B.M.S. COLLEGE OF ENGINEERING BENGALURU
Autonomous Institute, Affiliated to VTU

Lab Record

Artificial Intelligence

Submitted in partial fulfillment for the 5th Semester Laboratory

Bachelor of Technology
in
Computer Science and Engineering

Submitted by:

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B.M.S. COLLEGE OF ENGINEERING

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

CERTIFICATE

This is to certify that the Artificial Intelligence (22CS5PCAIN) laboratory has been carried out by Palle Padmavathi(1BM21CS125) during the 5th Semester November 2023-March 2024.

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1. **Implement Tic –Tac –Toe Game**

```
tic=[]
import random
def board(tic):
    for i in range(0,9,3):
        print("+"+"-"*29+"+")
        print("|"+" "*9+"|"+" "*9+"|"+" "*9+"|")
        print("|"+" "*3,tic[0+i]," "*3+"|"+" "*3,tic[1+i]," "*3+"|"+" "*3,tic[2+i],"
"*3+"|")
        print("|"+" "*9+"|"+" "*9+"|"+" "*9+"|")
    print("+"+"-"*29+"+")


def update_comp():
    global tic,num
    for i in range(9):
        if tic[i]==i+1:
            num=i+1
            tic[num-1]='X'
            if winner(num-1)==False:
                #reverse the change
                tic[num-1]=num
            else:
                return
    for i in range(9):
        if tic[i]==i+1:
            num=i+1
            tic[num-1]='O'
            if winner(num-1)==True:
                tic[num-1]='X'
                return
            else:
                tic[num-1]=num
    num=random.randint(1,9)
    while num  not in tic:
        num=random.randint(1,9)
    else:
        tic[num-1]='X'


def update_user():
    global tic,num
```

```
    num=int(input("enter a number on the board :"))
    while num not in tic:
        num=int(input("enter a number on the board :"))
    else:
        tic[num-1]='O'

def winner(num):
    if tic[0]==tic[4] and tic[4]==tic[8] or tic[2]==tic[4] and tic[4]==tic[6]:
        return True
    if tic[num]==tic[num-3] and tic[num-3]==tic[num-6]:
        return True
    if tic[num//3*3]==tic[num//3*3+1] and tic[num//3*3+1]==tic[num//3*3+2]:
        return True
    return False



try:
    for i in range(1,10):
        tic.append(i)
    count=0
    #print(tic)
    board(tic)
    while count!=9:
        if count%2==0:
            print("computer's turn :")
            update_comp()
            board(tic)
            count+=1
        else:
            print("Your turn :")
            update_user()
            board(tic)
            count+=1
        if count>=5:
            if winner(num-1):
                print("winner is ",tic[num-1])
                break
            else:
                continue
except:
    print("\nerror\n")
```

