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
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(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 **SHREESHA H SHETTY (1BM21CS209),** who is bonafide student of **B.M.S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum during the academic semester June-2023 to Sep-2023. The Lab report has been approved as it satisfies the academic requirements in respect of a **Artificial Intelligence (22CS5PCAIN)** work prescribed for the said degree.

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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]:
```

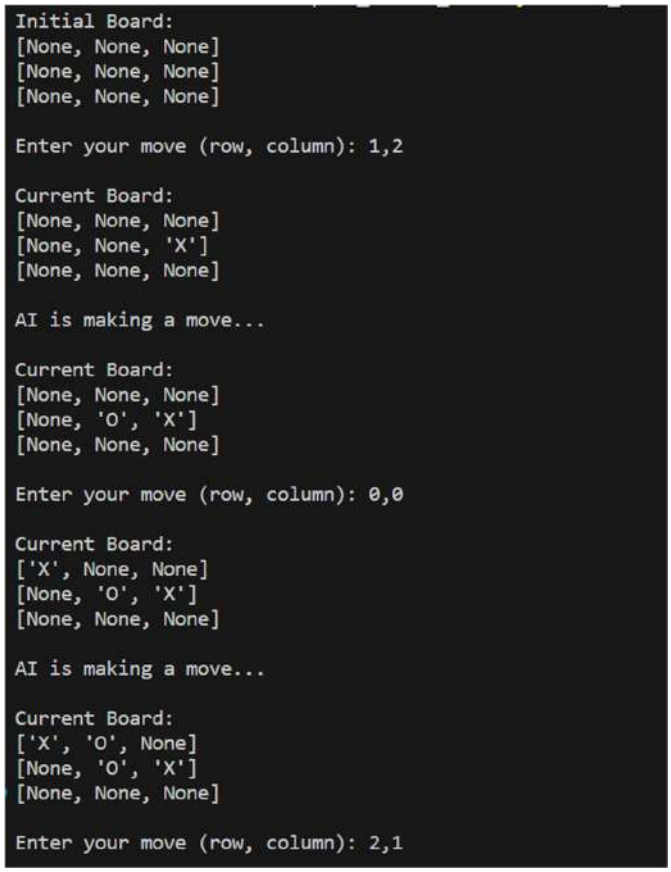
```
            s2.append(board[j][i])
        if (s2[0] == s2[1] == s2[2]):
            return s2[0]
    strikeD = []
    for i in [0, 1, 2]:
        strikeD.append(board[i][i])
    if (strikeD[0] == strikeD[1] == strikeD[2]):
        return strikeD[0]
    if (board[0][2] == board[1][1] == board[2][0]):
        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:
```

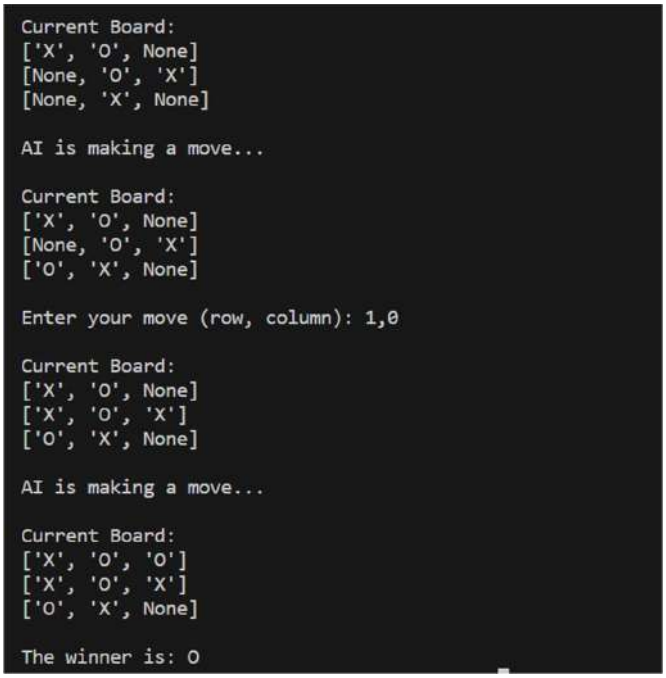
```
        return -1
    else:
        return 0


