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Applying Machine Learning to Sentiment Analysis

In the modern internet and social media age, people's opinions, reviews, and recommendations have become a valuable resource for political science and businesses. Thanks to modern technologies, we are now able to collect and analyze such data most efficiently. In this chapter, we will delve into a subfield of natural language processing (NLP) called sentiment analysis and learn how to use machine learning algorithms to classify documents based on their sentiment: the attitude of the writer. In particular, we are going to work with a dataset of 50,000 movie reviews from the **Internet Movie Database (IMDb)** and build a predictor that can distinguish between positive and negative reviews.

The topics that we will cover in this chapter include the following:

- Cleaning and preparing text data
- Building feature vectors from text documents
- Training a machine learning model to classify positive and negative movie reviews
- Working with large text datasets using out-of-core learning
- Inferring topics from document collections for categorization

Preparing the IMDb movie review data for text processing

As mentioned, sentiment analysis, sometimes also called **opinion mining**, is a popular subdiscipline of the broader field of NLP; it is concerned with analyzing the sentiment of documents. A popular task in sentiment analysis is the classification of documents based on the expressed opinions or emotions of the authors with regard to a particular topic.

In this chapter, we will be working with a large dataset of movie reviews from IMDb that has been collected by Andrew Maas and others (*Learning Word Vectors for Sentiment Analysis* by A. L. Maas, R. E. Daly, P. T. Pham, D. Huang, A. Y. Ng, and C. Potts, *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies*, pages 142–150, Portland, Oregon, USA, Association for Computational Linguistics, June 2011). The movie review dataset consists of 50,000 polar movie reviews that are labeled as either positive or negative; here, positive means that a movie was rated with more than six stars on IMDb, and negative means that a movie was rated with fewer than five stars on IMDb. In the following sections, we will download the dataset, preprocess it into a useable format for machine learning tools, and extract meaningful information from a subset of these movie reviews to build a machine learning model that can predict whether a certain reviewer liked or disliked a movie.

Obtaining the movie review dataset

A compressed archive of the movie review dataset (84.1 MB) can be downloaded from <http://ai.stanford.edu/~amaas/data/sentiment/> as a gzip-compressed tarball archive:

- If you are working with Linux or macOS, you can open a new terminal window, cd into the download directory, and execute `tar -zxf aclImdb_v1.tar.gz` to decompress the dataset.
- If you are working with Windows, you can download a free archiver, such as 7-Zip (<http://www.7-zip.org>), to extract the files from the download archive.
- Alternatively, you can unpack the gzip-compressed tarball archive directly in Python as follows:

```
>>> import tarfile  
>>> with tarfile.open('aclImdb_v1.tar.gz', 'r:gz') as tar:  
...     tar.extractall()
```

Preprocessing the movie dataset into a more convenient format

Having successfully extracted the dataset, we will now assemble the individual text documents from the decompressed download archive into a single CSV file. In the following code section, we will be reading the movie reviews into a pandas `DataFrame` object, which can take up to 10 minutes on a standard desktop computer.

To visualize the progress and estimated time until completion, we will use the **Python Progress Indicator** (`PyPrind`, <https://pypi.python.org/pypi/PyPrind/>) package, which was developed several years ago for such purposes. `PyPrind` can be installed by executing the `pip install pyprind` command:

```
>>> import pyprind  
>>> import pandas as pd  
>>> import os  
>>> import sys  
>>> # change the 'basepath' to the directory of the  
>>> # unzipped movie dataset  
>>> basepath = 'aclImdb'
```

```

>>>
>>> labels = {'pos': 1, 'neg': 0}
>>> pbar = pyprind.ProgBar(50000, stream=sys.stdout)
>>> df = pd.DataFrame()
>>> for s in ('test', 'train'):
...     for l in ('pos', 'neg'):
...         path = os.path.join(basepath, s, l)
...         for file in sorted(os.listdir(path)):
...             with open(os.path.join(path, file),
...                       'r', encoding='utf-8') as infile:
...                 txt = infile.read()
...                 df = df.append([[txt, labels[l]]],
...                               ignore_index=True)
...             pbar.update()
>>> df.columns = ['review', 'sentiment']
0%                                100%
[########################################] | ETA: 00:00:00
Total time elapsed: 00:00:25

```

In the preceding code, we first initialized a new progress bar object, `pbar`, with 50,000 iterations, which was the number of documents we were going to read in. Using the nested `for` loops, we iterated over the `train` and `test` subdirectories in the main `aclImdb` directory and read the individual text files from the `pos` and `neg` subdirectories that we eventually appended to the `df` pandas `DataFrame`, together with an integer class label (1 = positive and 0 = negative).

Since the class labels in the assembled dataset are sorted, we will now shuffle the `DataFrame` using the `permutation` function from the `np.random` submodule—this will be useful for splitting the dataset into training and test datasets in later sections, when we will stream the data from our local drive directly.

