VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (22CS5PCAIN)

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 **Varun S (1BM21CS238),** 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.

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8-puzzle.

```
import heapq

class PuzzleState
    def __init__ (self, board, goal, moves=0):
        self.board = board
        self.goal = goal
        self.moves = moves
        self.priority = self.calculate_priority()

    def __it__ (self.other):
        return self.priority < other.priority

    def calculate_priority(self):
        return self.moves + self.manhattan distance

    def manhattan_distance(self)
        distance = 0
        for i in range(3):
            for j in range(3):
                value = self.board[i][j]
                if value != 0:
                    goal_row, goal_col =
                        divmode(self.goal.index[10],3)
                    distance += abs(i-goal_row)
                    abs(j-goal_col)
                    return dis
                return distance
```

```
def get_possible_moves(state):
    moves = []
    row, col = next((i,j) for i in range(3)
                          for j in range(3))
    if (state.board[i][j] == 0):
        fo
        for i,j in ((row-1, col), (row+1, col),
                    (row, col-1), (row, col+1)):
            if (0<= i <=3 and 0<= j <=3):
                new_board[row][col]
                m
                moves.append(puzzlestate(new_board[i]
                    = new_board[i][j])
    return moves

def solve_puzzle(initial, goal):
    initial_state = PuzzleState(initial, goal)
    heap = [initial_state]
    visited = set()
    while (heap):
        current_state = heapq.heappop(heap)
        if (current_state.board == goal):
            return current_state.moves
        visited.add(tuple(map(tuple,
                    current_state.board)))
        for m in get_possible_moves(restate)
            if tuple(map(tuple, moveboard)
                heap.heappush(heap, move)
            retu
    return 1
```

Output:

src: 2,0,3,1,8,4,7,6,5

target: 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]

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

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Lab Program - 2
Tic-Tac-Toe

```
def print_board(board):
    for row in board:
        print("|".join(row))
        print("-"*9)

def check_winner(board,players):
    for i in range(3):
        if all(board[i][j]==players for j in range
        or
        all(board[i][j]==players for j in range(3)
        return True
        if all(board[i][j]==players for ji in range(3)
        or
        all(board[i][2-i]==player for i in range(3)
        return True
    return False

def get_move():
    while True:
        try
            move=int(input("Enter your move(1-9):
            if 1<=move<=9:
                return move
            else
                print("invalid move")
        except ValueError
            print("Invalid")
```

```
def Tic-Tac-toe:
    board [[" " for _ in range(3)]
           for _ in range(3)]
    current_player = "X"
    while True:
        print_board(board)
        move = get_move()
        row, col = (move-1)//3, (move-1)%3
        if board[row][col] == " ":
            board[row][col] == current_player
        else:
            if check_winner(board, current_player):
                print_board(board)
                print("Tie")
            else
                print("Invalid move"):
```

Output

```
enter your move (1-9)
X |   |       X |   |       X |   |
  |   |       O | X |       O | X |
  |   |         |   |       O |   | X
                              player 1 wins

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

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Vacuum Cleaner agent

```
def vacuum_world():
    goal_state = {'A':'0', 'B':'0'}
    cost = 0
    location_input = input("Enter location")
    status_input = input("Enter status of" + location_input)
    status_input_complement = input("Enter status of other room")

    if location_input == 'A':
        print("Vacuum 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("Loc B is dirty")
            print("Moving right to loc 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");
```

```
if status_input == '0':
    print("Loc A is already cleaned")
    if status_input_complement == '1':
        print("Loc B is Dirty")
        print("Moving right to location B")
        cost += 1
        goal_state['B'] = '0'
        cost += 1
        print("cost for suck " + str(cost))
        print("Loc B has been cleaned")
    else
        print("No action" + str(cost))
        print(cost)
        print("Location B is already cleaned")
else
    print("Vacuum is placed in loc B")
    if status_input == '1'
        print("Location B is dirty")
        goal_state['B'] = '0'
        cost += 1
        print("cost for cleaning" + str(cost))
        print("Loc B has been cleaned")
        is
        if status_input_complement == '1'
            print("Loc A is dirty")
            print("Moving Left to LOCA")
            cost += 1
            print("cost for moving LEFT" +
                  str(cost))
            print("Loc A has been cleaned")
```

