homework2

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1 50.040 Natural Language Processing (Summer 2020) Homework 2

Due

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[159]:
```
import copy
from collections import Counter
from nltk.tree import Tree
from nltk import Nonterminal
from nltk.corpus import LazyCorpusLoader, BracketParseCorpusReader
from collections import defaultdict
import time
```

[160]:
```
st = time.time()
```

[161]:
```
import nltk
nltk.download('treebank')
```

```
[nltk_data] Downloading package treebank to
[nltk_data]     /Users/wutianyu/nltk_data…
[nltk_data]   Package treebank is already up-to-date!
```

[161]: True

[162]:
```
def set_leave_lower(tree_string):
    if isinstance(tree_string, Tree):
        tree = tree_string
    else:
        tree = Tree.fromstring(tree_string)
    for idx, _ in enumerate(tree.leaves()):
```

```
        tree_location = tree.leaf_treeposition(idx)
        non_terminal = tree[tree_location[:-1]]
        non_terminal[0] = non_terminal[0].lower()
    return tree

def get_train_test_data():
    '''
    Load training and test set from nltk corpora
    '''
    train_num = 3900
    test_index = range(10)
    treebank = LazyCorpusLoader('treebank/combined', BracketParseCorpusReader,␣
 ↪r'wsj_.*\.mrg')
    cnf_train = treebank.parsed_sents()[:train_num]
    cnf_test = [treebank.parsed_sents()[i+train_num] for i in test_index]
    #Convert to Chomsky norm form, remove auxiliary labels
    cnf_train = [convert2cnf(t) for t in cnf_train]
    cnf_test = [convert2cnf(t) for t in cnf_test]
    return cnf_train, cnf_test
def convert2cnf(original_tree):
    '''
    Chomsky norm form
    '''
    tree = copy.deepcopy(original_tree)

    #Remove cases like NP->DT, VP->NP
    tree.collapse_unary(collapsePOS=True, collapseRoot=True)
    #Convert to Chomsky
    tree.chomsky_normal_form()

    tree = set_leave_lower(tree)
    return tree
```

[163]:
```
### GET TRAIN/TEST DATA
cnf_train, cnf_test = get_train_test_data()
```

[164]:
```
cnf_train[0].pprint()
```

```
(S
  (NP-SBJ
    (NP (NNP pierre) (NNP vinken))
    (NP-SBJ|<,-ADJP-,>
      (, ,)
      (NP-SBJ|<ADJP-,>
        (ADJP (NP (CD 61) (NNS years)) (JJ old))
        (, ,))))
  (S|<VP-.>
```

```
(VP
  (MD will)
  (VP
    (VB join)
    (VP|<NP-PP-CLR-NP-TMP>
      (NP (DT the) (NN board))
      (VP|<PP-CLR-NP-TMP>
        (PP-CLR
          (IN as)
          (NP
            (DT a)
            (NP|<JJ-NN> (JJ nonexecutive) (NN director))))
        (NP-TMP (NNP nov.) (CD 29))))))
(. .)))
```

1.1 Question 1

To better understand PCFG, let's consider the first parse tree in the training data "cnf_train" as an example. Run the code we have provided for you and then writedown the roles of.productions(), .rhs(), .lhs(), .leaves()in the ipynb notebook.

[165]:
```
rules = cnf_train[0].productions()
print(rules, type(rules[0]))
```

```
[S -> NP-SBJ S|<VP-.>, NP-SBJ -> NP NP-SBJ|<,-ADJP-,>, NP -> NNP NNP, NNP ->
'pierre', NNP -> 'vinken', NP-SBJ|<,-ADJP-,> -> , NP-SBJ|<ADJP-,>, , -> ',', NP-
SBJ|<ADJP-,> -> ADJP ,, ADJP -> NP JJ, NP -> CD NNS, CD -> '61', NNS -> 'years',
JJ -> 'old', , -> ',', S|<VP-.> -> VP ., VP -> MD VP, MD -> 'will', VP -> VB
VP|<NP-PP-CLR-NP-TMP>, VB -> 'join', VP|<NP-PP-CLR-NP-TMP> -> NP VP|<PP-CLR-NP-
TMP>, NP -> DT NN, DT -> 'the', NN -> 'board', VP|<PP-CLR-NP-TMP> -> PP-CLR NP-
TMP, PP-CLR -> IN NP, IN -> 'as', NP -> DT NP|<JJ-NN>, DT -> 'a', NP|<JJ-NN> ->
JJ NN, JJ -> 'nonexecutive', NN -> 'director', NP-TMP -> NNP CD, NNP -> 'nov.',
CD -> '29', . -> '.'] <class 'nltk.grammar.Production'>
```

