

CS224N Assignment 1: Exploring Word Vectors (25 Points)

Due 4:30pm, Tue Jan 14

Welcome to CS224n!

Before you start, make sure you read the README.txt in the same directory as this notebook. You will find many provided codes in the notebook. We highly encourage you to read and understand the provided codes as part of the learning :-)

```
In [1]: # ALL Import Statements Defined Here
# Note: Do not add to this list.
# -----

import sys
assert sys.version_info[0]==3
assert sys.version_info[1] >= 5

from gensim.models import KeyedVectors
from gensim.test.utils import datapath
import pprint
import matplotlib.pyplot as plt
plt.rcParams['figure.figsize'] = [10, 5]
import nltk
nltk.download('reuters')
from nltk.corpus import reuters
import numpy as np
import random
import scipy as sp
from sklearn.decomposition import TruncatedSVD
from sklearn.decomposition import PCA

START_TOKEN = '<START>'
END_TOKEN = '<END>'

np.random.seed(0)
random.seed(0)
# -----
```

```
[nltk_data] Downloading package reuters to
[nltk_data] C:\Users\orion.darley\AppData\Roaming\nltk_data...
[nltk_data] Package reuters is already up-to-date!
```

Word Vectors

Word Vectors are often used as a fundamental component for downstream NLP tasks, e.g. question answering, text generation, translation, etc., so it is important to build some intuitions as to their strengths and weaknesses. Here, you will explore two types of word vectors: those derived from *co-occurrence matrices*, and those derived via *GloVe*.

Assignment Notes: Please make sure to save the notebook as you go along. Submission Instructions are located at the bottom of the notebook.

Note on Terminology: The terms "word vectors" and "word embeddings" are often used interchangeably. The term "embedding" refers to the fact that we are encoding aspects of a word's meaning in a lower dimensional space. As [Wikipedia](https://en.wikipedia.org/wiki/Word_embedding) (https://en.wikipedia.org/wiki/Word_embedding) states, "*conceptually it involves a mathematical embedding from a space with one dimension per word to a continuous vector space with a much lower dimension*".

Part 1: Count-Based Word Vectors (10 points)

Most word vector models start from the following idea:

You shall know a word by the company it keeps ([Firth, J. R. 1957:11](https://en.wikipedia.org/wiki/John_Rupert_Firth) (https://en.wikipedia.org/wiki/John_Rupert_Firth))

Many word vector implementations are driven by the idea that similar words, i.e., (near) synonyms, will be used in similar contexts. As a result, similar words will often be spoken or written along with a shared subset of words, i.e., contexts. By examining these contexts, we can try to develop embeddings for our words. With this intuition in mind, many "old school" approaches to constructing word vectors relied on word counts. Here we elaborate upon one of those strategies, *co-occurrence matrices* (for more information, see [here](http://web.stanford.edu/class/cs124/lec/vectorsemantics.video.pdf) (<http://web.stanford.edu/class/cs124/lec/vectorsemantics.video.pdf>) or [here](https://medium.com/data-science-group-iitr/word-embedding-2d05d270b285) (<https://medium.com/data-science-group-iitr/word-embedding-2d05d270b285>)).

Co-Occurrence

A co-occurrence matrix counts how often things co-occur in some environment. Given some word w_i occurring in the document, we consider the *context window* surrounding w_i . Supposing our fixed window size is n , then this is the n preceding and n subsequent words in that document, i.e. words $w_{i-n} \dots w_{i-1}$ and $w_{i+1} \dots w_{i+n}$. We build a *co-occurrence matrix* M , which is a symmetric word-by-word matrix in which M_{ij} is the number of times w_j appears inside w_i 's window among all documents.

Example: Co-Occurrence with Fixed Window of $n=1$:

Document 1: "all that glitters is not gold"


Document 2: "all is well that ends well"

*	<START>	all	that	glitters	is	not	gold	well	ends	<END>
<START>	0	2	0	0	0	0	0	0	0	0

*	<START>	all	that	glitters	is	not	gold	well	ends	<END>
all	2	0	1	0	1	0	0	0	0	0
that	0	1	0	1	0	0	0	1	1	0
glitters	0	0	1	0	1	0	0	0	0	0
is	0	1	0	1	0	1	0	1	0	0
not	0	0	0	0	1	0	1	0	0	0
gold	0	0	0	0	0	1	0	0	0	1
well	0	0	1	0	1	0	0	0	1	1
ends	0	0	1	0	0	0	0	1	0	0
<END>	0	0	0	0	0	0	1	1	0	0

Note: In NLP, we often add <START> and <END> tokens to represent the beginning and end of sentences, paragraphs or documents. In this case we imagine <START> and <END> tokens encapsulating each document, e.g., "<START> All that glitters is not gold <END> ", and include these tokens in our co-occurrence counts.

The rows (or columns) of this matrix provide one type of word vectors (those based on word-word co-occurrence), but the vectors will be large in general (linear in the number of distinct words in a corpus). Thus, our next step is to run *dimensionality reduction*. In particular, we will run *SVD (Singular Value Decomposition)*, which is a kind of generalized *PCA (Principal Components Analysis)* to select the top k principal components. Here's a visualization of dimensionality reduction with SVD. In this picture our co-occurrence matrix is A with n rows corresponding to n words. We obtain a full matrix decomposition, with the singular values ordered in the diagonal S matrix, and our new, shorter length- k word vectors in U_k .

 Picture of an SVD

This reduced-dimensionality co-occurrence representation preserves semantic relationships between words, e.g. *doctor* and *hospital* will be closer than *doctor* and *dog*.