Output:

```
+-------------------------------+
|         |         |         |
|    1    |    2    |    3    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    4    |    5    |    6    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    7    |    8    |    9    |
|         |         |         |
+-------------------------------+
computer's turn :
+-------------------------------+
|         |         |         |
|    1    |    2    |    3    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    4    |    5    |    6    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    X    |    8    |    9    |
|         |         |         |
+-------------------------------+
Your turn :
enter a number on the board :2
+-------------------------------+
|         |         |         |
|    1    |    O    |    3    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    4    |    5    |    6    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    X    |    8    |    9    |
|         |         |         |
+-------------------------------+
```

```
+-----------------------------+
|         |         |         |
|    1    |    O    |    3    |
|         |         |         |
+-----------------------------+
|         |         |         |
|    4    |    5    |    X    |
|         |         |         |
+-----------------------------+
|         |         |         |
|    X    |    8    |    9    |
|         |         |         |
+-----------------------------+
Your turn :
enter a number on the board :5
+-----------------------------+
|         |         |         |
|    1    |    O    |    3    |
|         |         |         |
+-----------------------------+
|         |         |         |
|    4    |    O    |    X    |
|         |         |         |
+-----------------------------+
|         |         |         |
|    X    |    8    |    9    |
|         |         |         |
+-----------------------------+
computer's turn :
+-----------------------------+
|         |         |         |
|    1    |    O    |    3    |
|         |         |         |
+-----------------------------+
|         |         |         |
|    4    |    O    |    X    |
|         |         |         |
+-----------------------------+
|         |         |         |
|    X    |    X    |    9    |
|         |         |         |
+-----------------------------+
Your turn :
enter a number on the board :9
```

```
+-----------------------+
|       |       |       |
|   1   |   0   |   3   |
|       |       |       |
+-----------------------+
|       |       |       |
|   4   |   5   |   X   |
|       |       |       |
+-----------------------+
|       |       |       |
|   X   |   8   |   9   |
|       |       |       |
+-----------------------+
Your turn :
enter a number on the board :5
+-----------------------+
|       |       |       |
|   1   |   0   |   3   |
|       |       |       |
+-----------------------+
|       |       |       |
|   4   |   0   |   X   |
|       |       |       |
+-----------------------+
|       |       |       |
|   X   |   8   |   9   |
|       |       |       |
+-----------------------+
computer's turn :
+-----------------------+
|       |       |       |
|   1   |   0   |   3   |
|       |       |       |
+-----------------------+
|       |       |       |
|   4   |   0   |   X   |
|       |       |       |
+-----------------------+
|       |       |       |
|   X   |   X   |   9   |
|       |       |       |
+-----------------------+
Your turn :
enter a number on the board :9
```

```
+-------------------------------+
|         |         |         |
|    1    |    O    |    3    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    4    |    O    |    X    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    X    |    X    |    O    |
|         |         |         |
+-------------------------------+
computer's turn :
+-------------------------------+
|         |         |         |
|    X    |    O    |    3    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    4    |    O    |    X    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    X    |    X    |    O    |
|         |         |         |
+-------------------------------+
Your turn :
enter a number on the board :4
+-------------------------------+
|         |         |         |
|    X    |    O    |    3    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    O    |    O    |    X    |
|         |         |         |
+-------------------------------+
|         |         |         |
|    X    |    X    |    O    |
|         |         |         |
+-------------------------------+
```

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

2. 8 Puzzle Breadth First Search Algorithm

```
def bfs(src,target):
    queue=[]
    queue.append(src)
    exp=[]
    while len(queue)>0:
        source=queue.pop(0)
        #print("queue",queue)
        exp.append(source)

        print(source[0],'|',source[1],'|',source[2])
        print(source[3],'|',source[4],'|',source[5])
        print(source[6],'|',source[7],'|',source[8])
        print("................")
        if source==target:
            print("Success")
            return
        poss_moves_to_do=[]
        poss_moves_to_do=possible_moves(source,exp)
        #print("possible moves",poss_moves_to_do)
        for move in poss_moves_to_do:
            if move not in exp and move not in queue:
              #print("move",move)
              queue.append(move)

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

    #direction array
    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]
    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=[1,2,3,4,5,6,0,7,8]
target=[1,2,3,4,5,6,7,8,0]
bfs(src,target)
```

Output:

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

3. 8 Puzzle Iterative Deepening Search Algorithm

```
def id_dfs(puzzle, goal, get_moves):
    import itertools
#get_moves -> possible_moves
    def dfs(route, depth):
        if depth == 0:
            return
        if route[-1] == goal:
            return route
        for move in get_moves(route[-1]):
            if move not in route:
                next_route = dfs(route + [move], depth - 1)
                if next_route:
                    return next_route

    for depth in itertools.count():
        route = dfs([puzzle], depth)
        if route:
            return route


def possible_moves(state):
    b = state.index(0) # ) indicates White space -> so b has index of it.
    d = []  # direction

    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 = []
    for i in d:
        pos_moves.append(generate(state, i, b))
    return pos_moves


def generate(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


# calling ID-DFS
initial = [1, 2, 3, 0, 4, 6, 7, 5, 8]
goal = [1, 2, 3, 4, 5, 6, 7, 8, 0]

route = id_dfs(initial, goal, possible_moves)

if route:
    print("Success!! It is possible to solve 8 Puzzle problem")
    print("Path:", route)
else:
    print("Failed to find a solution")
```