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:





2. Solve 8 puzzle problems.

```
def bfs(src,target):
    queue = []
    queue.append(src)

    exp = []

    while len(queue) > 0:
        source = queue.pop(0)
        exp.append(source)

        print(source)

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

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

        for move in poss_moves_to_do:

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

    #directions array
```

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

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



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


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


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


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


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


    if m=='u':
```

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

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

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



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

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

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

OUTPUT:

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

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

3. Implement Iterative deepening search algorithm.

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

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

    if depth_limit == 0:
        return None

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

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

```
            return result

    return None

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

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

    pos_moves_it_can = []

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

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

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

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

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

    return temp

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

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

OUTPUT:

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

1 2 3
6 4 5
0 7 8

1 2 3
4 0 5
6 7 8

0 2 3
1 4 5
6 7 8

2 0 3
1 4 5
6 7 8

1 2 3
6 4 5
0 7 8

1 2 3
6 4 5
7 0 8

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

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

1 2 3
4 7 5
6 0 8

1 2 3
4 5 0
6 7 8

1 2 3
4 5 0
6 7 8

Success
```

4. Implement A* search algorithm.

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

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

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

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


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


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

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

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


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


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

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

OUTPUT:

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

1 2 3
  4 5
6 7 8


1 2 3
4   5
6 7 8


1 2 3
4 5
6 7 8

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

1 2 3
  4 5
6 7 8


1 2 3
6 4 5
  7 8

Success
```

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

1 2 3
7 4 5
6   8


1 2 3
7 4 5
  6 8


1 2 3
  4 5
7 6 8


  2 3
1 4 5
7 6 8


1 2 3
4   5
7 6 8


1 2 3
4 6 5
7   8
```

```
1 2 3
  6 5
4 7 8


1 2 3
6   5
4 7 8


1 2 3
6 7 5
4   8


1 2 3
6 7 5
  4 8


1 2 3
  7 5
6 4 8


  2 3
1 7 5
6 4 8


1 2 3
7   5
6 4 8
```

```
7 1 3
4 6 5
  2 8


7 1 3
4 6 5
2   8


7 1 3
4   5
2 6 8


7 1 3
4 6 5
2 8


7 1 3
  4 5
2 6 8


7 1 3
2 4 5
  6 8

Fail
```

5. Implement vacuum cleaner agent.

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

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

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

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

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

OUTPUT:

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


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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

                if expression_result and not query_result:
                    return False

    return True
```

```
def main():
    generate_truth_table()

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

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

OUTPUT:

```
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 prepositional logic and prove the given query using resolution

```
import re


def main(rules, goal):
    rules = rules.split(' ')
    steps = resolve(rules, goal)
    print('\nStep\t|Clause\t|Derivation\t')
    print('-' * 30)
    i = 1
    for step in steps:
        print(f' {i}.\t| {step}\t| {steps[step]}\t')
        i += 1
def negate(term):
    return f'~{term}' if term[0] != '~' else term[1]


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


split_terms('~PvR')
def contradiction(goal, clause):
    contradictions = [ f'{goal}v{negate(goal)}', f'{negate(goal)}v{goal}']
    return clause in contradictions or reverse(clause) in contradictions
def resolve(rules, goal):
```

```
    temp = rules.copy()
    temp += [negate(goal)]
    steps = dict()
    for rule in temp:
        steps[rule] = 'Given.'
    steps[negate(goal)] = 'Negated conclusion.'
    i = 0
    while i < len(temp):
        n = len(temp)
        j = (i + 1) % n
        clauses = []
        while j != i:
            terms1 = split_terms(temp[i])
            terms2 = split_terms(temp[j])
            for c in terms1:
                if negate(c) in terms2:
                    t1 = [t for t in terms1 if t != c]
                    t2 = [t for t in terms2 if t != negate(c)]
                    gen = t1 + t2
                    if len(gen) == 2:
                        if gen[0] != negate(gen[1]):
                            clauses += [f'{gen[0]}v{gen[1]}']
                        else:
                            if contradiction(goal,f'{gen[0]}v{gen[1]}'):
                                temp.append(f'{gen[0]}v{gen[1]}')
                                steps[''] = f'Resolved {temp[i]} and {temp[j]} to {temp[-1]}, which is in
turn null. \
                                \nA contradiction is found when {negate(goal)} is assumed as true.
Hence, {goal} is true."
                                return steps
                    elif len(gen) == 1:
```

```
                clauses += [f'{gen[0]}']
            else:
                if contradiction(goal,f'{terms1[0]}v{terms2[0]}'):
                    temp.append(f'{terms1[0]}v{terms2[0]}')
                    steps[''] = f'Resolved {temp[i]} and {temp[j]} to {temp[-1]}, which is in turn null. \
                    \nA contradiction is found when {negate(goal)} is assumed as true. Hence, {goal} is true."
                    return steps
        for clause in clauses:
            if clause not in temp and clause != reverse(clause) and reverse(clause) not in temp:
                temp.append(clause)
                steps[clause] = f'Resolved from {temp[i]} and {temp[j]}.'
        j = (j + 1) % n
    i += 1
  return steps
rules = 'Rv~P Rv~Q ~RvP ~RvQ' #(P^Q)<=>R : (Rv~P)v(Rv~Q)^(~RvP)^(~RvQ)
goal = 'R'
print('Rules: ',rules)
print("Goal: ",goal)
main(rules, goal)

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

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

print("Goal: ",goal)

main(rules, goal)

OUTPUT:

```
Example 1
Rules:  Rv~P Rv~Q ~RvP ~RvQ
Goal:  R

Step    |Clause |Derivation
------------------------------
 1.     | Rv~P  | Given.
 2.     | Rv~Q  | Given.
 3.     | ~RvP  | Given.
 4.     | ~RvQ  | Given.
 5.     | ~R    | Negated conclusion.
 6.     |       | Resolved Rv~P and ~RvP to Rv~R, which is in turn null.
A contradiction is found when ~R is assumed as true. Hence, R is true.

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

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

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

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

8. Implement unification in first order logic

```
import re

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

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

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

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

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

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

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

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



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



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

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

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

    if isConstant(exp1):
```

```
    return [(exp1, exp2)]

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

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

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

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

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

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

```
        return False
    if attributeCount1 == 1:
        return initialSubstitution

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

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

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

    initialSubstitution.extend(remainingSubstitution)
    return initialSubstitution

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

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

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

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

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


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

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

OUTPUT:

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

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

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

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

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

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

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

def fol_to_cnf(fol):
    statement = fol.replace("=>", "-")
    expr = '\[([^]]+)\]'
    statements = re.findall(expr, statement)
    for i, s in enumerate(statements):
        if '[' in s and ']' not in s:
            statements[i] += ']'
```

```
    for s in statements:
        statement = statement.replace(s, fol_to_cnf(s))
    while '-' in statement:
        i = statement.index('-')
        br = statement.index('[') if '[' in statement else 0
        new_statement = '~' + statement[br:i] + '|' + statement[i+1:]
        statement = statement[:br] + new_statement if br > 0 else new_statement
    return Skolemization(statement)


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


print(Skolemization(fol_to_cnf("animal(y)<=>loves(x,y)")))
print(Skolemization(fol_to_cnf("∀x[∀y[animal(y)=>loves(x,y)]]=>[∃z[loves(z,x)]]")))
print(fol_to_cnf("[american(x)&weapon(y)&sells(x,y,z)&hostile(z)]=>criminal(x)"))
```

OUTPUT:

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

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

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

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

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

10. Create a knowledge base consisting of first order logic statements and prove the given query using forward reasoning.