Notes: If you can barely remember what an eigenvalue is, here's [a slow, friendly introduction to SVD](https://daveyang.org/file/Singular_Value_Decomposition_Tutorial.pdf) (https://daveyang.org/file/Singular_Value_Decomposition_Tutorial.pdf). If you want to learn more thoroughly about PCA or SVD, feel free to check out lectures [7](https://web.stanford.edu/class/cs168/l/l7.pdf) (<https://web.stanford.edu/class/cs168/l/l7.pdf>), [8](http://theory.stanford.edu/~tim/s15/l/l8.pdf) (<http://theory.stanford.edu/~tim/s15/l/l8.pdf>), and [9](https://web.stanford.edu/class/cs168/l/l9.pdf) (<https://web.stanford.edu/class/cs168/l/l9.pdf>) of CS168. These course notes provide a great high-level treatment of these general purpose algorithms. Though, for the purpose of this class, you only need to know how to extract the k -dimensional embeddings by utilizing pre-programmed implementations of these algorithms from the numpy, scipy, or sklearn python packages. In practice, it is challenging to apply full SVD to large corpora because of the memory needed to perform PCA or SVD. However, if you only want the top

k vector components for relatively small k — known as [Truncated SVD](https://en.wikipedia.org/wiki/Singular_value_decomposition#Truncated_SVD) (https://en.wikipedia.org/wiki/Singular_value_decomposition#Truncated_SVD) — then there are reasonably scalable techniques to compute those iteratively.

Plotting Co-Occurrence Word Embeddings

Here, we will be using the Reuters (business and financial news) corpus. If you haven't run the import cell at the top of this page, please run it now (click it and press SHIFT-RETURN). The corpus consists of 10,788 news documents totaling 1.3 million words. These documents span 90 categories and are split into train and test. For more details, please see <https://www.nltk.org/book/ch02.html> (<https://www.nltk.org/book/ch02.html>). We provide a `read_corpus` function below that pulls out only articles from the "crude" (i.e. news articles about oil, gas, etc.) category. The function also adds `<START>` and `<END>` tokens to each of the documents, and lowercases words. You do **not** have to perform any other kind of pre-processing.

```
In [2]: def read_corpus(category="crude"):
        """ Read files from the specified Reuter's category.
            Params:
                category (string): category name
            Return:
                list of lists, with words from each of the processed files
        """
        files = reuters.fileids(category)
        return [[START_TOKEN] + [w.lower() for w in list(reuters.words(f))] + [END_TOKEN] for f in files]
```

Let's have a look what these documents are like....

```
In [3]: reuters_corpus = read_corpus()
        pprint.pprint(reuters_corpus[:3], compact=True, width=100)
```

...

Question 1.1: Implement `distinct_words` [code] (2 points)

Write a method to work out the distinct words (word types) that occur in the corpus. You can do this with `for` loops, but it's more efficient to do it with Python list comprehensions. In particular, [this](https://coderwall.com/p/rcmaea/flatten-a-list-of-lists-in-one-line-in-python) (<https://coderwall.com/p/rcmaea/flatten-a-list-of-lists-in-one-line-in-python>) may be useful to flatten a list of lists. If you're not familiar with Python list comprehensions in general, here's [more information](https://python-3-patterns-idioms-test.readthedocs.io/en/latest/Comprehensions.html) (<https://python-3-patterns-idioms-test.readthedocs.io/en/latest/Comprehensions.html>).

You may find it useful to use [Python sets](https://www.w3schools.com/python/python_sets.asp) (https://www.w3schools.com/python/python_sets.asp) to remove duplicate words.

```
In [4]: def distinct_words(corpus):
        """ Determine a list of distinct words for the corpus.
            Params:
                corpus (list of list of strings): corpus of documents
            Return:
                corpus_words (list of strings): list of distinct words across the corpus, sorted (using python 's
                num_corpus_words (integer): number of distinct words across the corpus
        """
        corpus_words = []
        num_corpus_words = -1

        # -----
        # Write your implementation here.

        corpus_words = [word for line in corpus for word in line]
        corpus_words = set(corpus_words)
        corpus_words = sorted(list(corpus_words))
        num_corpus_words = len(corpus_words)

        # -----

        return corpus_words, num_corpus_words
```

```

In [5]: # -----
# Run this sanity check
# Note that this not an exhaustive check for correctness.
# -----

# Define toy corpus
test_corpus = ["{} All that glitters isn't gold {}".format(START_TOKEN, END_TOKEN).split(" "), "{} All's well
test_corpus_words, num_corpus_words = distinct_words(test_corpus)

# Correct answers
ans_test_corpus_words = sorted([START_TOKEN, "All", "ends", "that", "gold", "All's", "glitters", "isn't", "we
ans_num_corpus_words = len(ans_test_corpus_words)

# Test correct number of words
assert(num_corpus_words == ans_num_corpus_words), "Incorrect number of distinct words. Correct: {}. Yours: {}

# Test correct words
assert (test_corpus_words == ans_test_corpus_words), "Incorrect corpus_words.\nCorrect: {}\nYours:   {}".form

# Print Success
print("-" * 80)
print("Passed All Tests!")
print("-" * 80)

```

```

-----
Passed All Tests!
-----

```

Question 1.2: Implement `compute_co_occurrence_matrix` [code] (3 points)