For our own convenience, we will also store the assembled and shuffled movie review dataset as a CSV file:

```

>>> import numpy as np
>>> np.random.seed(0)
>>> df = df.reindex(np.random.permutation(df.index))
>>> df.to_csv('movie_data.csv', index=False, encoding='utf-8')

```

Since we are going to use this dataset later in this chapter, let's quickly confirm that we have successfully saved the data in the right format by reading in the CSV and printing an excerpt of the first three examples:

```

>>> df = pd.read_csv('movie_data.csv', encoding='utf-8')
>>> # the following column renaming is necessary on some computers:
>>> df = df.rename(columns={"0": "review", "1": "sentiment"})
>>> df.head(3)

```

If you are running the code examples in a Jupyter notebook, you should now see the first three examples of the dataset, as shown in *Figure 8.1*:

	review	sentiment
0	In 1974, the teenager Martha Moxley (Maggie Gr...	1
1	OK... so... I really like Kris Kristofferson a...	0
2	***SPOILER*** Do not read this, if you think a...	0

Figure 8.1: The first three rows of the movie review dataset

As a sanity check, before we proceed to the next section, let's make sure that the DataFrame contains all 50,000 rows:

```
>>> df.shape
(50000, 2)
```

Introducing the bag-of-words model

You may remember from *Chapter 4, Building Good Training Datasets – Data Preprocessing*, that we have to convert categorical data, such as text or words, into a numerical form before we can pass it on to a machine learning algorithm. In this section, we will introduce the **bag-of-words** model, which allows us to represent text as numerical feature vectors. The idea behind bag-of-words is quite simple and can be summarized as follows:

1. We create a vocabulary of unique tokens—for example, words—from the entire set of documents.
2. We construct a feature vector from each document that contains the counts of how often each word occurs in the particular document.

Since the unique words in each document represent only a small subset of all the words in the bag-of-words vocabulary, the feature vectors will mostly consist of zeros, which is why we call them **sparse**. Do not worry if this sounds too abstract; in the following subsections, we will walk through the process of creating a simple bag-of-words model step by step.

Transforming words into feature vectors

To construct a bag-of-words model based on the word counts in the respective documents, we can use the `CountVectorizer` class implemented in scikit-learn. As you will see in the following code section, `CountVectorizer` takes an array of text data, which can be documents or sentences, and constructs the bag-of-words model for us:

```
>>> import numpy as np
>>> from sklearn.feature_extraction.text import CountVectorizer
>>> count = CountVectorizer()
>>> docs = np.array(['The sun is shining',
```

```
...                 'The weather is sweet',
...                 'The sun is shining, the weather is sweet,'
...
...                 'and one and one is two'])
>>> bag = count.fit_transform(docs)
```

By calling the `fit_transform` method on `CountVectorizer`, we constructed the vocabulary of the bag-of-words model and transformed the following three sentences into sparse feature vectors:

- 'The sun is shining'
- 'The weather is sweet'
- 'The sun is shining, the weather is sweet, and one and one is two'

Now, let's print the contents of the vocabulary to get a better understanding of the underlying concepts:

```
>>> print(count.vocabulary_)
{'and': 0,
'two': 7,
'shining': 3,
'one': 2,
'sun': 4,
'weather': 8,
'the': 6,
'sweet': 5,
'is': 1}
```

As you can see from executing the preceding command, the vocabulary is stored in a Python dictionary that maps the unique words to integer indices. Next, let's print the feature vectors that we just created:

```
>>> print(bag.toarray())
[[0 1 0 1 1 0 1 0 0]
 [0 1 0 0 0 1 1 0 1]
 [2 3 2 1 1 1 2 1 1]]
```

Each index position in the feature vectors shown here corresponds to the integer values that are stored as dictionary items in the `CountVectorizer` vocabulary. For example, the first feature at index position 0 resembles the count of the word 'and', which only occurs in the last document, and the word 'is', at index position 1 (the second feature in the document vectors), occurs in all three sentences. These values in the feature vectors are also called the **raw term frequencies**: $tf(t, d)$ —the number of times a term, t , occurs in a document, d . It should be noted that, in the bag-of-words model, the word or term order in a sentence or document does not matter. The order in which the term frequencies appear in the feature vector is derived from the vocabulary indices, which are usually assigned alphabetically.

N-gram models

The sequence of items in the bag-of-words model that we just created is also called the 1-gram or unigram model—each item or token in the vocabulary represents a single word. More generally, the contiguous sequences of items in NLP—words, letters, or symbols—are also called *n-grams*. The choice of the number, n , in the n-gram model depends on the particular application; for example, a study by Ioannis Kanaris and others revealed that n-grams of size 3 and 4 yield good performances in the anti-spam filtering of email messages (*Words versus character n-grams for anti-spam filtering by Ioannis Kanaris, Konstantinos Kanaris, Ioannis Houvardas, and Efstatios Stamatatos, International Journal on Artificial Intelligence Tools, World Scientific Publishing Company, 16(06): 1047-1067, 2007*).



To summarize the concept of the n-gram representation, the 1-gram and 2-gram representations of our first document, “the sun is shining”, would be constructed as follows:

- 1-gram: “the”, “sun”, “is”, “shining”
- 2-gram: “the sun”, “sun is”, “is shining”

The CountVectorizer class in scikit-learn allows us to use different n-gram models via its `ngram_range` parameter. While a 1-gram representation is used by default, we could switch to a 2-gram representation by initializing a new CountVectorizer instance with `ngram_range=(2, 2)`.

