Statistical Natural Language Processing (WS 20/21)

Exercise Sheet 3 - Manuel Hettich

1

```
'''
This function can be used for importing the corpus.
Parameters: path_to_file: string; path to the file containing the corpus
Returns: list of list; the first layer list contains the sentences of the corpus;
    the second layer list contains tuples (token,label) representing a labelled sentence
'''
def import_corpus(path_to_file):
    sentences = []
    sentence = []
    f = open(path_to_file)

    while True:
        line = f.readline()
        if not line: break

        line = line.strip()
        if len(line) == 0:
            sentences.append(sentence)
            sentence = []
            continue

        parts = line.split(' ')
        sentence.append((parts[0], parts[-1]))

    f.close()
    return sentences
```

2

```
# Imports
import itertools
import random
import numpy as np
import matplotlib.pyplot as plt
```

3

```
class MaxEntModel(object):
    # training corpus
    corpus = None

    # (numpy) array containing the parameters of the model
    # has to be initialized by the method 'initialize'
    theta = None

    # dictionary containing all possible features of a corpus and their corresponding index;
    # has to be set by the method 'initialize'; hint: use a Python dictionary
    feature_indices = None

    # set containing a list of possible labels
    # has to be set by the method 'initialize'
    labels = None

    # Caching normalization factors for (word, label)
    norm_factors = None
```

```python
# Exercise 1 a) ###################################################################
def initialize(self, corpus):
    """
    Initialize the maximum entropy model, i.e., build the set of all features, the set of
    and create an initial array 'theta' for the parameters of the model.
    Parameters: corpus: list of list representing the corpus, returned by the function 'i
    """
    self.corpus = corpus

    # Initialise the set of all words in the corpus
    words = set()
    # Add a custom label for the beginning of sentences
    self.labels = set()
    self.labels.add("start")

    # Fill the two sets with all the words and labels in the corpus
    for sentence in corpus:
        for word, label in sentence:
            words.add(word)
            self.labels.add(label)

    # Initialise the feature indices dictionary
    self.feature_indices = dict()
    # Build the necessary cartesian products and store them enumerated in the dict
    product = set()
    product.update(itertools.product(self.labels, self.labels))
    product.update(itertools.product(words, self.labels))
    for idx, feature in enumerate(product):
        self.feature_indices.update({feature: idx})

    # Initialize theta
    self.theta = np.ones(len(self.feature_indices))

    # Initialize norm_factors
    self.norm_factors = dict()

# Exercise 1 b) ###################################################################
def get_active_features(self, word, label, prev_label):
    """
    Compute the vector of active features.
    Parameters: word: string; a word at some position i of a given sentence
                label: string; a label assigned to the given word
                prev_label: string; the label of the word at position i-1
    Returns: (numpy) array containing only zeros and ones.
    """

    # Get the indices for the two features
    idx_word_label = self.feature_indices.get((word, label), -1)
    idx_label_label = self.feature_indices.get((prev_label, label), -1)

    # Create a numpy array with the two features set to 1
    # according to the indices in self.feature_indices
    active_features = np.zeros(len(self.feature_indices), dtype=bool)
    if idx_word_label != -1:
        active_features[idx_word_label] = True
    if idx_label_label != -1:
        active_features[idx_label_label] = True

    return active_features

# Exercise 2 a) ###################################################################
def cond_normalization_factor(self, word, prev_label):
    """
    Compute the normalization factor 1/Z(x_i).
    Parameters: word: string; a word x_i at some position i of a given sentence
                prev_label: string; the label of the word at position i-1
    Returns: float
    """
```

```python
        if (word, prev_label) in self.norm_factors:
            return self.norm_factors[(word, prev_label)]
        else:
            z = 0.0
            for label in self.labels:
                z += np.exp(np.dot(self.theta, self.get_active_features(word, label, prev_lab

            norm_factor = 1 / z
            # Cache the normalization factor
            self.norm_factors[(word, prev_label)] = norm_factor

            return norm_factor


    # Exercise 2 b) ###################################################################
    def conditional_probability(self, label, word, prev_label):
        """
        Compute the conditional probability of a label given a word x_i.
        Parameters: label: string; we are interested in the conditional probability of this l
                    word: string; a word x_i some position i of a given sentence
                    prev_label: string; the label of the word at position i-1
        Returns: float
        """

        normalization_factor = self.cond_normalization_factor(word, prev_label)

        return normalization_factor * np.exp(np.dot(self.theta, self.get_active_features(word


    # Exercise 3 a) ###################################################################
    def empirical_feature_count(self, word, label, prev_label):
        """
        Compute the empirical feature count given a word, the actual label of this word and t
        Parameters: word: string; a word x_i some position i of a given sentence
                    label: string; the actual label of the given word
                    prev_label: string; the label of the word at position i-1
        Returns: (numpy) array containing the empirical feature count
        """

        return self.get_active_features(word, label, prev_label)


    # Exercise 3 b) ###################################################################
    def expected_feature_count(self, word, prev_label):
        """
        Compute the expected feature count given a word, the label of the previous word and t
        (see variable theta)
        Parameters: word: string; a word x_i some position i of a given sentence
                    prev_label: string; the label of the word at position i-1
        Returns: (numpy) array containing the expected feature count
        """

        expected_feature_count = np.zeros(len(self.theta))

        for label in self.labels:
            expected_feature_count += self.get_active_features(word, label, prev_label) * sel

        return expected_feature_count


    # Exercise 4 a) ###################################################################
    def parameter_update(self, word, label, prev_label, learning_rate):
        """
        Do one learning step.
        Parameters: word: string; a randomly selected word x_i at some position i of a given
                    label: string; the actual label of the selected word
                    prev_label: string; the label of the word at position i-1
                    learning_rate: float
```

```python
        """

        self.theta += learning_rate * (self.empirical_feature_count(word, label, prev_label)

        # Reset the cached normalization factors
        self.norm_factors = dict()


    # Exercise 4 b) ###################################################################
    def train(self, number_iterations, learning_rate=0.1):
        """
        Implement the training procedure.
        Parameters: number_iterations: int; number of parameter updates to do
                    learning_rate: float
        """

        for iteration in range(number_iterations):
            print(f"Iteration {iteration + 1}/{number_iterations}")

            # Select a random sentence from the corpus
            random_sentence = random.choice(self.corpus)
            # Select a random tuple from the random sentence
            random_tuple = random.choice(random_sentence)
            word = random_tuple[0]
            label = random_tuple[1]

            # Get the label of the previous tuple in the random sentence
            idx_random_tuple = random_sentence.index(random_tuple)
            if idx_random_tuple == 0:
                prev_label = "start"
            else:
                prev_label = random_sentence[idx_random_tuple - 1][1]

            self.parameter_update(word, label, prev_label, learning_rate)


    # Exercise 4 c) ###################################################################
    def predict(self, word, prev_label):
        """
        Predict the most probable label of the word referenced by 'word'
        Parameters: word: string; a word x_i at some position i of a given sentence
                    prev_label: string; the label of the word at position i-1
        Returns: string; most probable label
        """

        maximum_probability = -np.inf
        result_label = None

        # Find the label with the maximum probability
        for label in self.labels:
            probability = self.conditional_probability(label, word, prev_label)

            if probability > maximum_probability:
                maximum_probability = probability
                result_label = label

        return result_label


    # Exercise 5 a) ###################################################################
    def empirical_feature_count_batch(self, sentences):
        """
        Predict the empirical feature count for a set of sentences
        Parameters: sentences: list; a list of sentences; should be a sublist of the list ret
        Returns: (numpy) array containing the empirical feature count
        """

        # Initialize the empirical feature count array
        empirical_feature_count_batch = np.zeros(len(self.theta), dtype=bool)
```

```
        for sentence in sentences:
            first_word = sentence[0][0]
            first_label = sentence[0][1]
            empirical_feature_count_batch += self.empirical_feature_count(first_word, first_l
            for idx, (word, label) in enumerate(sentence[1:]):
                prev_label = sentence[idx - 1][1]
                empirical_feature_count_batch += self.empirical_feature_count(word, label, pr

        return empirical_feature_count_batch


    # Exercise 5 a) ###################################################################
    def expected_feature_count_batch(self, sentences):
        """
        Predict the expected feature count for a set of sentences
        Parameters: sentences: list; a list of sentences; should be a sublist of the list ret
        Returns: (numpy) array containing the expected feature count
        """

        # Initialize the expected feature count array
        expected_feature_count_batch = np.zeros(len(self.theta))

        for sentence in sentences:
            first_word = sentence[0][0]
            first_label = sentence[0][1]
            expected_feature_count_batch += self.expected_feature_count(first_word, first_lab
            for idx, (word, label) in enumerate(sentence[1:]):
                prev_label = sentence[idx - 1][1]
                expected_feature_count_batch += self.expected_feature_count(word, prev_label)

        return expected_feature_count_batch


    # Exercise 5 b) ###################################################################
    def train_batch(self, number_iterations, batch_size, learning_rate=0.1):
        """
        Implement the training procedure which uses 'batch_size' sentences from to training c
        to compute the gradient.
        Parameters: number_iterations: int; number of parameter updates to do
                    batch_size: int; number of sentences to use in each iteration
                    learning_rate: float
        Returns: last batch of sentences
        """

        sentences = None

        for iteration in range(number_iterations):
            print(f"Iteration {iteration + 1}/{number_iterations}")

            # Choose multiple random sentences from the corpus
            sentences = random.choices(self.corpus, k=batch_size)

            self.theta += learning_rate * (self.empirical_feature_count_batch(sentences) - se

            # Reset the cached normalization factors
            self.norm_factors = dict()

        return sentences
```

