67658 Natural Language Processing

Exercise 2

Asaf Shul 207042714

Daniel Azulay 311119895

initialize notebook:

```
# uncomment to download the module:
# !python -m spacy download en_core_web_sm

import nltk
# nltk.download('brown') # uncomment to download the module
from nltk.corpus import brown

import spacy
nlp = spacy.load("en_core_web_sm")

import numpy as np
import pandas as pd
import seaborn as sns

from IPython.display import display

from itertools import chain
from collections import Counter

from copy import deepcopy

from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix

import matplotlib.pyplot as plt

import warnings
warnings.filterwarnings('ignore')
```

consts:

```
START       = 'START'
STOP        = 'STOP'
UNKNOWN_TAG = 'NN'
NOT_found   = -1
```

functions:

```
def add_start_stop(corpus):
    return [[(START, START)] + sent + [(STOP, STOP)] for sent in
corpus]

def flatten(corpus):
    return list(chain.from_iterable(corpus))

def replace_word_tag(flat_corpus):
    return [(tag, word) for word, tag in flat_corpus]

def emission_setup(corpus):
    return replace_word_tag(flatten(add_start_stop(corpus)))

def get_tag_pairs(corpus):
    pairs = []

    for sent in corpus:
        sent = [START] + [tag for _, tag in sent] + [STOP]
        pairs.extend([p for p in zip(sent[:-1], sent[1:])])

    return pairs

def get_freq_dict(base_dict, norm=True, smooth=0):
    freq_dict = {}

    # format to freq dict:
    for key, count in base_dict.items():
        word, tag = key
        if word not in freq_dict:
            freq_dict[word] = {tag : count}
        elif tag not in freq_dict[word]:
            freq_dict[word][tag] = count
        else:
            freq_dict[word][tag] += count

    if norm:
        # change count to relative probability:
        for word_counts in freq_dict.values():
            _N = sum(word_counts.values()) + len(word_counts) * smooth
            for key in word_counts:
#                 word_counts[key] = (word_counts[key] + smooth) / _N
                word_counts[key] = np.log((word_counts[key] + smooth)
/ _N)

    return freq_dict

def get_mle(train, test):
    unknown_words_dict = dict(Counter(chain.from_iterable(test)))
    freq_dict =
get_freq_dict(dict(Counter(chain.from_iterable(train))), norm=False)
```

```
    res_dict  = {}

    # find the POS using MLE:
    for word, counts_dict in freq_dict.items():
        res_dict[word] = max(counts_dict, key=counts_dict.get)

    # add missing words:
    for word, _ in unknown_words_dict.keys():
        if word not in res_dict:
            res_dict[word] = UNKNOWN_TAG
    return res_dict

def get_emission(corpus, smooth=0):
    return
pd.DataFrame(get_freq_dict(dict(Counter(emission_setup(corpus))),
smooth=smooth)).fillna(-np.inf)

def get_transitions(train, smooth=0):
    return
pd.DataFrame(get_freq_dict(dict(Counter(get_tag_pairs(train))),
smooth=smooth)).fillna(-np.inf)

def clean_tag(w):
    p = w.find('+')
    m = w.find('-')
    n = len(w)
    return w[:min(p if p > 0 else n, m if m > 0 else n)]

def clean_corpus(corpus):
    return [[(word, clean_tag(tag)) for word, tag in sent] for sent in
corpus]

def init_viterbi(tags, n):
    # initialize pi and bp
#     pi = pd.DataFrame(0, columns=tags, index=range(n-1))
#     pi.at[0, START] = 1

    pi = pd.DataFrame(-np.inf, columns=tags, index=range(n-1))
    pi.at[0, START] = 0

    bp = pd.DataFrame(np.nan, columns=tags, index=range(n-1))
    bp.loc[1] = START

    return pi, bp

def learn_viterbi(x, tags, n, pi, bp, transitions, emissions):
    tags_no_start = tags[1:]
    train_words = list(emissions.index)

    # dynamic array fill:
    pi.loc[1, transitions[START].keys()] = transitions[START]
    for k in range(2, n-1):
        word = x[k]
        known_word = (word in train_words)
        for curr_tag in tags_no_start:
            res = []
            cur_emission = emissions.at[word, curr_tag] if known_word
else 0

            for prev_tag in tags_no_start:
                cur_transition = transitions.at[curr_tag, prev_tag]#
if prev_known_word else 0
                p = pi.at[k-1, prev_tag] + cur_transition +
cur_emission
                res.append((p, prev_tag))

            if res:
                res = sorted(res, key=lambda t: t[0], reverse=True)
                if res[0][0] != -np.inf:
                    pi.at[k, curr_tag] = res[0][0]
                    bp.at[k, curr_tag] = res[0][1]

        if pi.loc[k].max() == -np.inf:
                pi.at[k, mle_model[word]] = 0
                bp.at[k, mle_model[word]] = pi.loc[k-1].idxmax()
    return pi, bp

def predict_viterbi(x, pi, bp):
    # prediction:
    pred = [(x[-2], pi.iloc[-1].idxmax())]
    for i, w in list(enumerate(x[1:-2]))[::-1]:
        pred.append((w, bp.loc[i+2, pred[-1][1]]))

    return pred[::-1]

def viterbi(sent, transitions, emissions):
    # initialize:
    x = [START] + sent + [STOP]
    n = len(x)
    tags = list(transitions.keys())
    train_words = list(emissions.index)

    pi, bp = init_viterbi(tags, n)
    pi, bp = learn_viterbi(x, tags, n, pi, bp, transitions, emissions)
    return predict_viterbi(x, pi, bp)

def mle_error_rate(corpus, model):
    return round(1 - sum([1 for (w, t) in corpus if model[w] == t]) /
len(corpus), 5)
```

```
def hmm_error_rate(test, emissions, transitions):
    known_succ = 0
    unknown_succ = 0
    known_guess = 0
    unknown_guess = 0

    unknown_words_words = [w for w, _ in unknown_words]

    for i, sent in enumerate(test):
        print('.', end='')
        preds = viterbi([w for w, _ in sent], transitions, emissions)

        for p in zip(sent, preds):
            if p[0][0] in unknown_words_words:
                unknown_succ += p[0] == p[1]
                unknown_guess += 1
            else:
                known_succ += p[0] == p[1]
                known_guess += 1
    print()
    return (round(1 - ((known_succ + unknown_succ) / (known_guess +
unknown_guess)), 5),
            round(1 - (known_succ / known_guess), 5),
            (round(1 - (unknown_succ / unknown_guess), 5)) if
unknown_guess else np.nan)
```

