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

```

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

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

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

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

```


OUTPUT:

Room Condition:

[1, 0, 0, 0]

[0, 1, 0, 1]

[1, 0, 1, 1]

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

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

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

6. Create a knowledge base using propositional 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
```

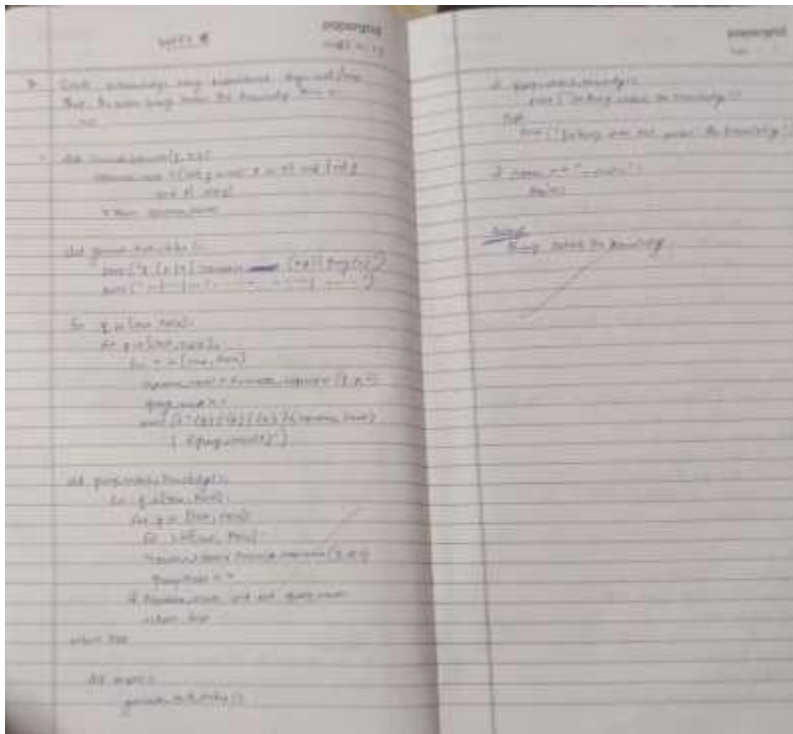
```

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:

KB: (p or q) and (not r or p)

p	q	r	Expression (KB)	Query (p^r)
True	True	True	True	True
True	True	False	True	False
True	False	True	True	True
True	False	False	True	False
False	True	True	False	False
False	True	False	True	False
False	False	True	False	False
False	False	False	False	False

- Query does not entail the knowledge.

7. Create a knowledge base using propositional 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)

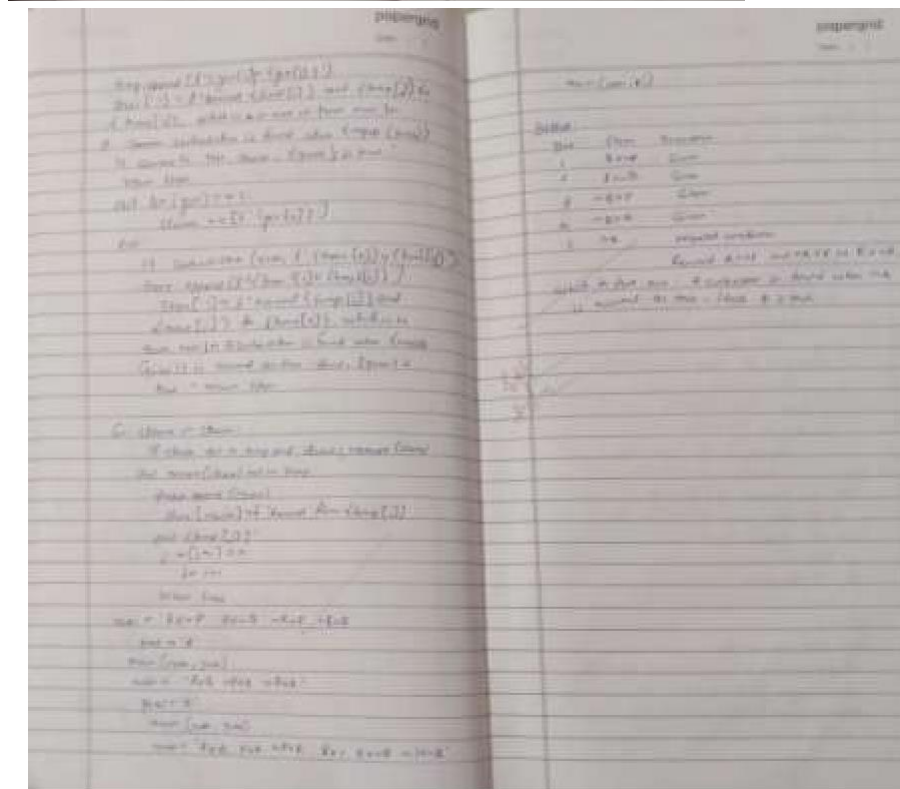
```

```

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: $R \vee \sim P$ $R \vee \sim Q$ $\sim R \vee P$ $\sim R \vee Q$

Goal: R

Step	Clause	Derivation

1.	$R \vee \sim P$	Given.
2.	$R \vee \sim Q$	Given.
3.	$\sim R \vee P$	Given.
4.	$\sim R \vee Q$	Given.
5.	$\sim R$	Negated conclusion.
6.		Resolved $R \vee \sim P$ and $\sim R \vee P$ to $R \vee \sim R$, which is in turn null.

A contradiction is found when $\sim R$ is assumed as true. Hence, R is true.

Example 2

Rules: $P \vee Q$ $\sim P \vee R$ $\sim Q \vee R$

Goal: R

Step	Clause	Derivation

1.	$P \vee Q$	Given.
2.	$\sim P \vee R$	Given.
3.	$\sim Q \vee R$	Given.
4.	$\sim R$	Negated conclusion.
5.	$Q \vee R$	Resolved from $P \vee Q$ and $\sim P \vee R$.
6.	$P \vee R$	Resolved from $P \vee Q$ and $\sim Q \vee R$.
7.	$\sim P$	Resolved from $\sim P \vee R$ and $\sim R$.
8.	$\sim Q$	Resolved from $\sim Q \vee R$ and $\sim R$.
9.	Q	Resolved from $\sim R$ and $Q \vee R$.
10.	P	Resolved from $\sim R$ and $P \vee R$.
11.	R	Resolved from $Q \vee R$ and $\sim Q$.
12.		Resolved R and $\sim R$ to $R \vee \sim R$, which is in turn null.

• A contradiction is found when $\sim R$ is assumed as true. Hence, R is true.

Example 3

Rules: $P \vee Q$ $P \vee R$ $\sim P \vee R$ $R \vee S$ $R \vee \sim Q$ $\sim S \vee \sim Q$

Goal: R

Step	Clause	Derivation

1.	$P \vee Q$	Given.
2.	$P \vee R$	Given.
3.	$\sim P \vee R$	Given.
4.	$R \vee S$	Given.
5.	$R \vee \sim Q$	Given.
6.	$\sim S \vee \sim Q$	Given.
7.	$\sim R$	Negated conclusion.
8.	$Q \vee R$	Resolved from $P \vee Q$ and $\sim P \vee R$.
9.	$P \vee \sim S$	Resolved from $P \vee Q$ and $\sim S \vee \sim Q$.
10.	P	Resolved from $P \vee R$ and $\sim R$.
11.	$\sim P$	Resolved from $\sim P \vee R$ and $\sim R$.
12.	$R \vee \sim S$	Resolved from $\sim P \vee R$ and $P \vee \sim S$.
13.	R	Resolved from $\sim P \vee R$ and P .
14.	S	Resolved from $R \vee S$ and $\sim R$.
15.	$\sim Q$	Resolved from $R \vee \sim Q$ and $\sim R$.
16.	Q	Resolved from $\sim R$ and $Q \vee R$.
17.	$\sim S$	Resolved from $\sim R$ and $R \vee \sim S$.
18.		Resolved $\sim R$ and R to $\sim R \vee R$, which is in turn null.

A contradiction is found when $\sim R$ is assumed as true. Hence, R is true.

8. Implement unification in first order logic

```
import re

def getAttributes(expression):
    expression = expression.split("(")[1:]
    expression = "(" + ".join(expression)
    expression = expression[:-1]
    expression = re.split("(?<!\(.\),(?!.\))", expression)
    return expression

def getInitialPredicate(expression):
    return expression.split("(")[0]

def isConstant(char):
    return char.isupper() and len(char) == 1

def isVariable(char):
    return char.islower() and len(char) == 1

def replaceAttributes(exp, old, new):
    attributes = getAttributes(exp)
    for index, val in enumerate(attributes):
        if val == old:
            attributes[index] = new
    predicate = getInitialPredicate(exp)
    return predicate + "(" + ", ".join(attributes) + ")"

def apply(exp, substitutions):
    for substitution in substitutions:
```



```
    new, old = substitution
    exp = replaceAttributes(exp, old, new)
return exp
```

```
def checkOccurs(var, exp):
    if exp.find(var) == -1:
        return False
    return True
```

```
def getFirstPart(expression):
    attributes = getAttributes(expression)
    return attributes[0]
```

```
def getRemainingPart(expression):
    predicate = getInitialPredicate(expression)
    attributes = getAttributes(expression)
    newExpression = predicate + "(" + ",".join(attributes[1:]) + ")"
    return newExpression
```

```
def unify(exp1, exp2):
    if exp1 == exp2:
        return []

    if isConstant(exp1) and isConstant(exp2):
        if exp1 != exp2:
            return False

    if isConstant(exp1):
```

```

    return [(exp1, exp2)]

if isConstant(exp2):
    return [(exp2, exp1)]

if isVariable(exp1):
    if checkOccurs(exp1, exp2):
        return False
    else:
        return [(exp2, exp1)]

if isVariable(exp2):
    if checkOccurs(exp2, exp1):
        return False
    else:
        return [(exp1, exp2)]

if getInitialPredicate(exp1) != getInitialPredicate(exp2):
    print("Predicates do not match. Cannot be unified")
    return False

attributeCount1 = len(getAttributes(exp1))
attributeCount2 = len(getAttributes(exp2))
if attributeCount1 != attributeCount2:
    return False

head1 = getFirstPart(exp1)
head2 = getFirstPart(exp2)
initialSubstitution = unify(head1, head2)
if not initialSubstitution:

```

```

    return False

if attributeCount1 == 1:
    return initialSubstitution

tail1 = getRemainingPart(exp1)
tail2 = getRemainingPart(exp2)

if initialSubstitution != []:
    tail1 = apply(tail1, initialSubstitution)
    tail2 = apply(tail2, initialSubstitution)

remainingSubstitution = unify(tail1, tail2)
if not remainingSubstitution:
    return False

initialSubstitution.extend(remainingSubstitution)
return initialSubstitution

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

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

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

```

```
exp2 = "knows(y,mother(y))"
```

```
print("Expression 1: ",exp1)
```

```
print("Expression 2: ",exp2)
```

```
substitutions = unify(exp1, exp2)
```

```
print("Substitutions:")
```

```
print(substitutions)
```

```
print("\nExample 3")
```

```
exp1 = "Student(x)"
```

```
exp2 = "Teacher(Rose)"
```

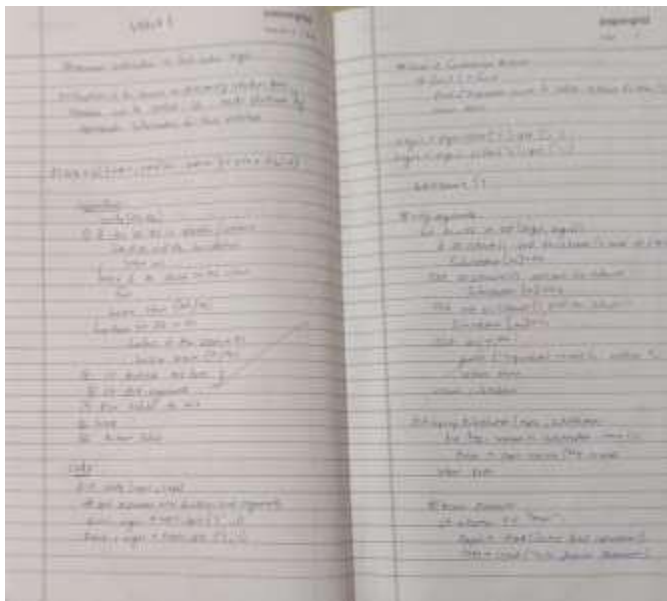
```
print("Expression 1: ",exp1)
```

```
print("Expression 2: ",exp2)
```

```
substitutions = unify(exp1, exp2)
```

```
print("Substitutions:")
```

```
print(substitutions)
```



1. $sum = 0$
 2. $sum = 0$
 3. $sum = 0$
 4. $sum = 0$
 5. $sum = 0$
 6. $sum = 0$
 7. $sum = 0$
 8. $sum = 0$
 9. $sum = 0$
 10. $sum = 0$
 11. $sum = 0$
 12. $sum = 0$
 13. $sum = 0$
 14. $sum = 0$
 15. $sum = 0$
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 22. $sum = 0$
 23. $sum = 0$
 24. $sum = 0$
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 28. $sum = 0$
 29. $sum = 0$
 30. $sum = 0$
 31. $sum = 0$
 32. $sum = 0$
 33. $sum = 0$
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 40. $sum = 0$
 41. $sum = 0$
 42. $sum = 0$
 43. $sum = 0$
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 86. $sum = 0$
 87. $sum = 0$
 88. $sum = 0$
 89. $sum = 0$
 90. $sum = 0$
 91. $sum = 0$
 92. $sum = 0$
 93. $sum = 0$
 94. $sum = 0$
 95. $sum = 0$
 96. $sum = 0$
 97. $sum = 0$
 98. $sum = 0$
 99. $sum = 0$
 100. $sum = 0$

OUTPUT:

Example 1

Expression 1: knows(f(x),y)

Expression 2: knows(J,John)

Substitutions:

[('J', 'f(x)'), ('John', 'y')]

Example 2

Expression 1: knows(John,x)

Expression 2: knows(y,mother(y))

Substitutions:

[('John', 'y'), ('mother(y)', 'x')]

Example 3

Expression 1: Student(x)

Expression 2: Teacher(Rose)

• Predicates do not match. Cannot be unified

Substitutions:

False

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

```

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

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

def Skolemization(statement):
    SKOLEM_CONSTANTS = [f'{chr(c)}' for c in range(ord('A'), ord('Z')+1)]
    matches = re.findall('[\exists].', 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:

```

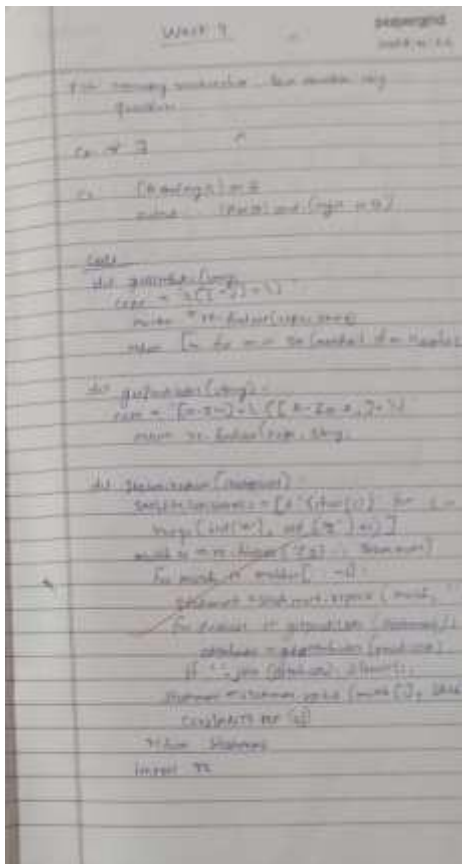
```

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:  $\text{bird}(x) \Rightarrow \neg \text{fly}(x)$ 
CNF:  $\neg \text{bird}(x) \vee \neg \text{fly}(x)$ 

Example 2
FOL:  $\exists x [\text{bird}(x) \Rightarrow \neg \text{fly}(x)]$ 
CNF:  $[\neg \text{bird}(A) \vee \neg \text{fly}(A)]$ 

Example 3
FOL:  $\text{animal}(y) \Leftrightarrow \text{loves}(x, y)$ 
CNF:  $\neg \text{animal}(y) \vee \text{loves}(x, y)$ 

Example 4
FOL:  $\forall x [\forall y [\text{animal}(y) \Rightarrow \text{loves}(x, y)]] \Rightarrow [\exists z [\text{loves}(z, x)]]$ 
CNF:  $\forall x \neg [\forall y [\neg \text{animal}(y) \vee \text{loves}(x, y)]] \vee [[\text{loves}(A, x)]]$ 

Example 5
FOL:  $[\text{american}(x) \wedge \text{weapon}(y) \wedge \text{sells}(x, y, z) \wedge \text{hostile}(z)] \Rightarrow \text{criminal}(x)$ 
CNF:  $\neg [\text{american}(x) \wedge \text{weapon}(y) \wedge \text{sells}(x, y, z) \wedge \text{hostile}(z)] \vee \text{criminal}(x)$ 

```

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()
```

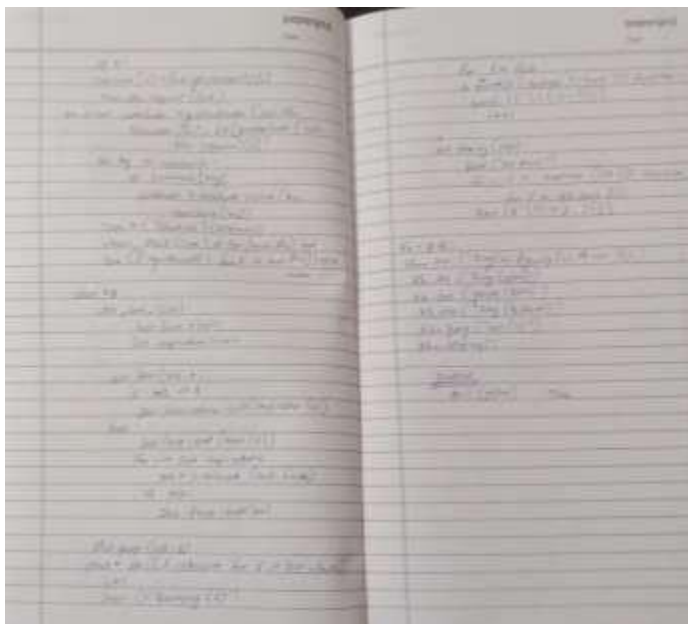
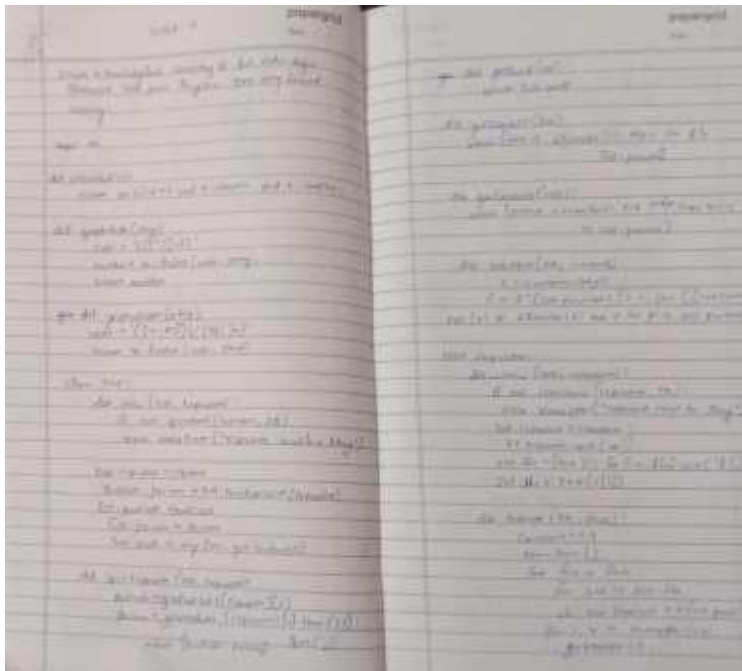
```
kb_.tell('king(x)&greedy(x)=>evil(x)')
```

```
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)