14
```
# Exercise 5 c) ###################################################################
def evaluate(corpus):
    """
    Compare the training methods 'train' and 'train_batch' in terms of convergence rate
    Parameters: corpus: list of list; a corpus returned by 'import_corpus'
    """
```

```python
def calculate_accuracy(model, num_words):
    # https://en.wikipedia.org/wiki/Accuracy_and_precision#In_binary_classification
    # Accuracy = (TP + TN)/(TP + TN + FP + FN)

    correct_predictions = 0

    for _ in range(num_words):
        random_sentence = random.choice(test_set)
        random_tuple = random.choice(random_sentence)
        idx_random_tuple = random_sentence.index(random_tuple)
        word = random_tuple[0]
        label = random_tuple[1]
        if idx_random_tuple == 0:
            prev_label = "start"
        else:
            prev_label = random_sentence[idx_random_tuple - 1][1]
        pred_label = model.predict(word, prev_label)
        if pred_label == label:
            correct_predictions += 1

    return correct_predictions / num_words

random.shuffle(corpus)

# Use 10% of the corpus as test set and the remaining data as training set
test_set = corpus[0:int(len(corpus) / 10)]
training_set = corpus[int(len(corpus) / 10):]

# Initialize two instances of MaxEntModel
model_a = MaxEntModel()
model_a.initialize(training_set)
model_b = MaxEntModel()
model_b.initialize(training_set)

# Initialize the word counters
w_a = 0
w_b = 0

# Initialize the accuracies
accuracy_a = dict()
accuracy_b = dict()

# Initialize the learning rates
learning_rate_a = 0.1
learning_rate_b = 0.1

num_iterations = 25
for iteration in range(num_iterations):
    print(f"Evaluation iteration: {iteration + 1}/{num_iterations}")
    # Train model A on a single random word using train()
    model_a.train(number_iterations=1, learning_rate=learning_rate_a)
    w_a += 1
    accuracy_a.update({w_a: calculate_accuracy(model_a, w_a)})

    # Train model B on a single random sentence using train_batch()
    sentences = model_b.train_batch(number_iterations=1, batch_size=1, learning_rate=lear
    w_b += len(sentences[0])
    accuracy_b.update({w_b: calculate_accuracy(model_b, w_b)})

fig = plt.figure()
ax = fig.add_subplot(1, 1, 1)
plt.plot(accuracy_a.keys(), accuracy_a.values(), color='blue')
plt.plot(accuracy_b.keys(), accuracy_b.values(), color='red')
plt.show()
```

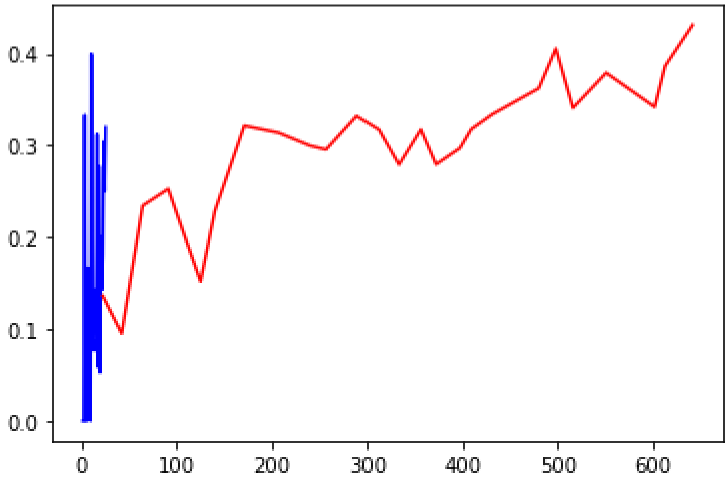
15

```python
evaluate(import_corpus("corpus_pos.txt"))
```

```
Evaluation iteration: 1/25
```

```
Iteration 1/1
Iteration 1/1
Evaluation iteration: 2/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 3/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 4/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 5/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 6/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 7/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 8/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 9/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 10/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 11/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 12/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 13/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 14/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 15/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 16/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 17/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 18/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 19/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 20/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 21/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 22/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 23/25
Iteration 1/1
Iteration 1/1
Evaluation iteration: 24/25
```

```
Iteration 1/1
Iteration 1/1
Evaluation iteration: 25/25
Iteration 1/1
Iteration 1/1
```




```
test_model = MaxEntModel()
test_model.initialize(import_corpus("corpus_pos.txt"))
```

6
```
test_model.train_batch(3, 5)
test_model.predict("Mr.", "CC")
```

```
Iteration 1/5
Iteration 2/5
Iteration 3/5
Iteration 4/5
Iteration 5/5
```

6
```
'IN'
```