Write a method that constructs a co-occurrence matrix for a certain window-size n (with a default of 4), considering words n before and n after the word in the center of the window. Here, we start to use `numpy` (`np`) to represent vectors, matrices, and tensors. If you're not familiar with NumPy, there's a NumPy tutorial in the second half of this cs231n [Python NumPy tutorial](http://cs231n.github.io/python-numpy-tutorial/) (<http://cs231n.github.io/python-numpy-tutorial/>).

```
In [6]: def compute_co_occurrence_matrix(corpus, window_size=4):
        """ Compute co-occurrence matrix for the given corpus and window_size (default of 4).

        Note: Each word in a document should be at the center of a window. Words near edges will have a small
        number of co-occurring words.

        For example, if we take the document "<START> All that glitters is not gold <END>" with window
        "All" will co-occur with "<START>", "that", "glitters", "is", and "not".

        Params:
            corpus (list of list of strings): corpus of documents
            window_size (int): size of context window
        Return:
            M (a symmetric numpy matrix of shape (number of unique words in the corpus , number of unique wor
            Co-occurrence matrix of word counts.
            The ordering of the words in the rows/columns should be the same as the ordering of the words
            word2Ind (dict): dictionary that maps word to index (i.e. row/column number) for matrix M.
        """
        words, num_words = distinct_words(corpus)
        M = None
        word2Ind = {}

        # -----
        # Write your implementation here.

        M = np.zeros((num_words, num_words))
        word2Ind = {w : i for i, w in enumerate(words)}

        for d in corpus:
            for i, w in enumerate(d):
                for j in range(i - window_size, i + window_size + 1):
                    if j < 0 or j >= len(d):
                        continue
                    if j != i:
                        M[word2Ind[w], word2Ind[d[j]]] += 1

        # -----
        return M, word2Ind
```



```

In [7]: # -----
# Run this sanity check
# Note that this is not an exhaustive check for correctness.
# -----

# Define toy corpus and get student's co-occurrence matrix
test_corpus = ["{} All that glitters isn't gold {}".format(START_TOKEN, END_TOKEN).split(" "), "{} All's well
M_test, word2Ind_test = compute_co_occurrence_matrix(test_corpus, window_size=1)

# Correct M and word2Ind
M_test_ans = np.array(
    [[0., 0., 0., 0., 0., 0., 1., 0., 0., 1.,],
     [0., 0., 1., 1., 0., 0., 0., 0., 0., 0.,],
     [0., 1., 0., 0., 0., 0., 0., 0., 1., 0.,],
     [0., 1., 0., 0., 0., 0., 0., 0., 0., 1.,],
     [0., 0., 0., 0., 0., 0., 0., 0., 1., 1.,],
     [0., 0., 0., 0., 0., 0., 0., 1., 1., 0.,],
     [1., 0., 0., 0., 0., 0., 0., 1., 0., 0.,],
     [0., 0., 0., 0., 0., 1., 1., 0., 0., 0.,],
     [0., 0., 1., 0., 1., 1., 0., 0., 0., 1.,],
     [1., 0., 0., 1., 1., 0., 0., 0., 1., 0.,]]
)
ans_test_corpus_words = sorted([START_TOKEN, "All", "ends", "that", "gold", "All's", "glitters", "isn't", "we
word2Ind_ans = dict(zip(ans_test_corpus_words, range(len(ans_test_corpus_words))))

# Test correct word2Ind
assert (word2Ind_ans == word2Ind_test), "Your word2Ind is incorrect:\nCorrect: {}\nYours: {}".format(word2Ind

# Test correct M shape
assert (M_test.shape == M_test_ans.shape), "M matrix has incorrect shape.\nCorrect: {}\nYours: {}".format(M_t

# Test correct M values
for w1 in word2Ind_ans.keys():
    idx1 = word2Ind_ans[w1]
    for w2 in word2Ind_ans.keys():
        idx2 = word2Ind_ans[w2]
        student = M_test[idx1, idx2]
        correct = M_test_ans[idx1, idx2]
        if student != correct:
            print("Correct M:")
            print(M_test_ans)
            print("Your M: ")

```

```
print(M_test)
raise AssertionError("Incorrect count at index ({}, {})=({}, {}) in matrix M. Yours has {} but sh

# Print Success
print("-" * 80)
print("Passed All Tests!")
print("-" * 80)
```

Passed All Tests!

Question 1.3: Implement `reduce_to_k_dim` [code] (1 point)

Construct a method that performs dimensionality reduction on the matrix to produce k-dimensional embeddings. Use SVD to take the top k components and produce a new matrix of k-dimensional embeddings.

Note: All of numpy, scipy, and scikit-learn (`sklearn`) provide *some* implementation of SVD, but only scipy and sklearn provide an implementation of Truncated SVD, and only sklearn provides an efficient randomized algorithm for calculating large-scale Truncated SVD. So please use [sklearn.decomposition.TruncatedSVD](https://scikit-learn.org/stable/modules/generated/sklearn.decomposition.TruncatedSVD.html) (<https://scikit-learn.org/stable/modules/generated/sklearn.decomposition.TruncatedSVD.html>).

```

In [8]: def reduce_to_k_dim(M, k=2):
        """ Reduce a co-occurrence count matrix of dimensionality (num_corpus_words, num_corpus_words)
            to a matrix of dimensionality (num_corpus_words, k) using the following SVD function from Scikit-Learn
            - http://scikit-learn.org/stable/modules/generated/sklearn.decomposition.TruncatedSVD.html

            Params:
                M (numpy matrix of shape (number of unique words in the corpus , number of unique words in the co
                k (int): embedding size of each word after dimension reduction
            Return:
                M_reduced (numpy matrix of shape (number of corpus words, k)): matrix of k-dimensioal word embedd
                In terms of the SVD from math class, this actually returns  $U * S$ 

        """
        n_iters = 10      # Use this parameter in your call to `TruncatedSVD`
        M_reduced = None
        print("Running Truncated SVD over %i words..." % (M.shape[0]))

        # -----
        # Write your implementation here.

        svd = TruncatedSVD(n_components = k, n_iter = n_iters)
        M_reduced = svd.fit_transform(M)

        # -----

        print("Done.")
        return M_reduced

```

```
In [9]: # -----
# Run this sanity check
# Note that this is not an exhaustive check for correctness
# In fact we only check that your M_reduced has the right dimensions.
# -----

# Define toy corpus and run student code
test_corpus = ["{} All that glitters isn't gold {}".format(START_TOKEN, END_TOKEN).split(" "), "{} All's well
M_test, word2Ind_test = compute_co_occurrence_matrix(test_corpus, window_size=1)
M_test_reduced = reduce_to_k_dim(M_test, k=2)

# Test proper dimensions
assert (M_test_reduced.shape[0] == 10), "M_reduced has {} rows; should have {}".format(M_test_reduced.shape[0]
assert (M_test_reduced.shape[1] == 2), "M_reduced has {} columns; should have {}".format(M_test_reduced.shape

# Print Success
print ("- " * 80)
print("Passed All Tests!")
print ("- " * 80)
```

Running Truncated SVD over 10 words...