results:

initialize data:

```
# get data:
tagged = clean_corpus(brown.tagged_sents(categories="news"))
train, test = train_test_split(tagged, test_size=0.1, shuffle=False)
```

a) create MLE:

```
%%time
mle_model = get_mle(train, test)
```

```
CPU times: user 19.4 ms, sys: 1.31 ms, total: 20.8 ms
Wall time: 20.2 ms
```

b) MLE accuracy:

```
f_train = flatten(train)
f_test = flatten(test)

f_train_words = [w for w, _ in flatten(train)]
f_test_words = [w for w, _ in flatten(test)]

known_words = [(w, t) for w, t in f_test if w in f_train_words]
unknown_words = [(w, t) for w, t in f_test if w not in f_train_words]
```

```
# calc accuracy:
print(f'Error rate using MLE:')
print(f'----------------------------------')
print(f'  - total words is   {mle_error_rate(flatten(test),
mle_model)}')
print(f'----------------------------------')
print(f'  - known words is   {mle_error_rate(known_words,
mle_model)}')
print(f'  - unknown words is {mle_error_rate(unknown_words,
mle_model)}')
print(f'----------------------------------')
```

```
Error rate using MLE:
----------------------------------
  - total words is   0.14811
----------------------------------
  - known words is   0.07044
  - unknown words is 0.75044
----------------------------------
```

c) HMM:

```
emissions = get_emission(train)
transitions = get_transitions(train)

total_error, known_error, unknown_error = hmm_error_rate(test,
emissions, transitions)
# calc accuracy:
print(f'Error rate using HMM:')
print(f'----------------------------------')
print(f'  - total words is   {total_error}')
print(f'----------------------------------')
print(f'  - known words is   {known_error}')
print(f'  - unknown words is {unknown_error}')
print(f'----------------------------------')
```

```
......................................................................
......................................................................
......................................................................
......................................................................
......................................................................
......................................................................
...........................................
Error rate using HMM:
----------------------------------
  - total words is   0.13635
----------------------------------
  - known words is   0.06301
  - unknown words is 0.70506
----------------------------------
```