```
import re

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

def getAttributes(string):
    expr = '\([^)]+\)'
    matches = re.findall(expr, string)
    return matches

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

class Fact:
    def __init__(self, expression):
        self.expression = expression
        predicate, params = self.splitExpression(expression)
        self.predicate = predicate
        self.params = params
        self.result = any(self.getConstants())

    def splitExpression(self, expression):
        predicate = getPredicates(expression)[0]
        params = getAttributes(expression)[0].strip('()').split(',')
        return [predicate, params]

    def getResult(self):
```

```
        return self.result

    def getConstants(self):
        return [None if isVariable(c) else c for c in self.params]

    def getVariables(self):
        return [v if isVariable(v) else None for v in self.params]

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

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

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

```
        predicate, attributes = getPredicates(self.rhs.expression)[0],
str(getAttributes(self.rhs.expression)[0])
        for key in constants:
            if constants[key]:
                attributes = attributes.replace(key, constants[key])
        expr = f'{predicate}{attributes}'
        return Fact(expr) if len(new_lhs) and all([f.getResult() for f in new_lhs]) else None


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


    def tell(self, e):
        if '=>' in e:
            self.implications.add(Implication(e))
        else:
            self.facts.add(Fact(e))
        for i in self.implications:
            res = i.evaluate(self.facts)
            if res:
                self.facts.add(res)


    def query(self, e):
        facts = set([f.expression for f in self.facts])
        i = 1
        print(f'Querying {e}:')
        for f in facts:
            if Fact(f).predicate == Fact(e).predicate:
                print(f'\t{i}. {f}')
                i += 1
```

```
    def display(self):
        print("All facts: ")
        for i, f in enumerate(set([f.expression for f in self.facts])):
            print(f'\t{i+1}. {f}')

kb = KB()
kb.tell('missile(x)=>weapon(x)')
kb.tell('missile(M1)')
kb.tell('enemy(x,America)=>hostile(x)')
kb.tell('american(West)')
kb.tell('enemy(Nono,America)')
kb.tell('owns(Nono,M1)')
kb.tell('missile(x)&owns(Nono,x)=>sells(West,x,Nono)')
kb.tell('american(x)&weapon(y)&sells(x,y,z)&hostile(z)=>criminal(x)')
kb.query('criminal(x)')
kb.display()

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

OUTPUT:

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

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

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Experiment: 1)

Implement Tic-Tac Toe game.

→

```
import random
board = [' ' for _ in range(10)]
def insertLetter(letter, pos):
    global board
    board[pos] = letter
def spaceIsFree(pos):
    return board[pos] == ' '
def printBoard(board):
    print(' ' + board[1] + '|' + board[2] + '|' +
                                        board[3])
    print('-----------')
    print(' ' + board[4] + '|' + board[5] + '|' +
                                        board[6])
    print('-----------')
    print(' ' + board[7] + '|' + board[8] + '|' +
                                        board[9])
def isWinner(bo, le):
    return (
        (bo[7] == le and bo[8] == le and bo[9] == le) or
        (bo[4] == le and bo[5] == le and bo[6] == le) or
        (bo[1] == le and bo[2] == le and bo[3] == le) or
        (bo[2] == le and bo[5] == le and bo[8] == le) or
        (bo[1] == le and bo[4] == le and bo[7] == le) or
        (bo[3] == le and bo[6] == le and bo[9] == le) or
        (bo[1] == le and bo[5] == le and bo[9] == le) or
        (bo[3] == le and bo[5] == le and bo[7] == le)
    )
```

```
def playerMove():
    global board
    run = True
    while run:
        move = input('Please select a position 1'X'[1-
        try:
            move = int(move)
            if 1 <= move <= 9:
                if spaceIsFree(move):
                    run = False
                    insertLetter('X', move)
                else:
                    print('Sorry, this space is occupi
            else:
                print('Please type a number within the
                    range!')
        except ValueError:
            print('Please type a number!')