Done.

Passed All Tests!

Question 1.4: Implement plot_embeddings [code] (1 point)

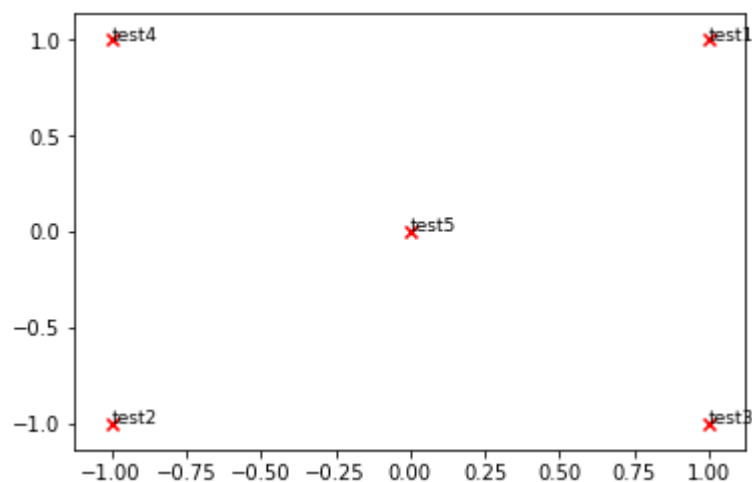
Here you will write a function to plot a set of 2D vectors in 2D space. For graphs, we will use Matplotlib (plt).

For this example, you may find it useful to adapt [this code](https://www.pythonmembers.club/2018/05/08/matplotlib-scatter-plot-annotate-set-text-at-label-each-point/) (<https://www.pythonmembers.club/2018/05/08/matplotlib-scatter-plot-annotate-set-text-at-label-each-point/>). In the future, a good way to make a plot is to look at [the Matplotlib gallery](https://matplotlib.org/gallery/index.html) (<https://matplotlib.org/gallery/index.html>), find a plot that looks somewhat like what you want, and adapt the code they give.

```
In [10]: def plot_embeddings(M_reduced, word2Ind, words):  
    """ Plot in a scatterplot the embeddings of the words specified in the list "words".  
    NOTE: do not plot all the words listed in M_reduced / word2Ind.  
    Include a label next to each point.  
  
    Params:  
        M_reduced (numpy matrix of shape (number of unique words in the corpus , 2)): matrix of 2-dimensi  
        word2Ind (dict): dictionary that maps word to indices for matrix M  
        words (list of strings): words whose embeddings we want to visualize  
    """  
  
    # -----  
    # Write your implementation here.  
  
    x_coords = M_reduced[:, 0]  
    y_coords = M_reduced[:, 1]  
  
    for word in words:  
        idx = word2Ind[word]  
        embedding = M_reduced[idx]  
        x = embedding[0]  
        y = embedding[1]  
  
        plt.scatter(x, y, marker='x', color='red')  
        plt.text(x, y, word, fontsize=9)  
  
    # -----
```

```
In [11]: # -----  
# Run this sanity check  
# Note that this is not an exhaustive check for correctness.  
# The plot produced should look like the "test solution plot" depicted below.  
# -----  
  
print("-" * 80)  
print("Outputted Plot:")  
  
M_reduced_plot_test = np.array([[1, 1], [-1, -1], [1, -1], [-1, 1], [0, 0]])  
word2Ind_plot_test = {'test1': 0, 'test2': 1, 'test3': 2, 'test4': 3, 'test5': 4}  
words = ['test1', 'test2', 'test3', 'test4', 'test5']  
plot_embeddings(M_reduced_plot_test, word2Ind_plot_test, words)  
  
print("-" * 80)
```

Outputted Plot:



Test Plot Solution



Question 1.5: Co-Occurrence Plot Analysis [written] (3 points)

Now we will put together all the parts you have written! We will compute the co-occurrence matrix with fixed window of 4 (the default window size), over the Reuters "crude" (oil) corpus. Then we will use TruncatedSVD to compute 2-dimensional embeddings of each word. TruncatedSVD returns $U \cdot S$, so we need to normalize the returned vectors, so that all the vectors will appear around the unit circle (therefore closeness is directional closeness). **Note:** The line of code below that does the normalizing uses the NumPy concept of *broadcasting*. If you don't know about broadcasting, check out [Computation on Arrays: Broadcasting by Jake VanderPlas](https://jakevdp.github.io/PythonDataScienceHandbook/02.05-computation-on-arrays-broadcasting.html) (<https://jakevdp.github.io/PythonDataScienceHandbook/02.05-computation-on-arrays-broadcasting.html>).

Run the below cell to produce the plot. It'll probably take a few seconds to run. What clusters together in 2-dimensional embedding space? What doesn't cluster together that you might think should have? **Note:** "bpd" stands for "barrels per day" and is a commonly used abbreviation in crude oil topic articles.