Assessing word relevancy via term frequency-inverse document frequency

When we are analyzing text data, we often encounter words that occur across multiple documents from both classes. These frequently occurring words typically don't contain useful or discriminatory information. In this subsection, you will learn about a useful technique called the **term frequency-inverse document frequency (tf-idf)**, which can be used to downweight these frequently occurring words in the feature vectors. The tf-idf can be defined as the product of the term frequency and the inverse document frequency:

$$tf\text{-}idf(t, d) = tf(t, d) \times idf(t, d)$$

Here, $tf(t, d)$ is the term frequency that we introduced in the previous section, and $idf(t, d)$ is the inverse document frequency, which can be calculated as follows:

$$idf(t, d) = \log \frac{n_d}{1 + df(d, t)}$$

Here, n_d is the total number of documents, and $df(d, t)$ is the number of documents, d , that contain the term t . Note that adding the constant 1 to the denominator is optional and serves the purpose of assigning a non-zero value to terms that occur in none of the training examples; the \log is used to ensure that low document frequencies are not given too much weight.

The scikit-learn library implements yet another transformer, the `TfidfTransformer` class, which takes the raw term frequencies from the `CountVectorizer` class as input and transforms them into tf-idfs:

```
>>> from sklearn.feature_extraction.text import TfidfTransformer
>>> tfidf = TfidfTransformer(use_idf=True,
...                           norm='l2',
...                           smooth_idf=True)
>>> np.set_printoptions(precision=2)
>>> print(tfidf.fit_transform(count.fit_transform(docs)))
...
[[ 0.        0.43      0.        0.56      0.43      0.        0.        ]
 [ 0.        0.43      0.        0.        0.56      0.43      0.        0.56]
 [ 0.5       0.45      0.5       0.19      0.19      0.19      0.3       0.25      0.19]]
```

As you saw in the previous subsection, the word 'is' had the largest term frequency in the third document, being the most frequently occurring word. However, after transforming the same feature vector into tf-idfs, the word 'is' is now associated with a relatively small tf-idf (0.45) in the third document, since it is also present in the first and second document and thus is unlikely to contain any useful discriminatory information.

However, if we'd manually calculated the tf-idfs of the individual terms in our feature vectors, we would have noticed that `TfidfTransformer` calculates the tf-idfs slightly differently compared to the standard textbook equations that we defined previously. The equation for the inverse document frequency implemented in scikit-learn is computed as follows:

$$idf(t, d) = \log \frac{1 + n_d}{1 + df(d, t)}$$

Similarly, the tf-idf computed in scikit-learn deviates slightly from the default equation we defined earlier:

$$tf-idf(t, d) = tf(t, d) \times (idf(t, d) + 1)$$

Note that the "+1" in the previous `idf` equation is due to setting `smooth_idf=True` in the previous code example, which is helpful for assigning zero weight (that is, $idf(t, d) = \log(1) = 0$) to terms that occur in all documents.

While it is also more typical to normalize the raw term frequencies before calculating the tf-idfs, the `TfidfTransformer` class normalizes the tf-idfs directly. By default (`norm='l2'`), scikit-learn's `TfidfTransformer` applies the L2-normalization, which returns a vector of length 1 by dividing an unnormalized feature vector, v , by its L2-norm:

$$v_{norm} = \frac{v}{\|v\|_2} = \frac{v}{\sqrt{v_1^2 + v_2^2 + \dots + v_n^2}} = \frac{v}{(\sum_{i=1}^n v_i^2)^{1/2}}$$

To make sure that we understand how `TfidfTransformer` works, let's walk through an example and calculate the tf-idf of the word 'is' in the third document. The word 'is' has a term frequency of 3 ($tf=3$) in the third document, and the document frequency of this term is 3 since the term 'is' occurs in all three documents ($df=3$). Thus, we can calculate the inverse document frequency as follows:

$$idf("is", d_3) = \log \frac{1 + 3}{1 + 3} = 0$$

Now, in order to calculate the tf-idf, we simply need to add 1 to the inverse document frequency and multiply it by the term frequency:

$$tf\text{-}idf("is", d_3) = 3 \times (0 + 1) = 3$$

If we repeated this calculation for all terms in the third document, we'd obtain the following tf-idf vectors: [3.39, 3.0, 3.39, 1.29, 1.29, 1.29, 2.0, 1.69, 1.29]. However, notice that the values in this feature vector are different from the values that we obtained from `TfidfTransformer` that we used previously. The final step that we are missing in this tf-idf calculation is the L2-normalization, which can be applied as follows:

$$\begin{aligned} tf\text{-}idf(d_3)_{norm} &= \frac{[3.39, 3.0, 3.39, 1.29, 1.29, 1.29, 2.0, 1.69, 1.29]}{\sqrt{3.39^2 + 3.0^2 + 3.39^2 + 1.29^2 + 1.29^2 + 1.29^2 + 2.0^2 + 1.69^2 + 1.29^2}} \\ &= [0.5, 0.45, 0.5, 0.19, 0.19, 0.19, 0.3, 0.25, 0.19] \end{aligned}$$

$$tf\text{-}idf("is", d_3) = 0.45$$

As you can see, the results now match the results returned by scikit-learn's `TfidfTransformer`, and since you now understand how tf-idfs are calculated, let's proceed to the next section and apply those concepts to the movie review dataset.

Cleaning text data

In the previous subsections, we learned about the bag-of-words model, term frequencies, and tf-idfs. However, the first important step—before we build our bag-of-words model—is to clean the text data by stripping it of all unwanted characters.