def compMove():
    global board
    possibleMoves = [x for x, letter in enumerate(board)
    if letter == ' ' and x != 0]
    for let in ['O', 'X']:
        for i in possibleMoves:
            boardCopy = board[:]
            boardCopy[i] = let
            if isWinner(boardCopy, let):
                return i
    cornersOpen = [i for i in possibleMoves if i in [1,3,7,
    if cornersOpen:
        return selectRandom(cornersOpen)
```

```
    if 5 in possibleMoves:
        return 5
    edgesOpen = [i for i in possibleMoves if i in [2,4,6,8]]
    if edgesOpen:
        return selectRandom(edgesOpen)
    return None
def selectRandom(li):
    ln = len(li)
    r = random.randrange(ln)
    return li[r]
def isBoardFull(board):
    return board.count(' ') <= 1
def main():
    global board
    print('Welcome to tic tac toe!')
    printBoard(board)
    while not isBoardFull(board):
        if not isWinner(board,'O'):
            playerMove()
            printBoard(board)
        else:
            print('Sorry, O's won this time!')
            break
        if not isWinner(board,'X'):
            move = compMove()
            if move is None:
                print('Tie Game!')
            else:
                insertLetter('O', move)
                print('Computer placed an 'O' in
                      position:', move,':')
                printBoard(board)
```

```
        else:
            print('X's wins this time! Good Job!')
            break
    if IsBoardFull(board):
        print('Tie Game!')
while True:
    answer = input('Do you want to play again? (Y/N)')
    if answer.lower() == 'y' or answer.lower() == 'yes':
        board = [' ' for i in range(10)]
        print('-----------')
        main()
    else:
        break
main()
```

Output:

```
   |   |
---|---|---
   |   |
---|---|---
   |   |
```

Enter your move (1-9): 1

```
 X |   |
---|---|---
   |   |
---|---|---
   |   |
```

Enter your move (1-9): 2

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

Enter your move (1-9): 4

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

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Enter your move (1-9) : 3

X	O	O
X		

Enter your move (1-9) : 7

X	O	O
X		
X		

Player X wins

Experiment: 2)

Solve 8 puzzle problem

```
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=[]
        pos_moves_to_do = possible_moves (source,
        for move in poss_moves_to_do:
            if move not in exp and move not i
                queue.append (move)
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_cannot 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 temp

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

Output:

Solution found:

Step 1:

1 2 3
4 5 -1
6 7 8

Step 2:

1 2 3
4 5 8
6 7 -1

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Step 3:
1 2 5
4 5 8
6 -1 7

Step 4:
1 2 3
4 5 8
-1 6 7

Step 5:
1 2 3
5 -1 8
4 6 7

Step 6:
1 2 3
5 -1 8
4 6 7

Step 7:
1 2 3
5 6 8
4 -1 7

Step 8:
1 2 3
5 6 8
4 7 -1

Step 9:
1 2 3
5 6 -1
4 7 8

Step 10:
1 2 3
5 -1 6
4 7 8

Step 11:
1 2 3
-1 5 6
4 7 8

Step 12:
1 2 3
4 5 6
-1 7 8

Step 13:
1 2 3
4 5 6
7 -1 8

Step 14:
1 2 3
4 5 6
7 8 -1

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Experiment : 3)