[166]:
```
rules[0].rhs(), type(rules[0].rhs()[0])
```

[166]:
```
((NP-SBJ, S|<VP-.>), nltk.grammar.Nonterminal)
```

[167]:
```
rules[10].rhs(), type(rules[10].rhs()[0])
```

[167]:
```
(('61',), str)
```

[168]:
```
rules[0].lhs(), type(rules[0].lhs())
```

[168]:
```
(S, nltk.grammar.Nonterminal)
```

[169]:
```
print(cnf_train[0].leaves())
```

```
['pierre', 'vinken', ',', '61', 'years', 'old', ',', 'will', 'join', 'the',
'board', 'as', 'a', 'nonexecutive', 'director', 'nov.', '29', '.']
```

ANSWER HERE - productions(): Method of parse tree, returning the list of all the rules in Chomsky normal form in preorder. - rhs(): Method of grammar rule (production), returning tuple of nonterminals of length 2 OR tuple of terminal (string) of length 1. In either case, it is the right-hand side of chomsky normal rules. - lhs(): Method of grammar rule (production), returning a nonterminal., which is the left-hand side of chomsky normal rules. - leaves(): Method of parse tree, returning the list of all terminals (words) from left to right.

1.2 Question 2

To count the number of unique rules, nonterminals and terminals, pleaseimplement functions **collect_rules, collect_nonterminals, collect_terminals**

[170]:
```python
def collect_rules(train_data):
    '''
    Collect the rules that appear in data.
    params:
        train_data: list[Tree] --- list of Tree objects
    return:
        rules: list[nltk.grammar.Production] --- list of rules (Production␣
↪objects)
        rules_counts: Counter object --- a dictionary that maps one rule (nltk.
↪Nonterminal) to its number of
                                                occurences (int) in train data.
    '''
    rules = list()
    rules_counts = Counter()
    ### YOUR CODE HERE (~ 2 lines)
    rules = [rule for tree in train_data for rule in tree.productions()]
    rules_counts = Counter(rules)
    ### YOUR CODE HERE
    return rules, rules_counts

def collect_nonterminals(rules):
    '''
    collect nonterminals that appear in the rules
    params:
        rules: list[nltk.grammar.Production] --- list of rules (Production␣
↪objects)
    return:
        nonterminals: set(nltk.Nonterminal) --- set of nonterminals
    '''
    nonterminals = list()
    ### YOUR CODE HERE (at least one line)
    nonterminals = [rule.lhs() for rule in rules]
```

```
    ### END OF YOUR CODE
    return set(nonterminals)

def collect_terminals(rules):
    '''
    collect terminals that appear in the rules
    params:
        rules: list[nltk.grammar.Production] --- list of rules (Production␣
↪objects)
    return:
        terminals: set of strings --- set of terminals
    '''
    terminals = list()
    ### YOUR CODE HERE (at least one line)
#     terminals = [rule.rhs()[0] for rule in rules if type(rule.rhs()[0]) ==␣
↪str]
    terminals = [rule.rhs()[0] for rule in rules if len(rule.rhs()) == 1]
    ### END OF YOUR CODE

    return set(terminals)
```

[171]:
```
train_rules, train_rules_counts = collect_rules(cnf_train)
nonterminals = collect_nonterminals(train_rules)
terminals = collect_terminals(train_rules)
```

[172]:
```
### CORRECT ANSWER (19xxxx, 3xxxx, 1xxxx, 7xxx)
len(train_rules), len(set(train_rules)), len(terminals), len(nonterminals)
```

[172]:
```
(196646, 31656, 11367, 7869)
```

[173]:
```
print(train_rules_counts.most_common(5))
```

```
[(, -> ',', 4876), (DT -> 'the', 4726), (. -> '.', 3814), (PP -> IN NP, 3273),
(S|<VP-.> -> VP ., 3003)]
```

1.3 Question 3

Implement the function **build_pcfg** which builds a dictionary that stores theterminal rules and nonterminal rules.