To illustrate why this is important, let's display the last 50 characters from the first document in the reshuffled movie review dataset:

```
>>> df.loc[0, 'review'][-50:]
'is seven.<br /><br />Title (Brazil): Not Available'
```

As you can see here, the text contains HTML markup as well as punctuation and other non-letter characters. While HTML markup does not contain many useful semantics, punctuation marks can represent useful, additional information in certain NLP contexts. However, for simplicity, we will now remove all punctuation marks except for emoticon characters, such as :), since those are certainly useful for sentiment analysis.

To accomplish this task, we will use Python's **regular expression (regex)** library, `re`, as shown here:

```
>>> import re
>>> def preprocessor(text):
...     text = re.sub('<[^>]*>', '', text)
...     emoticons = re.findall('(?:::|;|=)(?:-)?(?:\()|\\(|D|P)', text)
...     text = (re.sub('[\W]+', ' ', text.lower()) +
...             ''.join(emoticons).replace('-', ''))
...     return text
```

Via the first regex, `<[^>]*>`, in the preceding code section, we tried to remove all of the HTML markup from the movie reviews. Although many programmers generally advise against the use of regex to parse HTML, this regex should be sufficient to *clean* this particular dataset. Since we are only interested in removing HTML markup and do not plan to use the HTML markup further, using regex to do the job should be acceptable. However, if you prefer to use sophisticated tools for removing HTML markup from text, you can take a look at Python's HTML parser module, which is described at <https://docs.python.org/3/library/html.parser.html>. After we removed the HTML markup, we used a slightly more complex regex to find emoticons, which we temporarily stored as emoticons. Next, we removed all non-word characters from the text via the regex `[\W]+` and converted the text into lowercase characters.

Dealing with word capitalization



In the context of this analysis, we assume that the capitalization of a word—for example, whether it appears at the beginning of a sentence—does not contain semantically relevant information. However, note that there are exceptions; for instance, we remove the notation of proper names. But again, in the context of this analysis, it is a simplifying assumption that the letter case does not contain information that is relevant for sentiment analysis.

Eventually, we added the temporarily stored emoticons to the end of the processed document string. Additionally, we removed the *nose* character (- in :-) from the emoticons for consistency.

Regular expressions



Although regular expressions offer an efficient and convenient approach to searching for characters in a string, they also come with a steep learning curve. Unfortunately, an in-depth discussion of regular expressions is beyond the scope of this book. However, you can find a great tutorial on the Google Developers portal at <https://developers.google.com/edu/python/regular-expressions> or you can check out the official documentation of Python's `re` module at <https://docs.python.org/3.9/library/re.html>.

Although the addition of the emoticon characters to the end of the cleaned document strings may not look like the most elegant approach, we must note that the order of the words doesn't matter in our bag-of-words model if our vocabulary consists of only one-word tokens. But before we talk more about the splitting of documents into individual terms, words, or tokens, let's confirm that our preprocessor function works correctly:

```
>>> preprocessor(df.loc[0, 'review'][-50:])
'is seven title brazil not available'
>>> preprocessor("</a>This :) is :( a test :-)!")
'this is a test :) :( :)'
```

Lastly, since we will make use of the *cleaned* text data over and over again during the next sections, let's now apply our preprocessor function to all the movie reviews in our DataFrame:

```
>>> df['review'] = df['review'].apply(preprocessor)
```

Processing documents into tokens

After successfully preparing the movie review dataset, we now need to think about how to split the text corpora into individual elements. One way to *tokenize* documents is to split them into individual words by splitting the cleaned documents at their whitespace characters:

```
>>> def tokenizer(text):
...     return text.split()
>>> tokenizer('runners like running and thus they run')
['runners', 'like', 'running', 'and', 'thus', 'they', 'run']
```

In the context of tokenization, another useful technique is **word stemming**, which is the process of transforming a word into its root form. It allows us to map related words to the same stem. The original stemming algorithm was developed by Martin F. Porter in 1979 and is hence known as the **Porter stemmer** algorithm (*An algorithm for suffix stripping* by Martin F. Porter, *Program: Electronic Library and Information Systems*, 14(3): 130–137, 1980). The **Natural Language Toolkit (NLTK, <http://www.nltk.org>)** for Python implements the Porter stemming algorithm, which we will use in the following code section. To install the NLTK, you can simply execute `conda install nltk` or `pip install nltk`.

NLTK online book



Although the NLTK is not the focus of this chapter, I highly recommend that you visit the NLTK website as well as read the official NLTK book, which is freely available at <http://www.nltk.org/book/>, if you are interested in more advanced applications in NLP.

The following code shows how to use the Porter stemming algorithm:

```
>>> from nltk.stem.porter import PorterStemmer
>>> porter = PorterStemmer()
```

```
>>> def tokenizer_porter(text):
...     return [porter.stem(word) for word in text.split()]
>>> tokenizer_porter('runners like running and thus they run')
['runner', 'like', 'run', 'and', 'thu', 'they', 'run']
```

Using the PorterStemmer from the `nltk` package, we modified our `tokenizer` function to reduce words to their root form, which was illustrated by the simple preceding example where the word 'running' was *stemmed* to its root form 'run'.

Stemming algorithms

The Porter stemming algorithm is probably the oldest and simplest stemming algorithm. Other popular stemming algorithms include the newer Snowball stemmer (Porter2 or English stemmer) and the Lancaster stemmer (Paice/Husk stemmer). While both the Snowball and Lancaster stemmers are faster than the original Porter stemmer, the Lancaster stemmer is also notorious for being more aggressive than the Porter stemmer, which means that it will produce shorter and more obscure words. These alternative stemming algorithms are also available through the NLTK package (<http://www.nltk.org/api/nltk.stem.html>).