d) HMM: add-1 smothing

```
smooth_emissions = get_emission(train, smooth=1)
smooth_transitions = get_transitions(train, smooth=1)

total_error, known_error, unknown_error = hmm_error_rate(test,
smooth_emissions, smooth_transitions)
# calc accuracy:
print(f'Error rate using HMM + add-1 smoothing:')
print(f'----------------------------------')
print(f'  - total words is   {total_error}')
print(f'----------------------------------')
print(f'  - known words is   {known_error}')
print(f'  - unknown words is {unknown_error}')
print(f'----------------------------------')
```

```
......................................................................
......................................................................
......................................................................
......................................................................
......................................................................
......................................................................
...........................................
Error rate using HMM + add-1 smoothing:
----------------------------------
  - total words is   0.13575
----------------------------------
  - known words is   0.06211
  - unknown words is 0.70681
----------------------------------
```

d) HMM: Psuedo Words

```
f_test = [w for (w, _) in flatten(test)]
f_train = [w for (w, _) in flatten(train)]
unknown = pd.Series(1, index=[w for w in f_test if w not in f_train])

counts = pd.Series(Counter(f_train))
counts = counts[counts <= 5]

counts = pd.concat([counts, unknown])

years = counts[(counts.index.str.isdigit()) & (counts.index.str.len()
== 4)].index
counts = counts[~counts.index.isin(years)]

quantity = counts[(((counts.index.str.replace(',',
'')).str.replace('.', '')).str.isdigit())].index
counts = counts[~counts.index.isin(quantity)]

price = counts[(counts.index.str.contains('\$')) &
(counts.index.str.len() > 1)].index
counts = counts[~counts.index.isin(price)]

precentage = counts[(counts.index.str.contains('\%')) &
(counts.index.str.len() > 1)].index
counts = counts[~counts.index.isin(precentage)]

acronyms = counts[(counts.index.str.isupper()) &
counts.index.str.replace('.', '').str.isalpha() &
(counts.index.str.len() > 1)].index
counts = counts[~counts.index.isin(acronyms)]

letter = counts[(counts.index.str.isalpha()) & (counts.index.str.len()
== 1) & (counts.index != 'a') & (counts.index != 'I')].index
counts = counts[~counts.index.isin(letter)]

possession = counts[(counts.index.str.endswith("'s"))].index
counts = counts[~counts.index.isin(possession)]

rank = counts[(counts.index.str.endswith("th") |
counts.index.str.endswith("st") |\
              counts.index.str.endswith("nd") |
counts.index.str.endswith("rd")) & \
              (counts.index.str[:-2].str.isdigit())].index
counts = counts[~counts.index.isin(rank)]

short = counts[counts.index.str.endswith('.')].index
counts = counts[~counts.index.isin(short)]

date = counts[counts.index.str.replace('-', '').str.replace('/',
'').str.isdigit() & counts.index.str.contains('-')].index
counts = counts[~counts.index.isin(date)]

time = counts[counts.index.str.replace(':', '').str.isdigit() &
counts.index.str.contains(':')].index
counts = counts[~counts.index.isin(time)]

units = counts[counts.index.str[-1].str.isalpha() &
counts.index.str[0].str.isdigit()].index
counts = counts[~counts.index.isin(units)]

dash = counts[counts.index.str.replace('-', '').str.isalpha() &
counts.index.str.contains('-')].index
counts = counts[~counts.index.isin(dash)]

ly = counts[counts.index.str.endswith('ly')].index
counts = counts[~counts.index.isin(ly)]

ing = counts[counts.index.str.endswith('ing')].index
```

```
counts = counts[~counts.index.isin(ing)]

ion = counts[counts.index.str.endswith('ion')].index
counts = counts[~counts.index.isin(ion)]

ed = counts[counts.index.str.endswith('ed')].index
counts = counts[~counts.index.isin(ed)]

ment = counts[counts.index.str.endswith('ment')].index
counts = counts[~counts.index.isin(ment)]

er = counts[counts.index.str.endswith('er')].index
counts = counts[~counts.index.isin(er)]

tory = counts[counts.index.str.endswith('tory')].index
counts = counts[~counts.index.isin(tory)]