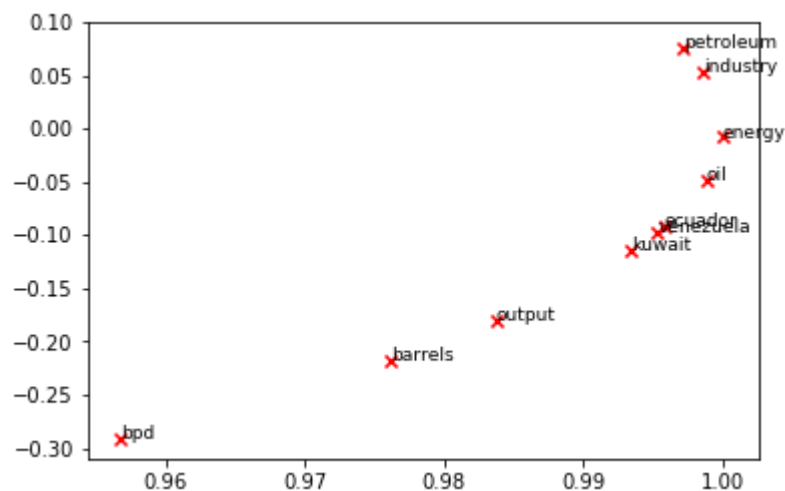
```
In [12]: # -----
# Run This Cell to Produce Your Plot
# -----
reuters_corpus = read_corpus()
M_co_occurrence, word2Ind_co_occurrence = compute_co_occurrence_matrix(reuters_corpus)
M_reduced_co_occurrence = reduce_to_k_dim(M_co_occurrence, k=2)

# Rescale (normalize) the rows to make them each of unit-length
M_lengths = np.linalg.norm(M_reduced_co_occurrence, axis=1)
M_normalized = M_reduced_co_occurrence / M_lengths[:, np.newaxis] # broadcasting

words = ['barrels', 'bpd', 'ecuador', 'energy', 'industry', 'kuwait', 'oil', 'output', 'petroleum', 'petroleum', 'venezuela']

plot_embeddings(M_normalized, word2Ind_co_occurrence, words)
```

Running Truncated SVD over 8185 words...
Done.



Write your answer here.

What clusters together in 2-dimensional embedding space?

Cluster one (countries): Kuwait, Venezuela, Ecuador. Cluster two (resources): oil, energy. Cluster three (function): petroleum, industry. Cluster four (production): barrels, output.

What doesn't cluster together that you might think should have? BPD did not cluster with barrels and output, possibly because it is an acronym. Output is not inclusive to just barrel production, but those three terms could be a hypothetical cluster.

Part 2: Prediction-Based Word Vectors (15 points)

As discussed in class, more recently prediction-based word vectors have demonstrated better performance, such as word2vec and GloVe (which also utilizes the benefit of counts). Here, we shall explore the embeddings produced by GloVe. Please revisit the class notes and lecture slides for more details on the word2vec and GloVe algorithms. If you're feeling adventurous, challenge yourself and try reading [GloVe's original paper \(https://nlp.stanford.edu/pubs/glove.pdf\)](https://nlp.stanford.edu/pubs/glove.pdf).

Then run the following cells to load the GloVe vectors into memory. **Note:** If this is your first time to run these cells, i.e. download the embedding model, it will take about 15 minutes to run. If you've run these cells before, rerunning them will load the model without redownloading it, which will take about 1 to 2 minutes.

```
In [13]: def load_embedding_model():
        """ Load GloVe Vectors
            Return:
                wv_from_bin: All 400000 embeddings, each length 200
        """
        import gensim.downloader as api
        wv_from_bin = api.load("glove-wiki-gigaword-200")
        print("Loaded vocab size %i" % len(wv_from_bin.vocab.keys()))
        return wv_from_bin
```

```
In [14]: # -----
        # Run Cell to Load Word Vectors
        # Note: This will take several minutes
        # -----
        wv_from_bin = load_embedding_model()
```

Loaded vocab size 400000

Note: If you are receiving reset by peer error, rerun the cell to restart the download.

Reducing dimensionality of Word Embeddings

Let's directly compare the GloVe embeddings to those of the co-occurrence matrix. In order to avoid running out of memory, we will work with a sample of 10000 GloVe vectors instead. Run the following cells to:

1. Put 10000 Glove vectors into a matrix M
2. Run `reduce_to_k_dim` (your Truncated SVD function) to reduce the vectors from 200-dimensional to 2-dimensional.

```
In [15]: def get_matrix_of_vectors(wv_from_bin, required_words=['barrels', 'bpd', 'ecuador', 'energy', 'industry', 'ku
        """ Put the GloVe vectors into a matrix M.
        Param:
            wv_from_bin: KeyedVectors object; the 400000 GloVe vectors loaded from file
        Return:
            M: numpy matrix shape (num words, 200) containing the vectors
            word2Ind: dictionary mapping each word to its row number in M
        """
        import random
        words = list(wv_from_bin.vocab.keys())
        print("Shuffling words ...")
        random.seed(224)
        random.shuffle(words)
        words = words[:10000]
        print("Putting %i words into word2Ind and matrix M..." % len(words))
        word2Ind = {}
        M = []
        curInd = 0
        for w in words:
            try:
                M.append(wv_from_bin.word_vec(w))
                word2Ind[w] = curInd
                curInd += 1
            except KeyError:
                continue
        for w in required_words:
            if w in words:
                continue
            try:
                M.append(wv_from_bin.word_vec(w))
                word2Ind[w] = curInd
                curInd += 1
            except KeyError:
                continue
        M = np.stack(M)
        print("Done.")
        return M, word2Ind
```

```
In [16]: # -----  
# Run Cell to Reduce 200-Dimensional Word Embeddings to k Dimensions  
# Note: This should be quick to run  
# -----  
M, word2Ind = get_matrix_of_vectors(wv_from_bin)  
M_reduced = reduce_to_k_dim(M, k=2)  
  
# Rescale (normalize) the rows to make them each of unit-length  
M_lengths = np.linalg.norm(M_reduced, axis=1)  
M_reduced_normalized = M_reduced / M_lengths[:, np.newaxis] # broadcasting
```

Shuffling words ...

Putting 10000 words into word2Ind and matrix M...

Done.

Running Truncated SVD over 10010 words...