While stemming can create non-real words, such as 'thu' (from 'thus'), as shown in the previous example, a technique called *lemmatization* aims to obtain the canonical (grammatically correct) forms of individual words—the so-called *lemmas*. However, lemmatization is computationally more difficult and expensive compared to stemming and, in practice, it has been observed that stemming and lemmatization have little impact on the performance of text classification (*Influence of Word Normalization on Text Classification*, by Michal Toman, Roman Tesar, and Karel Jezek, *Proceedings of InSciT*, pages 354–358, 2006).

Before we jump into the next section, where we will train a machine learning model using the bag-of-words model, let's briefly talk about another useful topic called **stop word removal**. Stop words are simply those words that are extremely common in all sorts of texts and probably bear no (or only a little) useful information that can be used to distinguish between different classes of documents. Examples of stop words are *is*, *and*, *has*, and *like*. Removing stop words can be useful if we are working with raw or normalized term frequencies rather than tf-idfs, which already downweight the frequently occurring words.

To remove stop words from the movie reviews, we will use the set of 127 English stop words that is available from the NLTK library, which can be obtained by calling the `nltk.download` function:

```
>>> import nltk
>>> nltk.download('stopwords')
```

After we download the stop words set, we can load and apply the English stop word set as follows:

```
>>> from nltk.corpus import stopwords
>>> stop = stopwords.words('english')
>>> [w for w in tokenizer_porter('a runner likes'
...   ' running and runs a lot')
...   if w not in stop]
['runner', 'like', 'run', 'run', 'lot']
```

Training a logistic regression model for document classification

In this section, we will train a logistic regression model to classify the movie reviews into *positive* and *negative* reviews based on the bag-of-words model. First, we will divide the `DataFrame` of cleaned text documents into 25,000 documents for training and 25,000 documents for testing:

```
>>> X_train = df.loc[:25000, 'review'].values
>>> y_train = df.loc[:25000, 'sentiment'].values
>>> X_test = df.loc[25000:, 'review'].values
>>> y_test = df.loc[25000:, 'sentiment'].values
```

Next, we will use a `GridSearchCV` object to find the optimal set of parameters for our logistic regression model using 5-fold stratified cross-validation:

```
>>> from sklearn.model_selection import GridSearchCV
>>> from sklearn.pipeline import Pipeline
>>> from sklearn.linear_model import LogisticRegression
>>> from sklearn.feature_extraction.text import TfidfVectorizer
>>> tfidf = TfidfVectorizer(strip_accents=None,
...                         lowercase=False,
...                         preprocessor=None)
>>> small_param_grid = [
...     {
...         'vect__ngram_range': [(1, 1)],
...         'vect__stop_words': [None],
...         'vect__tokenizer': [tokenizer, tokenizer_porter],
...         'clf__penalty': ['l2'],
...         'clf__C': [1.0, 10.0]
...     },
...     {
...         'vect__ngram_range': [(1, 1)],
...         'vect__stop_words': [stop, None],
...         'vect__tokenizer': [tokenizer],
```

```
...         'vect__use_idf':[False],
...         'vect__norm':[None],
...         'clf__penalty': ['l2'],
...         'clf__C': [1.0, 10.0]
...
...     },
...
... ]
>>> lr_tfidf = Pipeline([
...     ('vect', tfidf),
...     ('clf', LogisticRegression(solver='liblinear'))
... ])
>>> gs_lr_tfidf = GridSearchCV(lr_tfidf, small_param_grid,
...                               scoring='accuracy', cv=5,
...                               verbose=2, n_jobs=1)
>>> gs_lr_tfidf.fit(X_train, y_train)
```

Note that for the logistic regression classifier, we are using the LIBLINEAR solver as it can perform better than the default choice ('lbgfsg') for relatively large datasets.



Multiprocessing via the n_jobs parameter

Please note that we highly recommend setting `n_jobs=-1` (instead of `n_jobs=1`, as in the previous code example) to utilize all available cores on your machine and speed up the grid search. However, some Windows users reported issues when running the previous code with the `n_jobs=-1` setting related to pickling the `tokenizer` and `tokenizer_porter` functions for multiprocessing on Windows. Another workaround would be to replace those two functions, `[tokenizer, tokenizer_porter]`, with `[str.split]`. However, note that replacement by the simple `str.split` would not support stemming.

When we initialized the `GridSearchCV` object and its parameter grid using the preceding code, we restricted ourselves to a limited number of parameter combinations, since the number of feature vectors, as well as the large vocabulary, can make the grid search computationally quite expensive. Using a standard desktop computer, our grid search may take 5-10 minutes to complete.

In the previous code example, we replaced `CountVectorizer` and `TfidfTransformer` from the previous subsection with `TfidfVectorizer`, which combines `CountVectorizer` with the `TfidfTransformer`. Our `param_grid` consisted of two parameter dictionaries. In the first dictionary, we used `TfidfVectorizer` with its default settings (`use_idf=True`, `smooth_idf=True`, and `norm='l2'`) to calculate the tf-idfs; in the second dictionary, we set those parameters to `use_idf=False`, `smooth_idf=False`, and `norm=None` in order to train a model based on raw term frequencies. Furthermore, for the logistic regression classifier itself, we trained models using L2 regularization via the `penalty` parameter and compared different regularization strengths by defining a range of values for the inverse-regularization parameter `C`. As an optional exercise, you are also encouraged to add L1 regularization to the parameter grid by changing `'clf__penalty': ['l2']` to `'clf__penalty': ['l2', 'l1']`.