Implement vaccum cleaner agent

→
```
def vacuum_world():
    goal_state = {'A':'0','B':'0'}
    cost = 0
    location_input = input("Enter location of vaccum")
    status_input = input("Enter status of " +
                         location_input)
    status_input_complement = input("Enter status
                                    of other room")
    print("Initial location condition" +str(goal_state))
    if location_input == 'A':
        print("Vaccum is placed in location A")
        if status_input == '1':
            print("location A is Dirty")
            goal_state['A'] = '0'
            cost += 1
            print("Cost for cleaning A "+str(cost))
            print("location A has been cleaned")
            if status_input_complement == '1':
                print("location B is dirty")
                print("Moving right to the location B.")
                cost += 1
                print("Cost for moving right " +str(cost))
                goal_state['B']='0'
                cost += 1
                print("Cost for SUCK "+str(cost))
                print("location B has been cleaned..")
    else:
        print("No action "+str(cost))
        print("location B is always clean")
```

```
if status_input == '0':
    print("location A is already clean")
    if status_input_complement == '1':
        print("location B is dirty")
        print("Moving Right to the location B")
        cost += 1
        print("Cost for moving right "+str(cost))
        goal_state['B'] = '0'
        cost += 1
        print("Cost for SUCK "+str(cost))
        print("location B has been cleaned")
    else:
        print("No action "+str(cost))
        print(cost)
        print("location B is already clean")
else:
    print("Vaccum is placed in location B")
    if status_input == '1':
        print("location B is dirty")
        goal_state['B'] = '0'
        cost += 1
        print("Cost for cleaning "+str(cost))
        print("Location B has been cleaned")
        if status_input_complement == '1':
            print("Location A is dirty.")
            print("Moving left to the location A")
            cost += 1
            print("Cost for moving left", str(cost))
            print("location A has been cleaned")
    else:
        print("No action "+str(cost))
        print("Location A is already clean")
```

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```
        print("Goal State:")
        print(goal_state)
        print("Performance : "+str(cost))
vaccum_world()
```

Output :

Enter location of Vacuum : A
Enter status of A 1
Enter status of other room : 1
Initial location condition of vacuum A and status is 1
Vacuum is placed in location A
Location A is dirty.
Cost for cleaning A 1
Location A has been cleaned.
Location B is dirty.
Moving right to location B
Cost for moving right 2
Cost for Suck 3
Location B has been cleaned
GOAL STATE :
{'A': '0', 'B': '0'}
Performance Measurement : 3

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Experiment: 4)

Analyse Iterative Deepening search Algorithm. Demonstrate how 8 Puzzle problem could be solved using this algorithm. Implement the same

→

IDS:

```
def depth_limited_search (node, goal, depth_limit, visi
    if node == goal:
        return True
    if depth_limit == 0:
        return False
    if depth_limit > 0:
        for child in graph[node]:
            if child not in visited:
                visited.add(child)
                if depth_limited_search (child, goal,
                                depth_limit - 1, visited
                    return True
    return False

def iterative_deepening_search (start, goal, graph_size)
    if start not in graph or goal not in graph:
        return False, 0
    depth_limit = 0
    while depth_limit <= graph_size:
        visited = set()
        if depth_limited_search (start, goal, depth_l
                                visited)
            return True, depth_limit
        depth_limit += 1
    return False, 0
```

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```
graph = {
    'A' : ['B', 'C'],
    'B' : ['A', 'D', 'E'],
    'C' : ['A', 'F', 'G'],
    'D' : ['B'],
    'E' : ['B', 'H'],
    'F' : ['C'],
    'G' : ['C'],
    'H' : ['E']
}

graph_size = len(graph)
start_node = 'A'
goal_node = 'G'
result, depth = iterative_deepening_search(start_node,
                                           goalnode, graph_size)
if result:
    print("Goal reached at depth {depth}")
else:
    print("Goal not found.")
```

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IDS 8 puzzle:

```
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:
            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 ind in d:
        pos_moves_it_can.append(gen(state, ind, 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("{state[0]} {state[1]} {state[2]}\n
          {state[3]} {state[4]} {state[5]}\n
          {state[6]} {state[7]} {state[8]}\n")

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

iterative_deepening_search(src, target)
```

Output:

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

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

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

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Experiment : 5)

Analyse best first search algorithm and A* alogrithm Implement 8 puzzle problem using both algorithms. Calculate complexity in both cases and infer your answer.