```
else:
    print(cost)
    print("Loc B is already cleaned")
    if status_input-complement=='1':
        print("Location A is dirty")
        print("Moving left to Loc A")
        cost+=1
        print("cost for moving left"+str(cost))

        goal_state['A']='0'
        cost+=1
        print("cost="+str(cost)+" Loc A cleaned")

    else:
        print("No action"+str(cost))
        print("Location A is already clean.")

print("Goal state:")
print(goal_state)
print("performance measurement: "+str(cost))

vacuum_world()
```

Output:

```
Enter loc of vacuum A
Enter state of A: 1
Enter state of other room: 0
Initial {'A':'0','B':'1'}
Loc A is dirty
cost for cleaning A: 1
Loc B is already clean
Goal state:
{'A':'0','B':'1'}
performance measurement=1
```

Week-4

8 puzzle problem with iterative deepening Search

```
def iterative_deepening_search(src, target):
    depth_limit = 0;
    while True:
        result = depth_limited_search(src, target, depth_limit)
        if result not None:
            print("success");
            return
        depth_limit += 1
        if depth_limit > 30:
            print("Solution not found within 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)
    pos
    poss_moves_to_do = possible_moves(src, visited_states)

    for moves in poss_moves_to_do:
        if move not in visited_states:
            print_state(move)
            result = depth_limited_search
                (move, target, depth_limit -1,
                visited_state)
```

```
            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 == '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"
          f"{state[3]} {state[4]} {state[5]}\n"
          f"{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      0 2 3
1 4 5      4 0 5      1 4 5
6 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
4 2 5      4 7 5      4 5 0
6 7 8      6 0 8      6 7 8

Success
Solution found
```

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Week-5

8 puzzle using best first search.

```
input queue as Q
import goal = [[1,2,3], [4,5,6], [7,8,0]]
def isgoal(state):
    return state == goal.

def heuristicvalue(state):
    cnt = 0
    for i in range(len(goal)):
        for j in range(len(goal[i])):
            if goal[i][j] != state[i][j]:
                cnt += 1
    return cnt

def getCoordinates(currentState):
    for i in range(len(goal)):
        for j in range(len(goal[i])):
            if currentState[i][j] == 0:
                return (i, j)

def isValid(i, j) -> bool:
    return 0<= i <3 and 0<= j <3

def BFS(state, goal) -> int:
    visited = set()
    pq = Q.priorityqueue()
    pq.put([Heuristicvalue(state), 0, state])
    while not pq.empty():
        moves, current_state = pq.get()
```

```
if currentState == goal:
    return moves
if tuple(map(tuple, currentstate)):
    i, j = coordinates[0], coordinates[1]
return moves.

if tuple(map(tuple, currentstate)) in visited:
    continue.

for dx, dy in [[0,1],(0,1),(1,0),[-1,0]]:
    new-i, new-j = i+dx, j+dy
    if isvalid(new-i, new-j):
        new-state [row[i] for row in
                   currentstate)
    new_state[i][j], new_state[new-i][new-j]
                =
    new state[new-i][new-j], new-state[i][j]

State = [1,2,3], [4,5,6], [7,8]
State = [1,2,3], [4,5,6], [7,0,8]
moves = BFS (State, goal)
if moves == -1:
    print("No way to reach given state")
else
    print("Reached in " + str(moves)+"moves")
```

Output:

Reached in 1 moves.

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A* algorithm

```
import queue as Q
goal = [[1,2,3], [4,5,6], [7,8,0]]
def isgoal(state):
    return state == goal

def Heuristic Value(state):
    cnt=0
    for i in range((len(goal)):
        for j in range (len(goal[i])):
            if goal[i][j] != state[i][j]
                cnt += 1
    return cnt

def getCoordinates(currentstate):
    for i in range (len(goal)):
        for j in range (len(goal[i])):
            if currentstate[i][j] == 0:
                return (i,j)
def isValid(i,j) → bool:
    return 0 <= i<3 and 0 <= j<3

def A_star(state, goal) → int:
    visited = set()
    pq = Q.priorityQueue()
    pq.print((Heuristic value (state), 0, state))

while not pq.empty():
    _, moves, currentstate = pq.get()
        if currentstate == goal
            return moves
```

M4 PRO