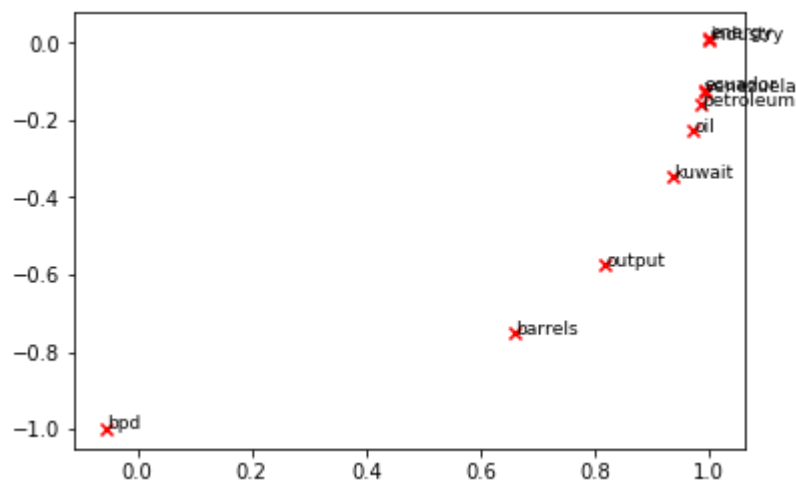
Done.

Question 2.1: GloVe Plot Analysis [written] (4 points)

Run the cell below to plot the 2D GloVe embeddings for ['barrels', 'bpd', 'ecuador', 'energy', 'industry', 'kuwait', 'oil', 'output', 'petroleum', 'venezuela'] .

What clusters together in 2-dimensional embedding space? What doesn't cluster together that you might think should have? How is the plot different from the one generated earlier from the co-occurrence matrix? What is a possible reason for causing the difference?

```
In [17]: words = ['barrels', 'bpd', 'ecuador', 'energy', 'industry', 'kuwait', 'oil', 'output', 'petroleum', 'venezuela']  
plot_embeddings(M_reduced_normalized, word2Ind, words)
```



Write your answer here.

What clusters together in 2-dimensional embedding space?

Cluster one (countries): Kuwait, Venezuela, Ecuador, oil, energy, petroleum, and industry. Cluster two (production): barrels, output.

What doesn't cluster together that you might think should have? BPD did not cluster with barrels and output, possibly because it is an acronym. Output is not inclusive to just barrel production, but those three terms could be a hypothetical cluster.

How is the plot different from the one generated earlier from the co-occurrence matrix? There is more distance between the outlier words like `bdp`, `barrels`, and `output` on this plot compared to the `smae` words for the first plot.

What is a possible reason for causing the difference? With GloVe, the loss function is the difference between the product of the vector differences and taking the log of the probability of co-occurrence minimizes the space between word associations.

Cosine Similarity

Now that we have word vectors, we need a way to quantify the similarity between individual words, according to these vectors. One such metric is cosine-similarity. We will be using this to find words that are "close" and "far" from one another.

We can think of n-dimensional vectors as points in n-dimensional space. If we take this perspective [L1 \(http://mathworld.wolfram.com/L1-Norm.html\)](http://mathworld.wolfram.com/L1-Norm.html) and [L2 \(http://mathworld.wolfram.com/L2-Norm.html\)](http://mathworld.wolfram.com/L2-Norm.html) Distances help quantify the amount of space "we must travel" to get between these two points. Another approach is to examine the angle between two vectors. From trigonometry we know that:



Instead of computing the actual angle, we can leave the similarity in terms of $similarity = \cos(\Theta)$. Formally the [Cosine Similarity \(https://en.wikipedia.org/wiki/Cosine_similarity\)](https://en.wikipedia.org/wiki/Cosine_similarity) s between two vectors p and q is defined as:

$$s = \frac{p \cdot q}{||p|| ||q||}, \text{ where } s \in [-1, 1]$$

Question 2.2: Words with Multiple Meanings (2 points) [code + written]

Polysemes and homonyms are words that have more than one meaning (see this [wiki page \(https://en.wikipedia.org/wiki/Polysemy\)](https://en.wikipedia.org/wiki/Polysemy) to learn more about the difference between polysemes and homonyms). Find a word with at least 2 different meanings such that the top-10 most similar words (according to cosine similarity) contain related words from *both* meanings. For example, "leaves" has both "vanishes" and "stalks" in the top 10, and "scoop" has both "handed_waffle_cone" and "lowdown". You will probably need to try several polysemous or homonymic words before you find one. Please state the word you discover and the multiple meanings that occur in the top 10. Why do you think many of the polysemous or homonymic words you tried didn't work (i.e. the top-10 most similar words only contain **one** of the meanings of the words)?

Note: You should use the `wv_from_bin.most_similar(word)` function to get the top 10 similar words. This function ranks all other words in the vocabulary with respect to their cosine similarity to the given word. For further assistance please check the [GenSim documentation \(https://radimrehurek.com/gensim/models/keyedvectors.html#gensim.models.keyedvectors.FastTextKeyedVectors.most_similar\)](https://radimrehurek.com/gensim/models/keyedvectors.html#gensim.models.keyedvectors.FastTextKeyedVectors.most_similar).

```
In [18]: # -----  
# Write your implementation here.  
polyseme = "procure"  
print("polyseme")  
list(wv_from_bin.most_similar(polyseme))  
  
# -----
```

polyseme

```
Out[18]: [('procuring', 0.6463401913642883),  
('procured', 0.6035971641540527),  
('obtain', 0.5592821836471558),  
('equip', 0.5188530087471008),  
('manufacture', 0.5124149918556213),  
('fabricate', 0.4991585910320282),  
('assemble', 0.49078986048698425),  
('smuggle', 0.48390424251556396),  
('distribute', 0.4838152527809143),  
('supplying', 0.48204174637794495)]
```

Write your answer here.