nt = counts[counts.index.str.endswith("n't")].index
counts = counts[~counts.index.isin(nt)]

init_cap = counts[counts.index.str[0].str.isupper()].index
counts = counts[~counts.index.isin(init_cap)]

lower = counts[counts.index.str.islower() &
counts.index.str.isalpha()].index
counts = counts[~counts.index.isin(lower)]

misc = counts.index


code_dict = \
{('*years*', '*years-tag*') : years,
 ('*quantity*', '*quantity-tag*') : quantity,
 ('*price*', '*price-tag*') : price,
 ('*precentage*', '*precentage-tag*') : precentage,
 ('*acronyms*', '*acronyms-tag*') : acronyms,
 ('*letter*', '*letter-tag*') : letter,
 ('*possession*', '*possession-tag*') : possession,
 ('*rank*', '*rank-tag*') : rank,
 ('*short*', '*short-tag*') : short,
 ('*date*', '*date-tag*') : date,
 ('*time*', '*time-tag*') : time,
 ('*units*', '*units-tag*') : units,
 ('*dash*', '*dash-tag*') : dash,
 ('*ly*', '*ly-tag*') : ly,
 ('*ing*', '*ing-tag*') : ing,
 ('*ion*', '*ion-tag*') : ion,
 ('*ed*', '*ed-tag*') : ed,
 ('*ment*', '*ment-tag*') : ment,
 ('*er*', '*er-tag*') : er,
 ('*tory*', '*tory-tag*') : tory,
 ('*nt*', '*nt-tag*') : nt,
 ('*years*', '*years-tag*') : years,
 ('*init_cap*', '*init_cap-tag*') : init_cap,
 ('*lower*', '*lower-tag*') : lower,
 ('*misc*', '*misc-tag*') : misc}

def replace_rare(w, t):
    for code, lst in code_dict.items():
        if w in lst:
            return code
    return (w, t)

psuedo = deepcopy(tagged)

for i in range(len(psuedo)):
    for j in range(len(psuedo[i])):
        psuedo[i][j] = replace_rare(*psuedo[i][j])

p_train, p_test = train_test_split(psuedo, test_size=0.1,
shuffle=False)

psuedo_emissions = get_emission(p_train)
psuedo_transitions = get_transitions(p_train)

mle_model = get_mle(p_train, p_test)

total_error, known_error, unknown_error = hmm_error_rate(p_test,
psuedo_emissions, psuedo_transitions)
# calc accuracy:
print(f'Error rate using HMM + psuedo words:')
print(f'----------------------------------')
print(f'  - total words is   {total_error}')
print(f'----------------------------------')
print(f'  - known words is   {known_error}')
print(f'  - unknown words is {unknown_error}')
print(f'----------------------------------')
```

```
.......................................................................
.......................................................................
.......................................................................
.......................................................................
.......................................................................
.......................................................................
...........................................
Error rate using HMM + psuedo words:
----------------------------------
  - total words is   0.05332
----------------------------------
  - known words is   0.05332
  - unknown words is nan
----------------------------------
```

```
smooth_psuedo_emissions = get_emission(p_train, smooth=1)
smooth_psuedo_transitions = get_transitions(p_train, smooth=1)

total_error, known_error, unknown_error = hmm_error_rate(p_test,
smooth_psuedo_emissions,

smooth_psuedo_transitions)
# calc accuracy:
print(f'Error rate using HMM + psuedo words + add-1 smoothing:')
print(f'----------------------------------')
print(f'  - total words is   {total_error}')
print(f'----------------------------------')
print(f'  - known words is   {known_error}')
print(f'  - unknown words is {unknown_error}')
print(f'----------------------------------')
```

```
......................................................................
......................................................................
......................................................................
......................................................................
......................................................................
......................................................................
...........................................
Error rate using HMM + psuedo words + add-1 smoothing:
----------------------------------
  - total words is   0.05342
----------------------------------
  - known words is   0.05342
  - unknown words is nan
----------------------------------
```