```
for dx, dy in [(0,1) (0,-1) (1,0) (-1,0)]
    new-i, new-j = i+dx, j+dy
    if isValid (new-i, new-j):
        new_state = [row[i] for row in
                     currentstate]

new-state[i][j], new-state[new-i][new-j]
= new-state[new-i][new-j], new-state[i][j]

if tuple(map(tup, new_state)) not in visited:
    pq.print((Heuristicvalues(new-state)
              + moves, moves+1,
              new-state))

    if new-state == goal:
        print(new-state)
return -1

states = [[1,2,3], [4,0,5], [6,7,8]]
moves = A-star (state, goal)
    if moves == -1;
        print("No way to reach")
    else:
        print("Reach in "+ str(moves)+ "moves")
```

Output:

Reach in 1 moves

13/12/23

20/12/2023

Week-6

Code: Create knowledgebase using propositional logic and show query entails knowledge base

```
def evaluate_first(premise, conclusion):
    models = [
    {'p': False, 'q': False, 'r': False},
    {'p': False, 'q': False, 'r': True},
    {'p': False, 'q': True, 'r': False},
    {'p': False, 'q': True, 'r': True},
    {'p': True, 'q': False, 'r': False},
    {'p': True, 'q': False, 'r': True},
    {'p': True, 'q': True, 'r': False},
    {'p': True, 'q': True, 'r': True},
    ]

    entails = True
    for model in models:
        if evaluate_expression(premise, model) !=
            evaluate_expression(conclusion, model):
            entails = True
            break
    return entails

def evaluate_second(premise, conclusion):
    models = [
        {'p': p, 'q': q, 'r': r}
        for p in [True, False]
            for q in [True, False]
                for r in [True, False]
    ]
```

```
entails = all (evaluate_expression (premise,mod
    for model in models if
    if evaluate_expression (conclusion, model)
    and evaluate_expression (premise, model)
    return entails

def evaluate_expression (expression, mode)):
    if is instance (expression, str):
        return model.get (expression, str)
    elif is instance (expression, tuple):
        op = expression[0]
        if op == 'not':
            return not evaluate_expression
                    (expression[1], model)
        elif op == 'and':
        # return evaluate_expression
                    (expression[1], model):
            and
        evaluate_expression(expression[2], model)

        elif op == 'if':
            return (not evaluate_expression
                    (expression[2], model))
            or evaluate_expression
                    (expression[2], model))
        elif op == 'or':
            return evaluate_expression
                    (expression[1], model)
                or
                    evaluate_expression
                    (expression[2], model)
```

```
first_premise = ('and', ('or', 'p', 'q'),
                        ('or', ('not', 'r'), 'p'))

first_conclusion = ('and', 'p', 'r')
second_premise = ('and', ('or', ('not', 'q'),
                          ('not', 'p'), 'r'),
                  ('and', ('not', 'q'), 'p'), 'r')

second_conclusion = 'r'
result_first = evaluate_first(first_premise,
                              first_conclusion)
result_second = evaluate_second(second_premise,
                                second_conclusion)

if result_first
    print("For the first input: The
          knowledge base entails query")

else
    print("For first input: Knowledge base
          does not entails query")
```

Output:

For first input: Knowledge base does not entail query

For second input: Knowledge base entails query.

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Week-7

Create knowledgebase using propositional logic and prove the given query using propositional logic

```
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')
['~P', 'R']

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]}')
                        :
```

Continued.

```
        temp.append(f'{gen[0]}v{gen[1]}')
        steps[''] = f"Resolved {temp[i]} and temp[j]}
                    to temp[-1], which is in turn
                    null.\n A 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{terms[0]}')
        steps[''] = f"Resolved {temp[i]} and
                    {temp[j]} to temp[-1],
                    which is in turn null,\n
                    A contradiction is found
                    when {negate(goal)} is
                    assumed as true, Hence
                    {goal} is true."
        return steps
    j = (j+1) % n
i += 1
return steps
```