After the grid search has finished, we can print the best parameter set:

```
>>> print(f'Best parameter set: {gs_lr_tfidf.best_params_}')
Best parameter set: {'clf__C': 10.0, 'clf__penalty': 'l2', 'vect__ngram_range':
(1, 1), 'vect__stop_words': None, 'vect__tokenizer': <function tokenizer at
0x169932dc0>}
```

As you can see in the preceding output, we obtained the best grid search results using the regular tokenizer without Porter stemming, no stop word library, and tf-idfs in combination with a logistic regression classifier that uses L2-regularization with the regularization strength C of 10.0.

Using the best model from this grid search, let's print the average 5-fold cross-validation accuracy scores on the training dataset and the classification accuracy on the test dataset:

```
>>> print(f'CV Accuracy: {gs_lr_tfidf.best_score_:.3f}')
CV Accuracy: 0.897
>>> clf = gs_lr_tfidf.best_estimator_
>>> print(f'Test Accuracy: {clf.score(X_test, y_test):.3f}')
Test Accuracy: 0.899
```

The results reveal that our machine learning model can predict whether a movie review is positive or negative with 90 percent accuracy.

The naïve Bayes classifier

A still very popular classifier for text classification is the naïve Bayes classifier, which gained popularity in applications of email spam filtering. Naïve Bayes classifiers are easy to implement, computationally efficient, and tend to perform particularly well on relatively small datasets compared to other algorithms. Although we don't discuss naïve Bayes classifiers in this book, the interested reader can find an article about naïve Bayes text classification that is freely available on arXiv (*Naive Bayes and Text Classification I – Introduction and Theory* by S. Raschka, Computing Research Repository (CoRR), abs/1410.5329, 2014, <http://arxiv.org/pdf/1410.5329v3.pdf>). Different versions of naïve Bayes classifiers referenced in this article are implemented in scikit-learn. You can find an overview page with links to the respective code classes here: https://scikit-learn.org/stable/modules/naive_bayes.html.



Working with bigger data – online algorithms and out-of-core learning

If you executed the code examples in the previous section, you may have noticed that it could be computationally quite expensive to construct the feature vectors for the 50,000-movie review dataset during a grid search. In many real-world applications, it is not uncommon to work with even larger datasets that can exceed our computer's memory.

Since not everyone has access to supercomputer facilities, we will now apply a technique called **out-of-core learning**, which allows us to work with such large datasets by fitting the classifier incrementally on smaller batches of a dataset.

Text classification with recurrent neural networks



In *Chapter 15, Modeling Sequential Data Using Recurrent Neural Networks*, we will revisit this dataset and train a deep learning-based classifier (a recurrent neural network) to classify the reviews in the IMDB movie review dataset. This neural network-based classifier follows the same out-of-core principle using the stochastic gradient descent optimization algorithm, but does not require the construction of a bag-of-words model.

Back in *Chapter 2, Training Simple Machine Learning Algorithms for Classification*, the concept of **stochastic gradient descent** was introduced; it is an optimization algorithm that updates the model's weights using one example at a time. In this section, we will make use of the `partial_fit` function of `SGDClassifier` in scikit-learn to stream the documents directly from our local drive and train a logistic regression model using small mini-batches of documents.

First, we will define a `tokenizer` function that cleans the unprocessed text data from the `movie_data.csv` file that we constructed at the beginning of this chapter and separates it into word tokens while removing stop words:

```
>>> import numpy as np
>>> import re
>>> from nltk.corpus import stopwords
>>> stop = stopwords.words('english')
>>> def tokenizer(text):
...     text = re.sub('<[^>]*>', '', text)
...     emoticons = re.findall('(?:[:|]=)(?:-)?(?:\:)|\(|D|P|',
...                           text)
...     text = re.sub('[\W]+', ' ', text.lower()) \
...             + ' '.join(emoticons).replace('-', '')
...     tokenized = [w for w in text.split() if w not in stop]
...     return tokenized
```

Next, we will define a generator function, `stream_docs`, that reads in and returns one document at a time:

```
>>> def stream_docs(path):
...     with open(path, 'r', encoding='utf-8') as csv:
...         next(csv) # skip header
...         for line in csv:
...             text, label = line[:-3], int(line[-2])
...             yield text, label
```

To verify that our `stream_docs` function works correctly, let's read in the first document from the `movie_data.csv` file, which should return a tuple consisting of the review text as well as the corresponding class label:

```
>>> next(stream_docs(path='movie_data.csv'))
('In 1974, the teenager Martha Moxley ... ',1)
```

We will now define a function, `get_minibatch`, that will take a document stream from the `stream_docs` function and return a particular number of documents specified by the `size` parameter:

```
>>> def get_minibatch(doc_stream, size):
...     docs, y = [], []
...     try:
...         for _ in range(size):
...             text, label = next(doc_stream)
...             docs.append(text)
...             y.append(label)
...     except StopIteration:
...         return None, None
...     return docs, y
```