[174]:
```
def build_pcfg(rules_counts):
    '''
    Build a dictionary that stores the terminal rules and nonterminal rules.
    param:
        rules_counts: Counter object --- a dictionary that maps one rule to its␣
↪number of occurences in train data.
    return:
```

```
        rules_dict: dict(dict(dict)) --- a dictionary has a form like:
                    rules_dict = {'terminals':{'NP':{'the':1000,'an':500},␣
↪'ADJ':{'nice':500,'good':100}},
                                  'nonterminals':{'S':{'NP@VP':1000},'NP':
↪{'NP@NP':540}}}
    When building "rules_dict", you need to use "lhs()", "rhs()" funtion and␣
↪convert Nonterminal to str.
    All the keys in the dictionary are of type str.
    '@' is used as a special symbol to split left and right nonterminal strings.
    '''

    rules_dict = dict()
    ### rules_dict['terminals'] contains rules like "NP->'the'"
    ### rules_dict['nonterminals'] contains rules like "S->NP@VP"
    rules_dict['terminals'] = defaultdict(dict)
    rules_dict['nonterminals'] = defaultdict(dict)

    ### YOUR CODE HERE
    for rule in rules_counts:
#         print(rule)
        if type(rule.rhs()[0]) == str:
#             print('terminal')
#             print(rules_counts[rule])
            rules_dict['terminals'][str(rule.lhs())][rule.rhs()[0]] =␣
↪rules_counts[rule]
#             print(rules_dict['terminals'][rule.lhs()][rule.rhs()[0]])
        else:
#             print('nonterminal')
#             print(str(rule.rhs()[0])+'@'+str(rule.rhs()[1]))
            rules_dict['nonterminals'][str(rule.lhs())][str(rule.
↪rhs()[0])+'@'+str(rule.rhs()[1])] = rules_counts[rule]
    ### END OF YOUR CODE
    return rules_dict
```

[175]:
```
train_rules_dict = build_pcfg(train_rules_counts)
```

1.4 Question 4

Estimate the probability of rule $NP \rightarrow NNP@NNP$

[176]:
```
NNPNNP_count = train_rules_dict['nonterminals']['NP']['NNP@NNP']
NP_count = sum(train_rules_dict['nonterminals']['NP'].values()) +␣
↪sum(train_rules_dict['terminals']['NP'].values())
NNPNNP_count/NP_count
```

[176]: 0.03950843529348353

1.5 Question 5

Find the terminal symbols in ''cnf_test[0]" that never appeared in the PCFG we built.

```
[177]: set(cnf_test[0].leaves()) - terminals
```

```
[177]: {'constitutional-law'}
```

1.6 Question 6

We can use smoothing techniques to handle these cases. A simple smoothing method is as follows. We first create a new "unknown" terminal symbol *unk*.

Next, for each original non-terminal symbol $A \in N$, we add one new rule $A \rightarrow unk$ to the original PCFG.

The smoothed probabilities for all rules can then be estimated as:

$$q_{smooth}(A \rightarrow \beta) = \frac{count(A \rightarrow \beta)}{count(A) + 1}$$

$$q_{smooth}(A \rightarrow unk) = \frac{1}{count(A) + 1}$$

where $|V|$ is the count of unique terminal symbols.

Implement the function **smooth_rules_prob** which returns the smoothed rule probabilities

```
[178]: def smooth_rules_prob(rules_counts):
    '''
    params:
        rules_counts: dict(dict(dict)) --- a dictionary has a form like:
                    rules_counts = {'terminals':{'NP':{'the':1000,'an':500},␣
 ↪'ADJ':{'nice':500,'good':100}},
                                    'nonterminals':{'S':{'NP@VP':1000},'NP':
 ↪{'NP@NP':540}}}

    return:
        rules_prob: dict(dict(dict)) --- a dictionary that has a form like:
                            rules_prob = {'terminals':{'NP':{'the':0.6,'an':
 ↪0.3, '<unk>':0.1},
                                                        'ADJ':{'nice':0.
 ↪6,'good':0.3,'<unk>':0.1},
                                                        'S':{'<unk>':0.01}}}
                                        'nonterminals':{'S':{'NP@VP':0.99}}
    '''
    rules_prob = copy.deepcopy(rules_counts)
    unk = '<unk>'
    ### Hint: don't forget to consider nonterminal symbols that don't appear in␣
 ↪rules_counts['terminals'].keys()
```

```
    ### YOUR CODE HERE
    nonterminals = set(rules_counts['terminals'].keys()).
↪union(set(rules_counts['nonterminals'].keys()))
    for nonterminal in nonterminals:
        rules_prob['terminals'][nonterminal][unk] = 1
        Occurence_sum = sum(rules_prob['nonterminals'][nonterminal].values()) +␣
↪\
                        sum(rules_prob['terminals'][nonterminal].values())
        for terminal in rules_prob['terminals'][nonterminal].keys():
            rules_prob['terminals'][nonterminal][terminal] /= Occurence_sum
        for rhs in rules_prob['nonterminals'][nonterminal].keys():
            rules_prob['nonterminals'][nonterminal][rhs] /= Occurence_sum
    ### END OF YOUR CODE
    return rules_prob
```