```
rules = 'RV~P RV~Q ~RVP ~RV~Q'
goal = 'R'
main(rules, goal)
rules = 'PVQ&PV~R~QVR'
goal = 'R'
main(rules, goal)
rules = 'PVQ PV~R~PVR RVS RV~Q~SV~Q'
main(rules, 'R')
```

Output:

Step	Clause	Derivation
1.	R∨¬P	Given.
2.	R∨¬Q	Given.
3.	¬R∨P	Given.
4.	¬R∨Q	Given.
5.	¬R	Negated conclusion
6.		Resolved R∨¬P and R∨¬R to R∨¬R, which is in turn null

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

Step	Clause	Derivation
1.	P∨Q	Given.
2.	¬P∨R	Given.
3.	¬Q∨R	Given.
4.	¬R	Negated conclusion
5.	Q∨R	Res. from P∨Q and ¬P∨R
6.	P∨R	Res. from P∨Q and ¬Q∨R
7.	¬P	Res. from ¬P∨R and ¬R
8.	¬Q	Res. from ¬Q∨R and ¬R
9.	Q	Res. from ¬R and Q∨R
10.	P	Res. from ¬R and P∨R
11.	R	Res. from Q∨R and ¬Q
12.		Res. from 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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Week-8

Implement unification in first order logic.

Code:

```
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):
        if a1.islower() and a2.islower and a1!=a2
            substitution[a1] = a2
        elif
            substitution [a1] = a2
        elif
            substitution [a2] = a1
        elif
            print("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 first expression")
    expr2 = input("Enter 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, substitution)
        expr2_result = apply_substitution(expr2, substitution)

        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))
```

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Week-9

First Order Logic to CNF:

Code:

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

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

def 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)]"))
```

Output:

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

8/12/24

Week-10

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

#Code:

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

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

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

class Fact:
    def __init__(self, expression):
        self.expression = expression
        predicate, params = self.splitExpression
                            (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 [v if 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 =~~
    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.fact.add(res)

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

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

P.T.O.

Output:

Querying evil(x):

1. evil (sushanth)
2. evil (John)

All facts:

1. evil (sushanth)
2. greedy(sushanth)
3. King (John)
4. evil (John)
5. king (Richard)
6. king (sushanth)
7. greedy (John

1.TIC-TAC-TOE

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

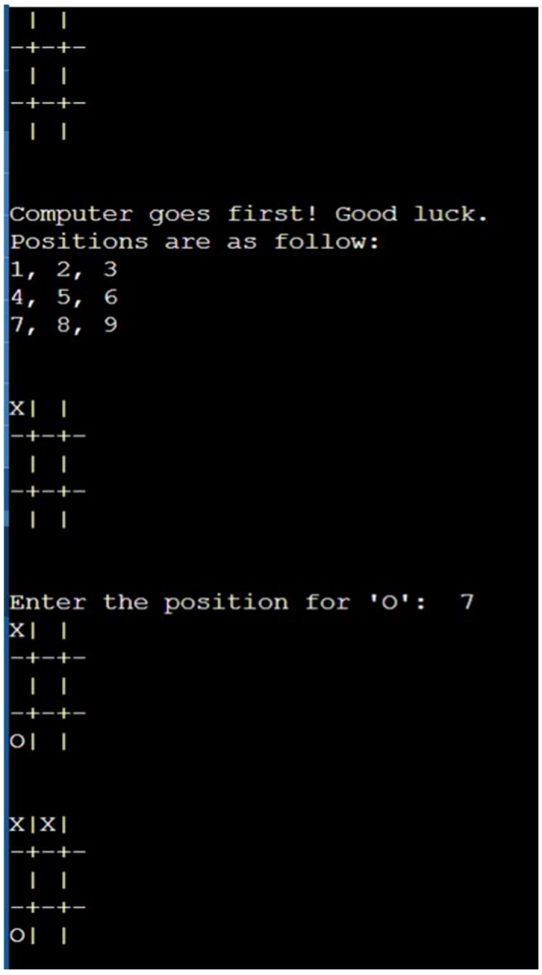
```
print("Can't insert there!")
position = int(input("Please enter new position: "))
insertLetter(letter, position)
return
def checkForWin():
if (board[1] == board[2] and board[1] == board[3] and board[1] != ' '):
return True
elif (board[4] == board[5] and board[4] == board[6] and board[4] != ' '):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

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

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

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

OUTPUT


| |
-+-+-
| |
-+-+-
| |
Computer goes first! Good luck.
Positions are as follow:
1, 2, 3
4, 5, 6
7, 8, 9
X| |
-+-+-
| |
-+-+-
| |
Enter the position for 'O': 7
X| |
-+-+-
| |
-+-+-
O| |
X|X|
-+-+-
| |
-+-+-
O| |

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


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


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


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


Bot wins!
```