Please state the word you discover and the multiple meanings that occur in the top 10. procure, multiple meanings - procuring, procured, obtain, equip, manufacture, fabricate, assemble, smuggle, distribute, supplying

Why do you think many of the polysemous or homonymic words you tried didn't work (i.e. the top-10 most similar words only contain one of the meanings of the words)? The verb "procure" is a good example of polysemy as it can mean "become," "get," or "understand". The author from the Reuters (business and financial news) corpus uses the word 'procure' in the business or economic sense. The top three words are closely associated to the general polyseme, rather the definition within economics.

Question 2.3: Synonyms & Antonyms (2 points) [code + written]

When considering Cosine Similarity, it's often more convenient to think of Cosine Distance, which is simply $1 - \text{Cosine Similarity}$.

Find three words (w_1, w_2, w_3) where w_1 and w_2 are synonyms and w_1 and w_3 are antonyms, but $\text{Cosine Distance}(w_1, w_3) < \text{Cosine Distance}(w_1, w_2)$. For example, $w_1 = \text{"happy"}$ is closer to $w_3 = \text{"sad"}$ than to $w_2 = \text{"cheerful"}$.

Once you have found your example, please give a possible explanation for why this counter-intuitive result may have happened.

You should use the `wv_from_bin.distance(w1, w2)` function here in order to compute the cosine distance between two words.

Please see the [GenSim documentation](#)

(<https://radimrehurek.com/gensim/models/keyedvectors.html#gensim.models.keyedvectors.FastTextKeyedVectors.distance>) for further assistance.

In [19]:

```
# -----  
# Write your implementation here.  
w1 = "good"  
w2 = "fine"  
w3 = "bad"  
w1_w2_dist = wv_from_bin.distance(w1, w2)  
w1_w3_dist = wv_from_bin.distance(w1, w3)  
  
print("Synonyms {}, {} have cosine distance: {}".format(w1, w2, w1_w2_dist))  
print("Antonyms {}, {} have cosine distance: {}".format(w1, w3, w1_w3_dist))  
  
# -----
```

Synonyms good, fine have cosine distance: 0.48414766788482666

Antonyms good, bad have cosine distance: 0.28903740644454956

Write your answer here.

$\text{Cosine Distance}(\text{good}, \text{bad}) < \text{Cosine Distance}(\text{good}, \text{fine})$ Cosine Similarity does not look at the magnitude between words, but measures the angle. It might seem intuitive if the output of w_1, w_2 was opposite of w_1, w_3 , rather having close proximity w_1, w_2 (0.484) and w_1, w_3 (0.289).

Solving Analogies with Word Vectors

Word vectors have been shown to *sometimes* exhibit the ability to solve analogies.

As an example, for the analogy "man : king :: woman : x" (read: man is to king as woman is to x), what is x?

In the cell below, we show you how to use word vectors to find x . The `most_similar` function finds words that are most similar to the words in the `positive` list and most dissimilar from the words in the `negative` list. The answer to the analogy will be the word ranked most similar (largest numerical value).

Note: Further Documentation on the `most_similar` function can be found within the [GenSim documentation](https://radimrehurek.com/gensim/models/keyedvectors.html#gensim.models.keyedvectors.FastTextKeyedVectors.most_similar) (https://radimrehurek.com/gensim/models/keyedvectors.html#gensim.models.keyedvectors.FastTextKeyedVectors.most_similar).

```
In [20]: # Run this cell to answer the analogy -- man : king :: woman : x
pprint.pprint(wv_from_bin.most_similar(positive=['woman', 'king'], negative=['man']))
```

```
[('queen', 0.6978678703308105),
 ('princess', 0.6081745028495789),
 ('monarch', 0.5889754891395569),
 ('throne', 0.5775108933448792),
 ('prince', 0.5750998258590698),
 ('elizabeth', 0.5463595986366272),
 ('daughter', 0.5399125814437866),
 ('kingdom', 0.5318052172660828),
 ('mother', 0.5168544054031372),
 ('crown', 0.5164473056793213)]
```

Question 2.4: Finding Analogies [code + written] (2 Points)

Find an example of analogy that holds according to these vectors (i.e. the intended word is ranked top). In your solution please state the full analogy in the form $x:y :: a:b$. If you believe the analogy is complicated, explain why the analogy holds in one or two sentences.

Note: You may have to try many analogies to find one that works!

```
In [21]: # -----  
# Write your implementation here.  
print('')  
print('white : black :: up : down')  
print('')  
pprint.pprint(wv_from_bin.most_similar(positive=['white', 'up'], negative=['down']))  
  
# -----
```

white : black :: up : down

```
[('black', 0.709771990776062),  
 ('with', 0.5913417339324951),  
 ('red', 0.5865756869316101),  
 ('brown', 0.5703251361846924),  
 ('green', 0.552123486995697),  
 ('colored', 0.5432795286178589),  
 ('yellow', 0.531940221786499),  
 ('blue', 0.5310556888580322),  
 ('pink', 0.5272434949874878),  
 ('house', 0.5265994071960449)]
```

Write your answer here.

'white : black :: up : down'. Black was produced and is the correct analogy.

Question 2.5: Incorrect Analogy [code + written] (1 point)

Find an example of analogy that does *not* hold according to these vectors. In your solution, state the intended analogy in the form x:y :: a:b, and state the (incorrect) value of b according to the word vectors.

In [22]:

```
# -----  
# Write your implementation here.  
  
print('')  
print('Dog : puppy :: cat : kitten')  
print('')  
pprint.pprint(wv_from_bin.most_similar(positive=['cat', 'dog'], negative=['puppy']))  
  
# -----
```

Dog : puppy :: cat : kitten

```
[('dogs', 0.6272706389427185),  
 ('cats', 0.5924872756004333),  
 ('horse', 0.5564484596252441),  
 ('pet', 0.5380032062530518),  
 ('animal', 0.5019071102142334),  
 ('rat', 0.4833652973175049),  
 ('bird', 0.47245192527770996),  
 ('eye', 0.47093015909194946),  
 ('bear', 0.4681668281555176),  
 ('animals', 0.4641147553920746)]
```

Write your answer here.