Unfortunately, we can't use `CountVectorizer` for out-of-core learning since it requires holding the complete vocabulary in memory. Also, `TfidfVectorizer` needs to keep all the feature vectors of the training dataset in memory to calculate the inverse document frequencies. However, another useful vectorizer for text processing implemented in scikit-learn is `HashingVectorizer`. `HashingVectorizer` is data-independent and makes use of the hashing trick via the 32-bit MurmurHash3 function by Austin Appleby (you can find more information about MurmurHash at <https://en.wikipedia.org/wiki/MurmurHash>):

```
>>> from sklearn.feature_extraction.text import HashingVectorizer
>>> from sklearn.linear_model import SGDClassifier
>>> vect = HashingVectorizer(decode_error='ignore',
...                           n_features=2**21,
...                           preprocessor=None,
...                           tokenizer=tokenizer)
>>> clf = SGDClassifier(loss='log', random_state=1)
>>> doc_stream = stream_docs(path='movie_data.csv')
```

Using the preceding code, we initialized `HashingVectorizer` with our `tokenizer` function and set the number of features to 2^{21} . Furthermore, we reinitialized a logistic regression classifier by setting the `loss` parameter of `SGDClassifier` to '`log`'. Note that by choosing a large number of features in `HashingVectorizer`, we reduce the chance of causing hash collisions, but we also increase the number of coefficients in our logistic regression model.

Now comes the really interesting part—having set up all the complementary functions, we can start the out-of-core learning using the following code:

```
>>> import pyprind  
>>> pbar = pyprind.ProgBar(45)  
>>> classes = np.array([0, 1])  
>>> for _ in range(45):  
...     X_train, y_train = get_minibatch(doc_stream, size=1000)  
...     if not X_train:  
...         break  
...     X_train = vect.transform(X_train)  
...     clf.partial_fit(X_train, y_train, classes=classes)  
...     pbar.update()  
0%          100%  
[#####] | ETA: 00:00:00  
Total time elapsed: 00:00:21
```

Again, we made use of the PyPrind package to estimate the progress of our learning algorithm. We initialized the progress bar object with 45 iterations and, in the following `for` loop, we iterated over 45 mini-batches of documents where each mini-batch consists of 1,000 documents. Having completed the incremental learning process, we will use the last 5,000 documents to evaluate the performance of our model:

```
>>> X_test, y_test = get_minibatch(doc_stream, size=5000)  
>>> X_test = vect.transform(X_test)  
>>> print(f'Accuracy: {clf.score(X_test, y_test):.3f}')  
Accuracy: 0.868
```

NoneType error

Please note that if you encounter a `NoneType` error, you may have executed the `X_test, y_test = get_minibatch(...)` code twice. Via the previous loop, we have 45 iterations where we fetch 1,000 documents each. Hence, there are exactly 5,000 documents left for testing, which we assign via:



```
>>> X_test, y_test = get_minibatch(doc_stream, size=5000)
```

If we execute this code twice, then there are not enough documents left in the generator, and `X_test` returns `None`. Hence, if you encounter the `NoneType` error, you have to start at the previous `stream_docs(...)` code again.

As you can see, the accuracy of the model is approximately 87 percent, slightly below the accuracy that we achieved in the previous section using the grid search for hyperparameter tuning. However, out-of-core learning is very memory efficient, and it took less than a minute to complete.

Finally, we can use the last 5,000 documents to update our model:

```
>>> clf = clf.partial_fit(X_test, y_test)
```

The word2vec model

A more modern alternative to the bag-of-words model is word2vec, an algorithm that Google released in 2013 (*Efficient Estimation of Word Representations in Vector Space* by T. Mikolov, K. Chen, G. Corrado, and J. Dean, <https://arxiv.org/abs/1301.3781>).



The word2vec algorithm is an unsupervised learning algorithm based on neural networks that attempts to automatically learn the relationship between words. The idea behind word2vec is to put words that have similar meanings into similar clusters, and via clever vector spacing, the model can reproduce certain words using simple vector math, for example, $king - man + woman = queen$.

The original C-implementation with useful links to the relevant papers and alternative implementations can be found at <https://code.google.com/p/word2vec/>.

Topic modeling with latent Dirichlet allocation

Topic modeling describes the broad task of assigning topics to unlabeled text documents. For example, a typical application is the categorization of documents in a large text corpus of newspaper articles. In applications of topic modeling, we then aim to assign category labels to those articles, for example, sports, finance, world news, politics, and local news. Thus, in the context of the broad categories of machine learning that we discussed in *Chapter 1, Giving Computers the Ability to Learn from Data*, we can consider topic modeling as a clustering task, a subcategory of unsupervised learning.

In this section, we will discuss a popular technique for topic modeling called **latent Dirichlet allocation (LDA)**. However, note that while latent Dirichlet allocation is often abbreviated as LDA, it is not to be confused with *linear discriminant analysis*, a supervised dimensionality reduction technique that was introduced in *Chapter 5, Compressing Data via Dimensionality Reduction*.

Decomposing text documents with LDA

Since the mathematics behind LDA is quite involved and requires knowledge of Bayesian inference, we will approach this topic from a practitioner's perspective and interpret LDA using layman's terms. However, the interested reader can read more about LDA in the following research paper: *Latent Dirichlet Allocation*, by David M. Blei, Andrew Y. Ng, and Michael I. Jordan, *Journal of Machine Learning Research* 3, pages: 993-1022, Jan 2003, <https://www.jmlr.org/papers/volume3/blei03a/blei03a.pdf>.