Confusion matrix

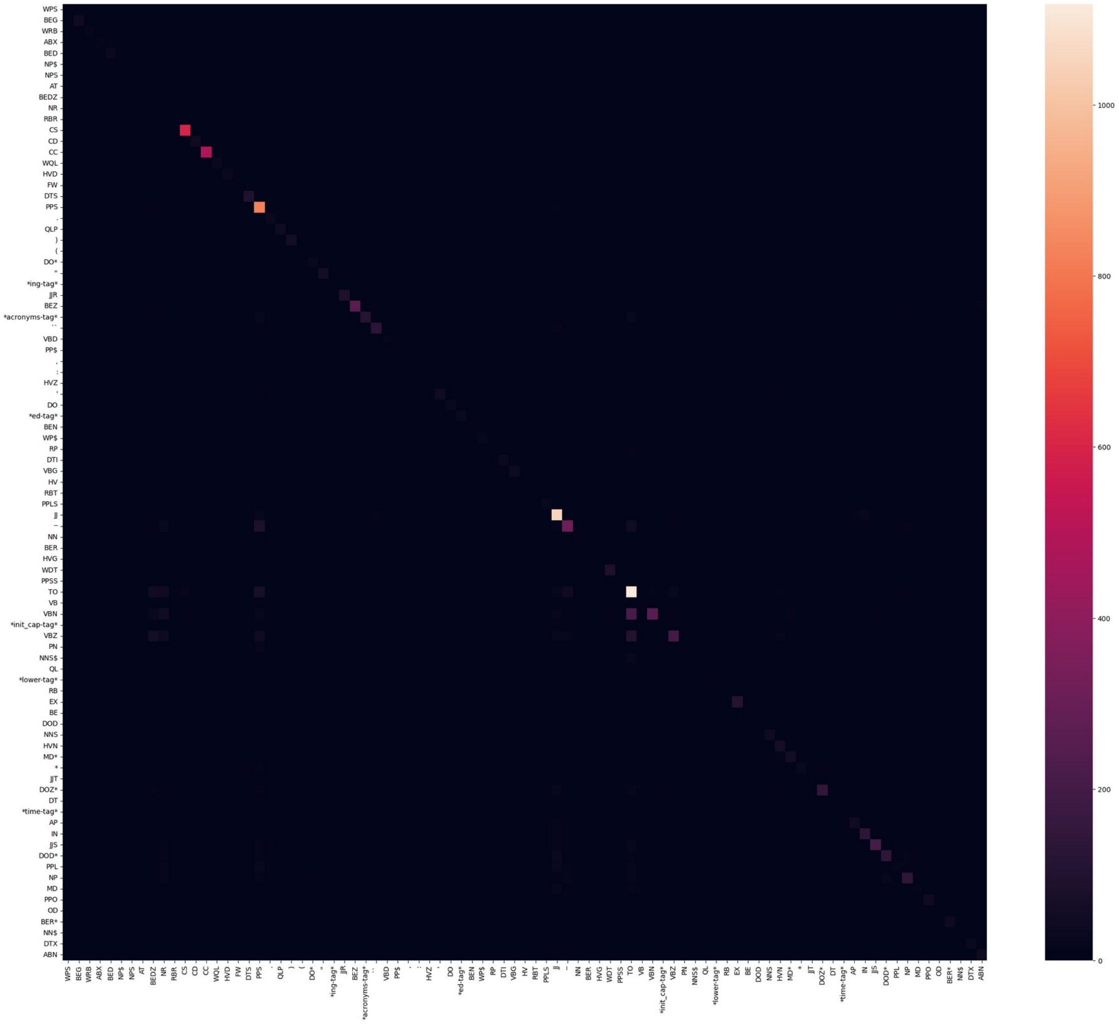
```
preds = []
labels = []
ticks = set()
for sent in test:
    print('.', end='')
    sent_pred = viterbi([w for w, _ in sent],
smooth_psuedo_transitions, smooth_psuedo_emissions)
    preds.extend([p for (_, p) in sent_pred])
    labels.extend([l for (_, l) in sent])
    ticks = ticks.union(set(labels)).union(set(preds))
print()
```

```
......................................................................
......................................................................
......................................................................
```

```
......................................................................
......................................................................
......................................................................
...........................................
```

```
plt.figure(figsize=(30, 25))
sns.heatmap(confusion_matrix(labels, preds), xticklabels=ticks,
yticklabels=ticks)
```

```
<AxesSubplot: >
```


WPS
BEG
WRB
ABX
BED
NP$
NPS
AT
BEDZ
NR
RBR
CS
CD
CC
WQL
HVD
FW
DTS
PPS
QLP
)
(
DO*
''
ing-tag
JJR
BEZ
acronyms-tag
``
VBD
PP$
:
HVZ
'
DO
ed-tag
BEN
WP$
RP
DTI
VBG
HV
RBT
PPLS
JJ
NN
BER
HVG
WDT
PPSS
TO
VB
VBN
init_cap-tag
VBZ
PN
NNS$
QL
lower-tag
RB
EX
BE
DOD
NNS
HVN
MD*
*
JJT
DOZ*
DT
time-tag
AP
IN
JJS
DOD*
PPL
NP
MD
PPO
OD
BER*
NN$
DTX
ABN