Output:

```
Success!! It is possible to solve 8 Puzzle problem
Path: [[1, 2, 3, 0, 4, 6, 7, 5, 8], [1, 2, 3, 4, 0, 6, 7, 5, 8], [1, 2, 3, 4, 5, 6, 7, 0, 8], [1, 2, 3, 4, 5, 6, 7, 8, 0]]
```

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 child nodes from the given node by moving the blank space
            either in the four directions {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 directions [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 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 hueristic value f(x) = h(x) + g(x) """
        return self.h(start.data,goal)+start.level

    def h(self,start,goal):
        """ Calculates the different 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("")
            print("  | ")
            print("  | ")
            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 opne 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 5 6
_ 7 8
Enter the goal state matrix

1 2 3
4 5 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 _
```

5. Vacuum Cleaner

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

    location_input = input("Enter Location of Vacuum")
    status_input = input("Enter status of " + location_input)
    status_input_complement = input("Enter status of other room")

    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
            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
                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
```

```
                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
            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
                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
                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))

print("0 indicates clean and 1 indicates dirty")
vacuum_world()
```

Output:

```
0 indicates clean and 1 indicates dirty
Enter Location of Vacuumb
Enter status of b1
Enter status of other room1
Vacuum is placed in location B
Location B is Dirty.
COST for CLEANING 1
Location B has been Cleaned.
Location A is Dirty.
Moving LEFT to the Location A.
COST for moving LEFT2
COST for SUCK 3
Location A has been Cleaned.
GOAL STATE:
{'A': '0', 'B': '0'}
Performance Measurement: 3
```

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

```
from sympy import symbols, And, Not, Implies, satisfiable
def create_knowledge_base():
    # Define propositional symbols
    p = symbols('p')
    q = symbols('q')
    r = symbols('r')

    # Define knowledge base using logical statements
    knowledge_base = And(
        Implies(p, q),        # If p then q
        Implies(q, r),        # If q then r
        Not(r)                # Not r
    )
    return knowledge_base
def query_entails(knowledge_base, query):
    # Check if the knowledge base entails the query
    entailment = satisfiable(And(knowledge_base, Not(query)))
    # If there is no satisfying assignment, then the query is entailed
    return not entailment
if__name__== "__main__":
    # Create the knowledge base
    kb = create_knowledge_base()

    # Define a query
    query = symbols('p')

    # Check if the query entails the knowledge base
    result = query_entails(kb, query)

    # Display the results
    print("Knowledge Base:", kb)
    print("Query:", query)
    print("Query entails Knowledge Base:", result)
```

Output:

```
Knowledge Base: ~r & (Implies(p, q)) & (Implies(q, r))
Query: p
Query entails Knowledge Base: False
```

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
```

Output:

```
rules = 'PvQ PvR ~PvR RvS Rv~Q ~Sv~Q' # (P=>Q)=>Q, (P=>P)=>R, (R=>S)=>~(S=>Q)
main(rules, '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
```

Output:

```
[9] exp1 = "knows(x)"
    exp2 = "knows(Richard)"
    substitutions = unify(exp1, exp2)
    print("Substitutions:")
    print(substitutions)

    Substitutions:
    [('Richard', 'x')]
```

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

    Predicates do not match. Cannot be unified
    Substitutions:
    False
```