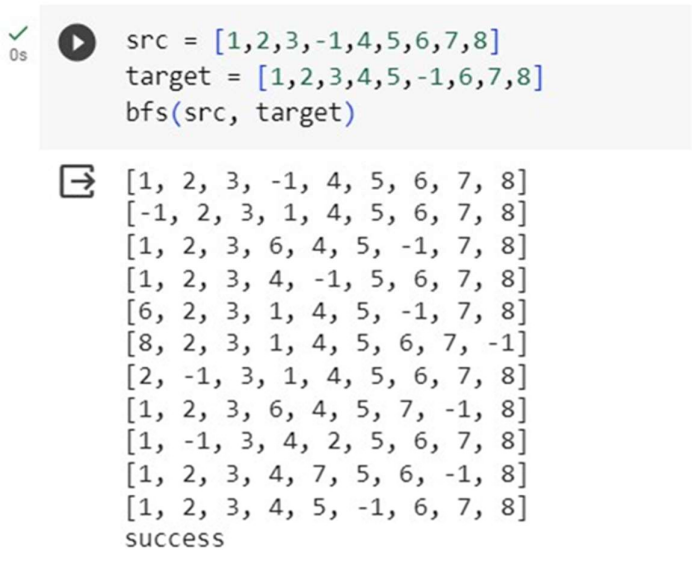
2. 8 Puzzle
(bfs)

```
import numpy as np
import pandas as pd
import os

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

    exp = []

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

        print(source)

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

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

        for move in poss_moves_to_do:

            if move not in exp and move not in queue:
                queue.append(move)
```

```
def possible_moves(state,visited_states):
    #index of empty spot
    b = state.index(-1)

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

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



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

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

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

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

def gen(state, m, b):
```

```
    temp = state.copy()

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

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

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

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


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

OUTPUT



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

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

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

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

3. Implement Iterative deepening search algorithm

```
def dfs(src,target,limit,visited_states):
    if src == target:
        return True
    if limit <= 0:
        return False
    visited_states.append(src)
    moves = possible_moves(src,visited_states)
    for move in moves:
        if dfs(move, target, limit-1, visited_states):
            return True
    return False


def possible_moves(state,visited_states):
    b = state.index(-1)
    d = []
    if b not in [0,1,2]:
        d += 'u'
    if b not in [6,7,8]:
        d += 'd'
    if b not in [2,5,8]:
        d += 'r'
    if b not in [0,3,6]:
        d += 'l'
    pos_moves = []
    for move in d:
        pos_moves.append(gen(state,move,b))
    return [move for move in pos_moves if move not in visited_states]
```

```
def gen(state, move, blank):
    temp = state.copy()
    if move == 'u':
        temp[blank-3], temp[blank] = temp[blank], temp[blank-3]
    if move == 'd':
        temp[blank+3], temp[blank] = temp[blank], temp[blank+3]
    if move == 'r':
        temp[blank+1], temp[blank] = temp[blank], temp[blank+1]
    if move == 'l':
        temp[blank-1], temp[blank] = temp[blank], temp[blank-1]
    return temp

def iddfs(src,target,depth):
     for i in range(depth):
        visited_states = []
        if dfs(src,target,i+1,visited_states):
            return True
     return False

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

depth=8

iddfs(src, target,depth)

OUTPUT

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

4. 8 Puzzle A* Search Algorithm

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

    def generate_child(self):
        # Generate hild nodes from the given node by moving the blank space
        # either in the four direction {up,down,left,right}
        x, y = self.find(self.data, '_')
        # val_list contains position values for moving the blank space in either of
        # the 4 direction [up,down,left,right] respectively.
        val_list = [[x, y - 1], [x, y + 1], [x - 1, y], [x + 1, y]]
        children = []
        for i in val_list:
            child = self.shuffle(self.data, x, y, i[0], i[1])
            if child is not None:
                child_node = Node(child, self.level + 1, 0)
                children.append(child_node)
        return children

    def shuffle(self, puz, x1, y1, x2, y2):
        # Move the blank space in the given direction and if the position value are out
        # of limits the return None
        if x2 >= 0 and x2 < len(self.data) and y2 >= 0 and y2 < len(self.data):
            temp_puz = []
            temp_puz = self.copy(puz)
            temp = temp_puz[x2][y2]
```

```
            temp_puz[x2][y2] = temp_puz[x1][y1]
            temp_puz[x1][y1] = temp
            return temp_puz
        else:
            return None

    def copy(self, root):
        # copy function to create a similar matrix of the given node
        temp = []
        for i in root:
            t = []
            for j in i:
                t.append(j)
            temp.append(t)
        return temp

    def find(self, puz, x):
        # Specifically used to find the position of the blank space
        for i in range(0, len(self.data)):
            for j in range(0, len(self.data)):
                if puz[i][j] == x:
                    return i, j


class Puzzle:
    def __init__(self, size):
        # Initialize the puzzle size by the the specified size,open and closed lists to empty
        self.n = size
        self.open = []
        self.closed = []
```

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

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

def h(self, start, goal):
    # Calculates the difference between the given puzzles
    temp = 0
    for i in range(0, self.n):
        for j in range(0, self.n):
            if start[i][j] != goal[i][j] and start[i][j] != '_':
                temp += 1
    return temp

def process(self):
    # Accept Start and Goal Puzzle state
    print("enter the start state matrix \n")
    start = self.accept()
    print("enter the goal state matrix \n")
    goal = self.accept()
    start = Node(start, 0, 0)
    start.fval = self.f(start, goal)
```

```
        # put the start node in the open list
        self.open.append(start)
        print("\n\n")
        while True:
            cur = self.open[0]
            print("=================================================\n")
            for i in cur.data:
                for j in i:
                    print(j, end=" ")
                print("")
            # if the difference between current and goal node is 0 we have reached the goal node
            if (self.h(cur.data, goal) == 0):
                break
            for i in cur.generate_child():
                i.fval = self.f(i, goal)
                self.open.append(i)
            self.closed.append(cur)
            del self.open[0]
            # sort the open list based on f value
            self.open.sort(key=lambda x: x.fval, reverse=False)
puz = Puzzle(3)
puz.process()
```

OUTPUT

```
enter the start state matrix

1 2 3
_ 4 6
7 5 8
enter the goal state matrix

1 2 3
4 5 6
7 8 _


==================================================

1 2 3
_ 4 6
7 5 8
==================================================

1 2 3
4 _ 6
7 5 8
==================================================

1 2 3
4 5 6
7 _ 8
==================================================

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

5.Vaccum cleaner

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

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

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

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

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

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

else:
    print("Vacuum is placed in location B")
    # Location B is Dirty.
```

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

    if status_input_complement == '1':
        # if A is Dirty
        print("Location A is Dirty.")
        print("Moving LEFT to the Location A. ")
        cost += 1  # cost for moving right
        print("COST for moving LEFT" + str(cost))
        # suck the dirt and mark it as clean
        goal_state['A'] = '0'
        cost += 1  # cost for suck
        print("COST for SUCK " + str(cost))
        print("Location A has been Cleaned.")

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

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

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

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


vacuum_world()
```

OUTPUT

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

```
vacuum_world()
```

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

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

6. Knowledge Base Entailment

```
def tell(kb, rule):
    kb.append(rule)

combinations = [(True, True, True), (True, True, False),
                (True, False, True), (True, False, False),
                (False, True, True), (False, True, False),
                (False, False, True), (False, False, False)]



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



kb = []

# Get user input for Rule 1
rule_str = input("Enter Rule 1 as a lambda function (e.g., lambda x: x[0] or x[1] and (x[0] and x[1]): ")
r1 = eval(rule_str)
tell(kb, r1)

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

```
#r2 = eval(rule_str)
#tell(kb, r2)

# Get user input for Query
query_str = input("Enter Query as a lambda function (e.g., lambda x: x[0] and x[1] and (x[0] or x[1]): ")
q = eval(query_str)

# Ask KB Query
result = ask(kb, q)
print(result)
```

OUTPUT

```
Enter Rule 1 as a lambda function (e.g., lambda x: x[0] or x[1] and (x[0] and x[1]): lambda x:  (x[0] or x[1]) and ( not x[2] or x[0])
Enter Query as a lambda function (e.g., lambda x: x[0] and x[1] and (x[0] or x[1]): lambda x:  (x[0] and x[2])
True True
True False
Does not entail
```

7. Knowledge Base Resolution

```
import re

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

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

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

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

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

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

```
            elif len(gen) == 1:
                clauses += [f'{gen[0]}']
            else:
                if contradiction(goal,f'{terms1[0]}v{terms2[0]}'):
                    temp.append(f'{terms1[0]}v{terms2[0]}')
                    steps[''] = f'Resolved {temp[i]} and {temp[j]} to {temp[-1]}, which is in turn null. \
                    \nA contradiction is found when {negate(goal)} is assumed as true. Hence, {goal} is true."
                    return steps
        for clause in clauses:
            if clause not in temp and clause != reverse(clause) and reverse(clause) not in temp:
                temp.append(clause)
                steps[clause] = f'Resolved from {temp[i]} and {temp[j]}.'
        j = (j + 1) % n
    i += 1
  return steps

rules = 'Rv~P Rv~Q ~RvP ~RvQ' #(P^Q)<=>R : (Rv~P)v(Rv~Q)^(~RvP)^(~RvQ)
goal = 'R'
main(rules, goal)
 rules = 'PvQ ~PvR ~QvR' #P=vQ, P=>Q : ~PvQ, Q=>R, ~QvR
goal = 'R'
main(rules, goal)
```

OUTPUT

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

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

8. Unification

```
import re

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

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

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

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

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

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

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

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

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

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

def unify(exp1, exp2):
    if exp1 == exp2:
        return []
    if isConstant(exp1) and isConstant(exp2):
        if exp1 != exp2:
            return False
    if isConstant(exp1):
        return [(exp1, exp2)]
    if isConstant(exp2):
        return [(exp2, exp1)]
    if isVariable(exp1):
        if checkOccurs(exp1, exp2):
```

```
        return False
    else:
        return [(exp2, exp1)]
if isVariable(exp2):
    if checkOccurs(exp2, exp1):
        return False
    else:
        return [(exp1, exp2)]
if getInitialPredicate(exp1) != getInitialPredicate(exp2):
    print("Predicates do not match. Cannot be unified")
    return False
attributeCount1 = len(getAttributes(exp1))
attributeCount2 = len(getAttributes(exp2))
if attributeCount1 != attributeCount2:
    return False
head1 = getFirstPart(exp1)
head2 = getFirstPart(exp2)
initialSubstitution = unify(head1, head2)
if not initialSubstitution:
    return False
if attributeCount1 == 1:
    return initialSubstitution
tail1 = getRemainingPart(exp1)
tail2 = getRemainingPart(exp2)
if initialSubstitution != []:
    tail1 = apply(tail1, initialSubstitution)
    tail2 = apply(tail2, initialSubstitution)
remainingSubstitution = unify(tail1, tail2)
if not remainingSubstitution:
    return False
```

```
    initialSubstitution.extend(remainingSubstitution)
    return initialSubstitution


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

OUTPUT

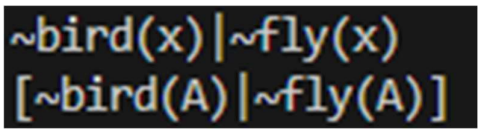
```
Substitutions:
[('A', 'y'), ('mother(y)', 'x')]
```

9. FOL to CNF

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

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

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

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

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

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

OUTPUT



10. Forward Reasoning

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

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

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

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

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

    def getResult(self):
        return self.result
```

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

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

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

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

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

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

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

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

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

    def display(self):
```

```
        print("All facts: ")
        for i, f in enumerate(set([f.expression for f in self.facts])):
            print(f'\t{i+1}. {f}')
kb_ = KB()
kb_.tell('king(x)&greedy(x)=>evil(x)')
kb_.tell('king(John)')
kb_.tell('greedy(John)')
kb_.tell('king(Richard)')
kb_.query('evil(x)')
```

OUTPUT