[179]:
```
s_rules_prob = smooth_rules_prob(train_rules_dict)
terminals.add('<unk>')
```

[180]:
```
print(s_rules_prob['nonterminals']['S']['NP-SBJ@S|<VP-.>'])
print(s_rules_prob['nonterminals']['S']['NP-SBJ-1@S|<VP-.>'])
print(s_rules_prob['nonterminals']['NP']['NNP@NNP'])
print(s_rules_prob['terminals']['NP'])
```

```
0.1300172371337109
0.025240088648116228
0.039506305917861376
{'<unk>': 5.389673385792821e-05}
```

[181]:
```
len(terminals)
```

[181]: 11368

1.7 CKY Algorithm

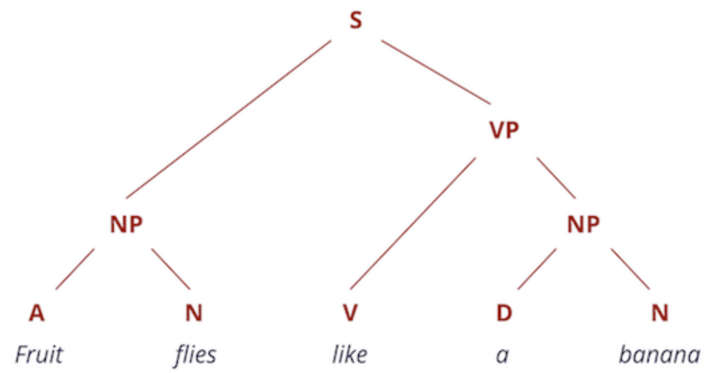
Similar to the Viterbi algorithm, the CKY algorithm is a dynamic-programming algorithm. Given a PCFG $G = (N,\ \Sigma,\ S,\ R,\ q)$, we can use the CKY algorithm described in class to find the highest scoring parse tree for a sentence.

First, let us complete the *CKY* function from scratch using only Python built-in functions and the Numpy package.

The output should be two dictionaries π and bp, which store the optimal probability and backpointer information respectively.

Given a sentence $w_0, w_1, ..., w_{n-1}$, $\pi(i, k, X)$, $bp(i, k, X)$ refer to the highest score and backpointer for the (partial) parse tree that has the root X (a non-terminal symbol) and covers the word span

$w_i, ..., w_{k-1}$, where $0 \leq i < k \leq n$. Note that a backpointer includes both the best grammar rule chosen and the best split point.



1.8 Question 7

Implement **CKY** function and run the test code to check your implementation.