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

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

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

```
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 DeMorgan(sentence):
    string = ''.join(list(sentence).copy())
    string = string.replace('~~','')
    flag = '[' in string
    string = string.replace('~[','')
    string = string.strip(']')
    for predicate in getPredicates(string):
        string = string.replace(predicate, f'~{predicate}')
    s = list(string)
    for i, c in enumerate(string):
        if c == '|':
            s[i] = '&'
        elif c == '&':
            s[i] = '|'
    string = ''.join(s)
    string = string.replace('~~','')
    return f'[{string}]' if flag else string

def Skolemization(sentence):
    SKOLEM_CONSTANTS = [f'{chr(c)}' for c in range(ord('A'), ord('Z')+1)]
    statement = ''.join(list(sentence).copy())
    matches = re.findall('[∀∃].', statement)
    for match in matches[::-1]:
        statement = statement.replace(match, '')
        statements = re.findall('\[\[[^]]+\]]', statement)
        for s in statements:
            statement = statement.replace(s, s[1:-1])
        for predicate in getPredicates(statement):
            attributes = getAttributes(predicate)
            if ''.join(attributes).islower():
                statement = statement.replace(match[1],SKOLEM_CONSTANTS.pop(0))
            else:
                aL = [a for a in attributes if a.islower()]
```

```
            aU = [a for a in attributes if not a.islower()][0]
            statement = statement.replace(aU,
f'{SKOLEM_CONSTANTS.pop(0)}({aL[0] if len(aL) else match[1]})')
    return statement
import re

def fol_to_cnf(fol):

    statement = fol.replace("<=>", "_")
    while '_' in statement:
        i = statement.index('_')
        new_statement = '[' + statement[:i] + '=>' + statement[i+1:] + ']&['+
statement[i+1:] + '=>' + statement[:i] + ']'
        statement = new_statement
    statement = statement.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
    while '~∀' in statement:
        i = statement.index('~∀')
        statement = list(statement)
        statement[i], statement[i+1], statement[i+2] = '∃', statement[i+2], '~'
        statement = ''.join(statement)
    while '~∃' in statement:
        i = statement.index('~∃')
        s = list(statement)
        s[i], s[i+1], s[i+2] = '∀', s[i+2], '~'
        statement = ''.join(s)
    statement = statement.replace('~[∀','[~∀')
    statement = statement.replace('~[∃','[~∃')
    expr = '(~[∀|∃].)'
    statements = re.findall(expr, statement)
    for s in statements:
        statement = statement.replace(s, fol_to_cnf(s))
```

```
    expr = '~\[[^]]+\]'
    statements = re.findall(expr, statement)
    for s in statements:
        statement = statement.replace(s, DeMorgan(s))
    return statement
```

Output:

```
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)"))
```

```
[~animal(y)|loves(x,y)]&[~loves(x,y)|animal(y)]
[animal(G(x))&~loves(x,G(x))]|[loves(F(x),x)]
[~american(x)|~weapon(y)|~sells(x,y,z)|~hostile(z)]|criminal(x)
```

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

```
import re

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

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

def getPredicates(string):
    expr = '([a-z~]+)\([^&|]+\)'
    return re.findall(expr, string)
class Fact:
    def__init_(self, expression):
        self.expression = expression
        predicate, params = self.splitExpression(expression)
        self.predicate = predicate
        self.params = params
        self.result = any(self.getConstants())

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

    def getResult(self):
        return self.result

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

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

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

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

    def evaluate(self, facts):
        constants = {}
        new_lhs = []
        for fact in facts:
            for val in self.lhs:
                if val.predicate == fact.predicate:
                    for i, v in enumerate(val.getVariables()):
                        if v:
                            constants[v] = fact.getConstants()[i]
                    new_lhs.append(fact)
        predicate, attributes = getPredicates(self.rhs.expression)[0],
str(getAttributes(self.rhs.expression)[0])
        for key in constants:
            if constants[key]:
                attributes = attributes.replace(key, constants[key])
        expr = f'{predicate}{attributes}'
        return Fact(expr) if len(new_lhs) and all([f.getResult() for f in new_lhs]) else
None

class KB:
    def___init__(self):
        self.facts = set()
        self.implications = set()

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

    def query(self, e):
        facts = set([f.expression for f in self.facts])
        i = 1
```

```
        print(f'Querying {e}:')
        for f in facts:
            if Fact(f).predicate == Fact(e).predicate:
                print(f'\t{i}. {f}')
                i += 1

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

Output:

```
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()
```

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

```
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)')
```

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