Dog : puppy :: cat : kitten. Kitten was the correct analogy, however it was not produced.

Question 2.6: Guided Analysis of Bias in Word Vectors [written] (1 point)

It's important to be cognizant of the biases (gender, race, sexual orientation etc.) implicit in our word embeddings. Bias can be dangerous because it can reinforce stereotypes through applications that employ these models.

Run the cell below, to examine (a) which terms are most similar to "woman" and "worker" and most dissimilar to "man", and (b) which terms are most similar to "man" and "worker" and most dissimilar to "woman". Point out the difference between the list of female-associated words and the list of male-associated words, and explain how it is reflecting gender bias.

```
In [23]: # Run this cell
# Here `positive` indicates the list of words to be similar to and `negative` indicates the list of words to
# most dissimilar from.
pprint.pprint(wv_from_bin.most_similar(positive=['woman', 'worker'], negative=['man']))
print()
pprint.pprint(wv_from_bin.most_similar(positive=['man', 'worker'], negative=['woman']))
```

```
[('employee', 0.6375863552093506),
 ('workers', 0.6068919897079468),
 ('nurse', 0.5837947130203247),
 ('pregnant', 0.5363885760307312),
 ('mother', 0.5321309566497803),
 ('employer', 0.5127025842666626),
 ('teacher', 0.5099577307701111),
 ('child', 0.5096741914749146),
 ('homemaker', 0.5019455552101135),
 ('nurses', 0.4970571994781494)]

[('workers', 0.611325740814209),
 ('employee', 0.5983108878135681),
 ('working', 0.5615329742431641),
 ('laborer', 0.5442320108413696),
 ('unemployed', 0.5368517637252808),
 ('job', 0.5278826951980591),
 ('work', 0.5223963260650635),
 ('mechanic', 0.5088937282562256),
 ('worked', 0.5054520964622498),
 ('factory', 0.4940453767776489)]
```

Write your answer here.

'Workers' is a gender neutral term, however in the first list men can be nurses, employees, homemaker, etc.. In the second list, woman can be workers, employees, working, laborers, etc.

Question 2.7: Independent Analysis of Bias in Word Vectors [code + written] (1 point)

Use the `most_similar` function to find another case where some bias is exhibited by the vectors. Please briefly explain the example of bias that you discover.

In [24]:

```

# -----
# Write your implementation here.

pprint.pprint(wv_from_bin.most_similar(positive=['man', 'solider'], negative=['woman']))
print()
pprint.pprint(wv_from_bin.most_similar(positive=['woman', 'solider'], negative=['man']))

# -----

[('serviceman', 0.47422173619270325),
 ('soldier', 0.453141987323761),
 ('soliders', 0.4464874863624573),
 ('peacekeeper', 0.4324309229850769),
 ('beefy', 0.4253820478916168),
 ('crewman', 0.4212471842765808),
 ('mustached', 0.3806219696998596),
 ('privates', 0.3796985149383545),
 ('sgt', 0.3769349455833435),
 ('mutineer', 0.3749666213989258)]

[('soliders', 0.5773683786392212),
 ('serviceman', 0.5757607817649841),
 ('solders', 0.49688705801963806),
 ('passerby', 0.48241591453552246),
 ('servicemember', 0.46611881256103516),
 ('crewmember', 0.4597702920436859),
 ('schoolmistress', 0.4408072233200073),
 ('peacekeeper', 0.44013288617134094),
 ('policewoman', 0.4347541034221649),
 ('bystander', 0.4280003011226654)]

```

Write your answer here.

The number of women 'soldiers' (servicemen and servicewoman) have increased over the years within the army. In today's terminology a solider is either a man or woman and according to the output 'solider' is closer to 'man' than 'woman'.

Question 2.8: Thinking About Bias [written] (2 points)

What might be the causes of these biases in the word vectors? You should give least 2 explanations how bias get into the word vectors. How might you be able to investigate/test these causes?

Write your answer here.

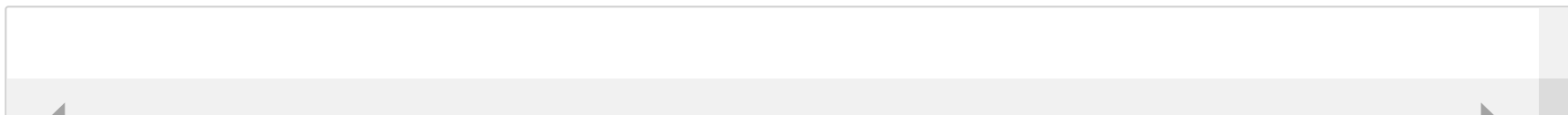
Female terms such as “her”, “she”, “woman” are closer to family and arts/education than they are to professional positions and math studies, whereas the reverse is true for male terms. Vector embeddings used on older content could capture these biases in their relationships. Another way biases can get into word vectors is that patterns can exist between people’s names and common lower-case words and phrases, even more so in other languages like German ('der' for the masculine nouns, 'die' for female).

Testing for bias can include searching the original training documents and removing biases and retraining algorithms used word embeddings.

Submission Instructions

1. Click the Save button at the top of the Jupyter Notebook.
2. Select Cell -> All Output -> Clear. This will clear all the outputs from all cells (but will keep the content of all cells).
3. Select Cell -> Run All. This will run all the cells in order, and will take several minutes.
4. Once you've rerun everything, select File -> Download as -> PDF via LaTeX (If you have trouble using "PDF via LaTeX", you can also save the webpage as pdf. [Make sure all your solutions especially the coding parts are displayed in the pdf](#), it's okay if the provided codes get cut off because lines are not wrapped in code cells).
5. Look at the PDF file and make sure all your solutions are there, displayed correctly. The PDF is the only thing your graders will see!
6. Submit your PDF on Gradescope.

In []:



In []:

