

VISVESVARAYA TECHNOLOGICAL UNIVERSITY

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ARTIFICIAL INTELLIGENCE

LAB REPORT

Submitted by

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in partial fulfilment for the award of the degree of

BACHELOR OF ENGINEERING

In

COMPUTER SCIENCE AND ENGINEERING



B.M.S. COLLEGE OF ENGINEERING

(Autonomous Institution under VTU)

BENGALURU-560019

Oct-2021 to Jan-2022

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CERTIFICATE

This is to certify that the Advance Data Structures Lab for Cycle 2 (CIE 2) carried out by, **RAVI SAJJANAR (1BM19CS127)** who are Bonafede students of **B. M. S. College of Engineering**. It is in partial fulfilment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visveswaraiah Technological University, Belgaum during the year 2021-2022. The Lab report has been approved as it satisfies the academic requirements in respect of **ARTIFICIAL INTELLIGENCE (20CS5PCAIP)** work prescribed for the said degree.

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

```
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)]
```

```
variable={'p':0,'q':1, 'r':2}
```

```
kb=""
```

```
q=""
```

```
priority={'~':3,'v':1,'^':2}
```

```
def input_rules():
```

```
    global kb, q
```

```
    kb = (input("Knowledge base : "))
```

```
    q = input("Query : ")
```

```
def entailment():
```

```
    global kb, q
```

```
    print("*10+"Truth Table Reference"+"*10)
```

```
    print('kb   α')
```

```
    print('-'*10)
```

```
    for comb in combinations:
```

```
        s = evaluatePostfix(toPostfix(kb), comb)
```

```
        f = evaluatePostfix(toPostfix(q), comb)
```

```
        print(s, f)
```

```
        if s is True and f is False:
```

```
            return False
```

```
    return True
```

```
def isOperand(c):
```

```
    return c.isalpha() and c!='v'
```

```
def isLeftParanthesis(c):
```

```
    return c == '('
```

```
def isRightParanthesis(c):
```

```
    return c == ')'
```

```
def isEmpty(stack):  
    return len(stack) == 0
```

```
def peek(stack):  
    return stack[-1]
```

```
def hasLessOrEqualPriority(c1, c2):  
    try:  
        return priority[c1]<=priority[c2]  
    except KeyError:  
        return False
```

```
def toPostfix(infix):  
    stack = []  
    postfix = ""  
    for c in infix:  
        if isOperand(c):  
            postfix += c  
        else:  
            if isLeftParanthesis(c):  
                stack.append(c)  
            elif isRightParanthesis(c):  
                operator = stack.pop()  
                while not isLeftParanthesis(operator):  
                    postfix += operator  
                    operator = stack.pop()  
            else:  
                while (not isEmpty(stack)) and hasLessOrEqualPriority(c, peek(stack)):  
                    postfix += stack.pop()  
                stack.append(c)  
    while (not isEmpty(stack)):  
        postfix += stack.pop()  
  
    return postfix
```

```
def evaluatePostfix(exp, comb):  
    stack = []  
    for i in exp:  
        if isOperand(i):
```

```
    stack.append(comb[variable[i]])
elif i == '~':
    val1 = stack.pop()
    stack.append(not val1)
else:
    val1 = stack.pop()
    val2 = stack.pop()
    stack.append(_eval(i, val2, val1))
return stack.pop()
```

```
def _eval(i, val1, val2):
    if i == '^':
        return val2 and val1
    return val2 or val1
```

```
input_rules()
ans = entailment()
if ans:
    print("The Knowledge Base entails query")
    print(" KB  $\models \alpha$  ")
else:
    print("The Knowledge Base does not entail query")
print("\n")
```

OUTPUT SCREEN

Test Case 1:

PROBLEMS OUTPUT TERMINAL DEBUG CONSOLE

```
Windows PowerShell
Copyright (C) Microsoft Corporation. All rights reserved.

Try the new cross-platform PowerShell https://aka.ms/pscore6

PS C:\Users\ravis> python -u "d:\codes\Artificial Intelligence Lab\Python\lab6.py"
Knowledge base : (~qv~pvr)^(~q^p)^q
Query : r
Truth Table Reference
kb   α
-----
False True
False False
False True
False False
False True
False False
False True
False False
The Knowledge Base entails query
KB |= α
```

Test Case 2:

PROBLEMS OUTPUT TERMINAL DEBUG CONSOLE

```
Windows PowerShell
Copyright (C) Microsoft Corporation. All rights reserved.

Try the new cross-platform PowerShell https://aka.ms/pscore6

PS C:\Users\ravis> python -u "d:\codes\Artificial Intelligence Lab\Python\lab6.py"
Knowledge base : (pvq)^(~rvp)
Query : r
Truth Table Reference
kb   α
-----
True True
True False
The Knowledge Base does not entail query
```