[182]:
```
import math
import numpy as np
```

[183]:
```
def CKY(sent, rules_prob):
    '''
    params:
        sent: list[str] --- a list of strings
        rules_prob: dict(dict(dict)) --- a dictionary that has a form like:
                                    rules_prob = {'terminals':{'NP':
↪{'the':0.6,'an':0.3, '<unk>':0.1},
                                                                        'ADJ':
↪{'nice':0.6,'good':0.3,'<unk>':0.1},
                                                                        'S':
↪{'<unk>':0.01}}}
                                                          'nonterminals':{'S':
↪{'NP@VP':0.99}}
    return:
        score: dict() --- score[(i,i+span)][root] represents the highest score␣
↪for the parse (sub)tree that has the root "root"
                          across words w_i, w_{i+1},..., w_{i+span-1}.
        back: dict() --- back[(i,i+span)][root] = (split , left_child,␣
↪right_child); split: int;
                         left_child: str; right_child: str.
    '''
    score = defaultdict(dict)
    back = defaultdict(dict)
    sent_len = len(sent)
    ### YOUR CODE HERE
    for i in range(sent_len):
```

```
        for nonterminal in rules_prob['terminals']:
            # handle the
#             if sent[i] in rules_prob['terminals'][nonterminal]:
#                 score[(i,i+1)][nonterminal] = math.
↪log(rules_prob['terminals'][nonterminal][sent[i]])
#             else:
#                 score[(i,i+1)][nonterminal] = math.
↪log(rules_prob['terminals'][nonterminal]['<unk>'])
#             back[(i,i+1)][nonterminal] = (-1, sent[i], None)
            if sent[i] in rules_prob["terminals"][nonterminal]:
                score[(i,i+1)][nonterminal] = math.
↪log(rules_prob['terminals'][nonterminal][sent[i]])
                back[(i,i+1)][nonterminal] = (-1, sent[i], None)
    for span in range(2, sent_len+1):
        for begin in range(sent_len-span+1):
            end = begin + span
            for split in range(begin+1, end):
                if begin == 0 and span == sent_len:
#                     print('entering the last one')
                    temp_iterable = ['S']
                else:
                    temp_iterable = rules_prob['nonterminals']
                for left in temp_iterable:
                    for right in rules_prob['nonterminals'][left]:
                        first, second = right.split('@')
                        if (first in score[(begin,split)]) and (second in␣
↪score[(split,end)]):
                            new_score = score[begin,split][first] +␣
↪score[split,end][second] + \
                                math.
↪log(rules_prob['nonterminals'][left][right])
                            if left not in score[begin,end]:
                                score[(begin,end)][left] = new_score
                                back[(begin,end)][left] = (split, first, second)
                            else:
                                if new_score > score[(begin,end)][left]:
                                    score[(begin,end)][left] = new_score
                                    back[(begin,end)][left] = (split, first,␣
↪second)
    ### END OF YOUR CODE
    return score, back
```

[184]:
```
sent = cnf_train[0].leaves()
score, back = CKY(sent, s_rules_prob)
```

[185]:
```
score[(0, len(sent))]['S']
```

[185]: -117.52227496068694

[186]:
```
math.exp(score[(0, len(sent))]['S'])
```

[186]: 9.135335125206607e-52

1.9 Question 8

Implement **build_tree** function according to algorithm 2 to reconstruct theparse tree

[187]:
```
def build_tree(back, root):
    '''
    Build the tree recursively.
    params:
        back: dict() --- back[(i,i+span)][X] = (split , left_child,␣
 ↪right_child); split:int; left_child: str; right_child: str.
        root: tuple() --- (begin, end, nonterminal_symbol), e.g., (0, 10, 'S
    return:
        tree: nltk.tree.Tree
    '''
    begin = root[0]
    end = root[1]
    root_label = root[2]
    ### YOUR CODE HERE
    split, left_child, right_child = back[(begin, end)][root_label]
    if right_child:
        left_tree = build_tree(back, (begin, split, left_child))
        right_tree = build_tree(back, (split, end, right_child))
        tree = nltk.tree.Tree(root_label, [left_tree, right_tree])
    else:
        tree = nltk.tree.Tree(root_label, [left_child])
    ### END OF YOUR CODE
    return tree
```

[188]:
```
build_tree(back, (0, len(sent), 'S')).pprint()
```

```
(S
  (NP-SBJ
    (NP (NNP pierre) (NNP vinken))
    (NP-SBJ|<,-NP-,>
      (, ,)
      (NP-SBJ|<NP-,>
        (NP (CD 61) (NP|<NNS-JJ> (NNS years) (JJ old)))
        (, ,))))
  (S|<VP-.>
    (VP
      (MD will)
```

```
      (VP
        (VB join)
        (VP|<NP-PP-CLR-NP-TMP>
          (NP (DT the) (NN board))
          (VP|<PP-CLR-NP-TMP>
            (PP-CLR
              (IN as)
              (NP
                (DT a)
                (NP|<JJ-NN> (JJ nonexecutive) (NN director))))
            (NP-TMP (NNP nov.) (CD 29))))))
    (. .)))
```