→ Best first search :

```
from queue import PriorityQueue

def best_first_search(graph, start, goal, heuristic):
    queue = PriorityQueue()
    queue.put((heuristic[start], start))
    visited = set()
    while not queue.empty():
        _, current = queue.get()
        if current == goal:
            return True
        visited.add(current)
        for neighbor in graph[current]:
            if neighbor not in visited:
                priority = heuristic[neighbor]
                queue.put((priority, neighbor))
    return False

graph = {
    'A': ['B', 'C'],
    'B': ['D', 'E'],
    'C': ['F'],
    'D': [],
    'E': ['G'],
    'F': [],
    'G': []
}
```

```
heuristic = {
    'A': 10,
    'B': 5,
    'C': 8,
    'D': 4,
    'E': 3,
    'F': 2,
    'G': 6
}

start_node = 'A'
goal_node = 'G'
result = best_first_search(graph, start_node, goal_node,
                           heuristic)
if result:
    print("Goal reached!")
else
    print("No solution found.")
```

Output:

Goal reached

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A* algorithm :

```
def aStarAlgo(start_node, stop_node):
    open_set = set(start_node)
    closed_set = set()
    g = {}
    parents = {}
    g[start_node] = 0
    parents[start_node] = start_node
    while len(open_set) > 0:
        n = None
        for v in open_set:
            if n == None or g[v] + heuristic(v) <
                                g[n] + heuristic(n):
                n = v
        if n == stop_node or Graph_nodes[n] == None:
            pass
        else:
            for (m, weight) in get_neighbors(n):
                if m not in open_set and m
                        not in closed_set:
                    open_set.add(m)
                    parents[m] = n
                    g[m] = g[n] + weight
                else:
                    if g[m] > g[n] + weight:
                        g[m] = g[n] + weight
                        parents[m] = n
                        if m in closed_set:
                            closed_set.remove(m)
                            open_set.add(m)
    if n == None:
        print('Path does not exist!')
        return None
```

```
        if n == stop_node:
            path = []
            while parents[n] != n:
                path.append(n)
                n = parents[n]
            path.append(start_node)
            path.reverse()
            print('Path found: {}'.format(path))
            return path
        open_set.remove(n)
        closed_set.add(n)
    print('Path does not exist!')
    return None

def get_neighbors(v):
    if v in Graph_nodes:
        return Graph_nodes[v]
    else:
        return None

def heuristic(n):
    H_dist = {
        'A': 3,
        'B': 4,
        'C': 2,
        'D': 6,
        'G': 0,
    }
    return H_dist[n]
```

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```
Graph_nodes = {
    'S': [('A', 1), ('G', 10)],
    'A': [('B', 2), ('C', 1)],
    'B': [('D', 5)],
    'C': [('D', 3), ('G', 4)],
    'D': [('G', 0)],
    'G': None
}

aStarAlgo('S', 'B')
```

Output:

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Experiment : 6)

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

→

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

def generate_truth_table():
    print ("q | p | r | Expression (KB) | Query (r)")
    print ("---|---|---|---------------|---------")
    for q in [True, False]:
        for p in [True, False]:
            for r in [True, False]:
                expression_result = evaluate_expression
                                    (q,p,r)
                query_result = r
                print (f" {q} | {p} | {r} | {expression_result

def query_entails_knowledge():
    for q in [True, False]:
        for p in [True, False]:
            for r in [True, False]:
                expression_result = evaluate_expression
                query_result = r                    (q,p,r)
                if expression_result and not query_resu
                    return False
    return True
```

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```
def main():
    generate_truth_table()
    if query_entails_knowledge():
        print("In Query entails the knowledge.")
    else:
        print("In Query does not entails the knowledge")
if __name__=="__main__":
    main()
```

Output:

q	P	r	Expression (KB)	Query (r)
True	True	True	False	True
True	True	False	False	False
True	False	True	False	True
True	False	False	False	False
False	True	True	False	True
False	True	False	False	False
False	False	True	False	True
False	False	False	False	False

Query entails the knowledge.

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Experiment: 7)

Create a knowledgebase using propositional logic and prove the given query using resolution.

→

```
import re

def main(rules, goal):
    rules = rules.split(' ')
    steps = resolve(rules, goal)
    print('\n Step \t| Clause \t| Derivation \t')
    print('-' * 30)
    i = 1
    for step in steps:
        print(f' {i}. \t| {step} \t| {steps[step]} \t')
        i += 1

def negate(term):
    return f'~{term}' if term[0] != '~' else term[1]

def reverse(clause):
    if len(clause) > 2:
        t = split_terms(clause)
        return f'{t[1]}v{t[0]}'
    return ''

def split_terms(rule):
    exp = '(~*[PQRS])'
    terms = re.findall(exp, rule)
    return terms
split_terms('~PvR')
['~P', 'R']
```

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```
def contradiction(goal, clause):
    contradiction = [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]}')
    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.
                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]}'):
            steps[''] = f"Resolved {temp[i]} and
                {temp[j]} to {temp[-1]}, which
                is in turn null. 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'
goals = 'R'
main (rules, goal)
rules = 'PVQ PVR ~PVR RVS RV~Q ~SV~Q'
main (rules, 'R')
```

Output :

Step	Clauses	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.

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

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

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Experiment 8)

Implement unification in first order logic.

→

```
def unify(expr1, expr2):
    func1, args1 = expr1.split('(', 1)
    func2, args2 = expr2.split('(', 1)
    if func1 != func2:
        print("Expressions cannot be unified. Different functions.")
        return None
    args1 = args1.rstrip(')').split(',')
    args2 = args2.rstrip(')').split(',')
    substitution = {}
    for a1, a2 in zip(args1, args2):
        ~~substitution[a1] = a2~~
    ~~elif a1.islo:~~
        if a1.islower() and a2.islower() and a1 != a2:
            substitution[a1] = a2
        elif a1.islower() and not a2.islower():
            substitution[a1] = a2
        elif not a1.islower() and a2.islower():
            substitution[a2] = a1
        elif a1 != a2:
            print("Expressions cannot be unified. Incompatible arguments.")
            return None
    return substitution

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

```
if __name__ == "__main__":
    expr1 = input("Enter the first expression: ")
    expr2 = input("Enter the second expression: ")
    substitution = unify(expr1, expr2)
    if substitution:
        print("The substitutions are:")
        for key, value in substitution.items():
            print(f'{key} / {value}')
        expr1_result = apply_substitution(expr1, substitut
        expr2_result = apply_substitution(expr2, substitu
        print(f'Unified expression 1: {expr1_result}')
        print(f'Unified expression 2: {expr2_result}')
```

Output:

Enter the first expression: knows(John, x)

Enter the second expression: knows(y, mother(y))

The substitutions are:

y / John

x / mother(y)

Unified expression 1: knows(John, mother(y))

Unified expression 2: knows(John, mother(John))

Eg:-

P(x, F(y)) — ① P(a, F(g(z))) — ②

① & ② are identical if x is replace with a

P(a, F(g(z)) & y is replace with g(z)

[a/x, g(z)/y]

substitution set

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Experiment : 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-zA-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],
    return statement                SKOLEM_CONSTANTS.pop(0)
import re
```

```
def fol_to_cnf(fol):
    statement = fol.replace("=>", "-")
    expr = '\[([^]]+)\]'
    statements = re.findall(expr, statement)
    for i, s in enumerate(statement):
        if '[' in s and ']' not in s:
            statements[i] += ']'
    for s in statements:
        statement = statement.replace(s, fol_to_cnf(s))
    while '-' in statement:
        i = statement.index('-')
        br = statement.index('[') if '[' in statement else 0
        new_statement = '~' + statement[br:i] + '|' + statement[i+1:]
        statement = statement[:br] + new_statement if br > 0 else new_statement
    return Skolemization(statement)
print(fol_to_cnf("bird(x)=>~fly(x)"))
print(fol_to_cnf("∃x [bird(x)=>~fly(x)]"))
```

Output:

~bird(x) | ~fly(x)

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

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Experiment : 10)

Create a knowledgebase consisting of first order logic statements and prove the 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])})"

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(Implementation(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.expressio
                                   for f in self.facts])):

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)')
```