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

Global variable kb (knowledge base)

```
kb = []
```

Reset kb to an empty list

```
def Clear():
```

```
    global kb
```

```
    kb = []
```

Insert sentence to the kb

```
def AddSentence(sentence):
```

```
    global kb
```

```
    # If the sentence is a clause, insert directly.
```

```
    if isClause(sentence):
```

```
        kb.append(sentence)
```

```
    # If not, convert to CNF, and then insert clauses one by one.
```

```
    else:
```

```
        sentenceCNF = convertCNF(sentence)
```

```
        if not sentenceCNF:
```

```
            print("Illegal input")
```

```
            return
```

```
        # Insert clauses one by one when there are multiple clauses
```

```
        if isAndList(sentenceCNF):
```

```
            for s in sentenceCNF[1:]:
```

```
                kb.append(s)
```

```
        else:
```

```
            kb.append(sentenceCNF)
```

'Query' the kb whether a sentence is True or not

```
def Query(sentence):
```

```
    global kb
```

```
    # Negate the sentence, and convert it to CNF accordingly.
```

```
    if isClause(sentence):
```

```
        neg = negation(sentence)
```

```
    else:
```

```
        sentenceCNF = convertCNF(sentence)
```

```
        if not sentenceCNF:
```

```
            print("Illegal input")
```

```
            return
```

```
        neg = convertCNF(negation(sentenceCNF))
```



```

# Insert individual clauses that we need to ask to ask_list.
ask_list = []
if isAndList(neg):
    for n in neg[1:]:
        nCNF = makeCNF(n)
        if type(nCNF).__name__ == 'list':
            ask_list.insert(0, nCNF)
        else:
            ask_list.insert(0, nCNF)
    else:
        ask_list = [neg]
# Create a new list combining the asked sentence and kb.
# Resolution will happen between the items in the list.
clauses = ask_list + kb[:]

# Recursively conduct resolution between items in the clauses list
# until it produces an empty list or there's no more progress.
while True:
    new_clauses = []
    for c1 in clauses:
        for c2 in clauses:
            if c1 is not c2:
                resolved = resolve(c1, c2)
                if resolved == False:
                    continue
                if resolved == []:
                    return True
                new_clauses.append(resolved)

    if len(new_clauses) == 0:
        return False
    new_in_clauses = True
    for n in new_clauses:
        if n not in clauses:
            new_in_clauses = False
            clauses.append(n)
    if new_in_clauses:
        return False
    return False
# Conduct resolution on two CNF clauses.
def resolve(arg_one, arg_two):
    resolved = False

```

```
s1 = make_sentence(arg_one)
s2 = make_sentence(arg_two)
```

```
resolve_s1 = None
resolve_s2 = None
```

```
# Two for loops that iterate through the two clauses.
```

```
for i in s1:
```

```
    if isNotList(i):
```

```
        a1 = i[1]
```

```
        a1_not = True
```

```
    else:
```

```
        a1 = i
```

```
        a1_not = False
```

```
for j in s2:
```

```
    if isNotList(j):
```

```
        a2 = j[1]
```

```
        a2_not = True
```

```
    else:
```

```
        a2 = j
```

```
        a2_not = False
```

```
# cancel out two literals such as 'a' & ['not', 'a']
```

```
if a1 == a2:
```

```
    if a1_not != a2_not:
```

```
        # Return False if resolution already happend
```

```
        # but contradiction still exists.
```

```
        if resolved:
```

```
            return False
```

```
        else:
```

```
            resolved = True
```

```
            resolve_s1 = i
```

```
            resolve_s2 = j
```

```
            break
```

```
        # Return False if not resolution happened
```

```
if not resolved:
```

```
    return False
```

```
# Remove the literals that are canceled
```

```
s1.remove(resolve_s1)
```

```
s2.remove(resolve_s2)
```

Remove duplicates

```
result = clear_duplicate(s1 + s2)
```

Format the result.

```
if len(result) == 1:
```

```
    return result[0]
```

```
elif len(result) > 1:
```

```
    result.insert(0, 'or')
```

```
return result
```

Prepare sentences for resolution.

```
def make_sentence(arg):
```

```
    if isLiteral(arg) or isNotList(arg):
```

```
        return [arg]
```

```
    if isOrList(arg):
```

```
        return clear_duplicate(arg[1:])
```

```
    return
```

Clear out duplicates in a sentence.

```
def clear_duplicate(arg):
```

```
    result = []
```

```
    for i in range(0, len(arg)):
```

```
        if arg[i] not in arg[i+1:]:
```

```
            result.append(arg[i])
```

```
    return result
```

Check whether a sentence is a legal CNF clause.

```
def isClause(sentence):
```

```
    if isLiteral(sentence):
```

```
        return True
```

```
    if isNotList(sentence):
```

```
        if isLiteral(sentence[1]):
```

```
            return True
```

```
        else:
```

```
            return False
```

```
    if isOrList(sentence):
```

```
        for i in range(1, len(sentence)):
```

```
            if len(sentence[i]) > 2:
```

```
                return False
```

```
            elif not isClause(sentence[i]):
```

```
                return False
```

```
    return True
return False
```

Check if a sentence is a legal CNF.

```
def isCNF(sentence):
    if isClause(sentence):
        return True
    elif isAndList(sentence):
        for s in sentence[1:]:
            if not isClause(s):
                return False
        return True
    return False
```

Negate a sentence.

```
def negation(sentence):
    if isLiteral(sentence):
        return ['not', sentence]
    if isNotList(sentence):
        return sentence[1]
```

DeMorgan:

```
if isAndList(sentence):
    result = ['or']
    for i in sentence[1:]:
        if isNotList(sentence):
            result.append(i[1])
        else:
            result.append(['not', sentence])
    return result
if isOrList(sentence):
    result = ['and']
    for i in sentence[:]:
        if isNotList(sentence):
            result.append(i[1])
        else:
            result.append(['not', i])
    return result
return None
```

Convert a sentence into CNF.

```
def convertCNF(sentence):
```

```
while not isCNF(sentence):
    if sentence is None:
        return None
    sentence = makeCNF(sentence)
return sentence
```

```
def makeCNF(sentence):
    if isLiteral(sentence):
        return sentence
```

```
if (type(sentence).__name__ == 'list'):
    operand = sentence[0]
    if isNotList(sentence):
        if isLiteral(sentence[1]):
            return sentence
        cnf = makeCNF(sentence[1])
        if cnf[0] == 'not':
            return makeCNF(cnf[1])
        if cnf[0] == 'or':
            result = ['and']
            for i in range(1, len(cnf)):
                result.append(makeCNF(['not', cnf[i]]))
            return result
        if cnf[0] == 'and':
            result = ['or']
            for i in range(1, len(cnf)):
                result.append(makeCNF(['not', cnf[i]]))
            return result
    return "False: not"
```

Implication Elimination:

```
if operand == 'implies' and len(sentence) == 3:
    return makeCNF(['or', ['not', makeCNF(sentence[1])], makeCNF(sentence[2])])
```

Biconditional Elimination:

```
if operand == 'biconditional' and len(sentence) == 3:
    s1 = makeCNF(['implies', sentence[1], sentence[2]])
    s2 = makeCNF(['implies', sentence[2], sentence[1]])
    return makeCNF(['and', s1, s2])
```

```
if isAndList(sentence):
    result = ['and']
```

```

for i in range(1, len(sentence)):
    cnf = makeCNF(sentence[i])
    # Distributivity:
    if isAndList(cnf):
        for i in range(1, len(cnf)):
            result.append(makeCNF(cnf[i]))
        continue
    result.append(makeCNF(cnf))
return result

```

```

if isOrList(sentence):
    result1 = ['or']
    for i in range(1, len(sentence)):
        cnf = makeCNF(sentence[i])
        # Distributivity:
        if isOrList(cnf):
            for i in range(1, len(cnf)):
                result1.append(makeCNF(cnf[i]))
            continue
        result1.append(makeCNF(cnf))
    # Associativity:
    while True:
        result2 = ['and']
        and_clause = None
        for r in result1:
            if isAndList(r):
                and_clause = r
                break

        # Finish when there's no more 'and' lists
        # inside of 'or' lists
        if not and_clause:
            return result1

        result1.remove(and_clause)

    for i in range(1, len(and_clause)):
        temp = ['or', and_clause[i]]
        for o in result1[1:]:
            temp.append(makeCNF(o))
        result2.append(makeCNF(temp))
    result1 = makeCNF(result2)

```

```
    return None
return None
```

Below are 4 functions that check the type of a variable

```
def isLiteral(item):
```

```
    if type(item).__name__ == 'str':
        return True
    return False
```

```
def isNotList(item):
```

```
    if type(item).__name__ == 'list':
        if len(item) == 2:
            if item[0] == 'not':
                return True
    return False
```

```
def isAndList(item):
```

```
    if type(item).__name__ == 'list':
        if len(item) > 2:
            if item[0] == 'and':
                return True
    return False
```

```
def isOrList(item):
```

```
    if type(item).__name__ == 'list':
        if len(item) > 2:
            if item[0] == 'or':
                return True
    return False
```

```
AddSentence(['and', 'p', 'q'])
```

```
AddSentence(['or', 'r', 's'])
```

```
print(Query(['and', ['or', 'p', 'r'], ['or', 'q', 's']]))
```

OUTPUT SCREEN

Test Case 1:

PROBLEMS OUTPUT TERMINAL DEBUG CONSOLE

Windows PowerShell

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PS C:\Users\ravis> python -u "d:\codes\Artificial Intelligence Lab\Python\lab7.py"

True

PS C:\Users\ravis>

3. Implement unification in first order logic.

```
import re
```

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

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

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

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

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

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

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

```
def getFirstPart(expression):
```

```
attributes = getAttributes(expression)
return attributes[0]
```

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

```
def unify(exp1, exp2):
```

```
    if exp1 == exp2:
        return []
```

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

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

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

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

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

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

```
    attributeCount1 = len(getAttributes(exp1))
    attributeCount2 = len(getAttributes(exp2))
```

```
if attributeCount1 != attributeCount2:  
    return False
```

```
head1 = getFirstPart(exp1)  
head2 = getFirstPart(exp2)  
initialSubstitution = unify(head1, head2)  
if not initialSubstitution:  
    return False  
if attributeCount1 == 1:  
    return initialSubstitution
```

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

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

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

```
initialSubstitution.extend(remainingSubstitution)  
return initialSubstitution
```

```
print("\n\nTest Case 1:\n")  
exp1 = "knows(A,x)"  
exp2 = "knows(y,Y)"  
substitutions = unify(exp1, exp2)  
print("Substitutions:")  
print(substitutions)
```

```
print("\n\nTest Case 2:\n")  
exp1 = "knows(A,x)"  
exp2 = "knows(y,mother(y))"  
substitutions = unify(exp1, exp2)  
print("Substitutions:")  
print(substitutions)
```

OUTPUT SCREEN

PROBLEMS OUTPUT TERMINAL DEBUG CONSOLE

Windows PowerShell

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Try the new cross-platform PowerShell <https://aka.ms/pscore6>

```
PS C:\Users\ravis> python -u "d:\codes\Artificial Intelligence Lab\Python\lab8.py"
```

Test Case 1:

Substitutions:

```
[('A', 'y'), ('Y', 'x')]
```

Test Case 2:

Substitutions:

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

```
PS C:\Users\ravis>
```

4. Convert 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('[\forall\exists].', 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:
        aU = [a for a in attributes if not a.islower()][0]
        statement = statement.replace(aU,
f'{SKOLEM_CONSTANTS.pop(0)}({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('~[ $\exists$ ','~ $\exists$ ')
expr = '(~[ $\forall$ | $\exists$ ].)'
statements = re.findall(expr, statement)
for s in statements:
    statement = statement.replace(s, fol_to_cnf(s))
expr = '~\[[ $\wedge$ ]+\]'
statements = re.findall(expr, statement)
for s in statements:
    statement = statement.replace(s, DeMorgan(s))
return statement

```

```

print("\n Test Case: 1 ")

```

```

print(Skolemization(fol_to_cnf("animal(y)<=>loves(x,y)")))

```

```

print("\n Test Case: 2 ")

```

```

print(Skolemization(fol_to_cnf(" $\forall x[\forall y[\text{animal}(y) \Rightarrow \text{loves}(x,y)]] \Rightarrow [\exists z[\text{loves}(z,x)]]$ ")))

```

```

print("\n Test Case: 3 ")

```

```

print(Skolemization(fol_to_cnf("[american(x)&weapon(y)&sells(x,y,z)&hostile(z)]=>criminal(x)")))

```

```

print("\n \n ")

```

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Windows PowerShell

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PS C:\Users\ravis> python -u "d:\codes\Artificial Intelligence Lab\Python\lab9.py"

Test Case: 1

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

Test Case: 2

[animal(G(x))&~loves(x,G(x))][loves(F(y),x)]

Test Case: 3

[~american(x)|~weapon(y)|~sells(x,y,z)|~hostile(z)]|criminal(x)

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PS C:\Users\ravis> python -u "d:\codes\Artificial Intelligence Lab\Python\lab8.py"

Test Case 1:

Substitutions:

[('A', 'y'), ('Y', 'x')]

Test Case 2:

Substitutions:

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

PS C:\Users\ravis>

5. Create a knowledgebase 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}')

print("\n\n Test Case 1:")

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()

print("\n\n Test Case 2:")

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)')

```

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Test Case 1:

Querying criminal(x):

1. criminal(West)

All facts:

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

Test Case 2:

Querying evil(x):

1. evil(Richard)
2. evil(John)

PS C:\Users\ravis>