1.10 Question 9

[189]:
```python
def set_leave_index(tree):
    '''
    Label the leaves of the tree with indexes
    Arg:
        tree: original tree, nltk.tree.Tree
    Return:
        tree: preprocessed tree, nltk.tree.Tree
    '''
    for idx, _ in enumerate(tree.leaves()):
        tree_location = tree.leaf_treeposition(idx)
        non_terminal = tree[tree_location[:-1]]
        non_terminal[0] = non_terminal[0] + "_" + str(idx)
    return tree

def get_nonterminal_bracket(tree):
    '''
    Obtain the constituent brackets of a tree
    Arg:
        tree: tree, nltk.tree.Tree
    Return:
        nonterminal_brackets: constituent brackets, set
    '''
    nonterminal_brackets = set()
    for tr in tree.subtrees():
        label = tr.label()
        #print(tr.leaves())
        if len(tr.leaves()) == 0:
            continue
        start = tr.leaves()[0].split('_')[-1]
        end = tr.leaves()[-1].split('_')[-1]
        if start != end:
```

```
            nonterminal_brackets.add(label+'-('+start+':'+end+')')
    return nonterminal_brackets

def word2lower(w, terminals):
    '''
    Map an unknow word to "unk"
    '''
    return w.lower() if w in terminals else '<unk>'
```

[190]:
```
correct_count = 0
pred_count = 0
gold_count = 0
for i, t in enumerate(cnf_test):
    #Protect the original tree
    t = copy.deepcopy(t)
    sent = t.leaves()
    #Map the unknow words to "unk"
    sent = [word2lower(w.lower(), terminals) for w in sent]

    #CKY algorithm
    score, back = CKY(sent, s_rules_prob)
    candidate_tree = build_tree(back, (0, len(sent), 'S'))

    #Extract constituents from the gold tree and predicted tree
    pred_tree = set_leave_index(candidate_tree)
    pred_brackets = get_nonterminal_bracket(pred_tree)

    #Count correct constituents
    pred_count += len(pred_brackets)
    gold_tree = set_leave_index(t)
    gold_brackets = get_nonterminal_bracket(gold_tree)
    gold_count += len(gold_brackets)
    current_correct_num = len(pred_brackets.intersection(gold_brackets))
    correct_count += current_correct_num

    print('#'*20)
    print('Test Tree:', i+1)
    print('Constituent number in the predicted tree:', len(pred_brackets))
    print('Constituent number in the gold tree:', len(gold_brackets))
    print('Correct constituent number:', current_correct_num)

recall = correct_count/gold_count
precision = correct_count/pred_count
f1 = 2*recall*precision/(recall+precision)
```

```
####################
Test Tree: 1
```

```
Constituent number in the predicted tree: 20
Constituent number in the gold tree: 20
Correct constituent number: 14
####################
Test Tree: 2
Constituent number in the predicted tree: 54
Constituent number in the gold tree: 54
Correct constituent number: 26
####################
Test Tree: 3
Constituent number in the predicted tree: 30
Constituent number in the gold tree: 30
Correct constituent number: 23
####################
Test Tree: 4
Constituent number in the predicted tree: 17
Constituent number in the gold tree: 17
Correct constituent number: 16
####################
Test Tree: 5
Constituent number in the predicted tree: 32
Constituent number in the gold tree: 32
Correct constituent number: 26
####################
Test Tree: 6
Constituent number in the predicted tree: 40
Constituent number in the gold tree: 40
Correct constituent number: 18
####################
Test Tree: 7
Constituent number in the predicted tree: 22
Constituent number in the gold tree: 22
Correct constituent number: 7
####################
Test Tree: 8
Constituent number in the predicted tree: 18
Constituent number in the gold tree: 18
Correct constituent number: 6
####################
Test Tree: 9
Constituent number in the predicted tree: 28
Constituent number in the gold tree: 28
Correct constituent number: 16
####################
Test Tree: 10
Constituent number in the predicted tree: 40
Constituent number in the gold tree: 40
Correct constituent number: 8
```

[191]:

```
print('Overall precision: {:.3f}, recall: {:.3f}, f1: {:.3f}'.format(precision,␣
↪recall, f1))
```

```
Overall precision: 0.532, recall: 0.532, f1: 0.532
```

[192]:

```
print('Overall precision: {:.3f}, recall: {:.3f}, f1: {:.3f}'.format(precision,␣
↪recall, f1))
```

```
Overall precision: 0.532, recall: 0.532, f1: 0.532
```

[193]:

```
et=time.time()
print(et - st)
```

```
567.4165601730347
```

[ ]:

```
```