LDA is a generative probabilistic model that tries to find groups of words that appear frequently together across different documents. These frequently appearing words represent our topics, assuming that each document is a mixture of different words. The input to an LDA is the bag-of-words model that we discussed earlier in this chapter.

Given a bag-of-words matrix as input, LDA decomposes it into two new matrices:

- A document-to-topic matrix
- A word-to-topic matrix

LDA decomposes the bag-of-words matrix in such a way that if we multiply those two matrices together, we will be able to reproduce the input, the bag-of-words matrix, with the lowest possible error. In practice, we are interested in those topics that LDA found in the bag-of-words matrix. The only downside may be that we must define the number of topics beforehand—the number of topics is a hyperparameter of LDA that has to be specified manually.

LDA with scikit-learn

In this subsection, we will use the `LatentDirichletAllocation` class implemented in scikit-learn to decompose the movie review dataset and categorize it into different topics. In the following example, we will restrict the analysis to 10 different topics, but readers are encouraged to experiment with the hyperparameters of the algorithm to further explore the topics that can be found in this dataset.

First, we are going to load the dataset into a pandas `DataFrame` using the local `movie_data.csv` file of the movie reviews that we created at the beginning of this chapter:

```
>>> import pandas as pd
>>> df = pd.read_csv('movie_data.csv', encoding='utf-8')
>>> # the following is necessary on some computers:
>>> df = df.rename(columns={"0": "review", "1": "sentiment"})
```

Next, we are going to use the already familiar `CountVectorizer` to create the bag-of-words matrix as input to the LDA.

For convenience, we will use scikit-learn's built-in English stop word library via `stop_words='english'`:

```
>>> from sklearn.feature_extraction.text import CountVectorizer
>>> count = CountVectorizer(stop_words='english',
...                         max_df=.1,
...                         max_features=5000)
>>> X = count.fit_transform(df['review'].values)
```

Notice that we set the maximum document frequency of words to be considered to 10 percent (`max_df=.1`) to exclude words that occur too frequently across documents. The rationale behind the removal of frequently occurring words is that these might be common words appearing across all documents that are, therefore, less likely to be associated with a specific topic category of a given document. Also, we limited the number of words to be considered to the most frequently occurring 5,000 words (`max_features=5000`), to limit the dimensionality of this dataset to improve the inference performed by LDA. However, both `max_df=.1` and `max_features=5000` are hyperparameter values chosen arbitrarily, and readers are encouraged to tune them while comparing the results.

The following code example demonstrates how to fit a `LatentDirichletAllocation` estimator to the bag-of-words matrix and infer the 10 different topics from the documents (note that the model fitting can take up to 5 minutes or more on a laptop or standard desktop computer):

```
>>> from sklearn.decomposition import LatentDirichletAllocation
>>> lda = LatentDirichletAllocation(n_components=10,
...                                 random_state=123,
...                                 learning_method='batch')
>>> X_topics = lda.fit_transform(X)
```

By setting `learning_method='batch'`, we let the `lda` estimator do its estimation based on all available training data (the bag-of-words matrix) in one iteration, which is slower than the alternative '`online`' learning method, but can lead to more accurate results (setting `learning_method='online'` is analogous to online or mini-batch learning, which we discussed in *Chapter 2, Training Simple Machine Learning Algorithms for Classification*, and previously in this chapter).

Expectation-maximization

The scikit-learn library's implementation of LDA uses the **expectation-maximization (EM)** algorithm to update its parameter estimates iteratively. We haven't discussed the EM algorithm in this chapter, but if you are curious to learn more, please see the excellent overview on Wikipedia (https://en.wikipedia.org/wiki/Expectation–maximization_algorithm) and the detailed tutorial on how it is used in LDA in Colorado Reed's tutorial, *Latent Dirichlet Allocation: Towards a Deeper Understanding*, which is freely available at http://obphio.us/pdfs/lda_tutorial.pdf.



After fitting the LDA, we now have access to the `components_` attribute of the `lda` instance, which stores a matrix containing the word importance (here, 5000) for each of the 10 topics in increasing order:

```
>>> lda.components_.shape
(10, 5000)
```

To analyze the results, let's print the five most important words for each of the 10 topics. Note that the word importance values are ranked in increasing order. Thus, to print the top five words, we need to sort the topic array in reverse order:

```
>>> n_top_words = 5
>>> feature_names = count.get_feature_names_out()
>>> for topic_idx, topic in enumerate(lda.components_):
...     print(f'Topic {topic_idx + 1}:')
...     print(' '.join([feature_names[i]
...                   for i in topic.argsort()\
...                   [-n_top_words - 1:-1]]))
Topic 1:
```

```
worst minutes awful script stupid
Topic 2:
family mother father children girl
Topic 3:
american war dvd music tv
Topic 4:
human audience cinema art sense
Topic 5:
police guy car dead murder
Topic 6:
horror house sex girl woman
Topic 7:
role performance comedy actor performances
Topic 8:
series episode war episodes tv
Topic 9:
book version original read novel
Topic 10:
action fight guy guys cool
```

Based on reading the five most important words for each topic, you may guess that the LDA identified the following topics:

1. Generally bad movies (not really a topic category)
2. Movies about families
3. War movies
4. Art movies
5. Crime movies
6. Horror movies
7. Comedy movie reviews
8. Movies somehow related to TV shows
9. Movies based on books
10. Action movies

To confirm that the categories make sense based on the reviews, let's plot three movies from the horror movie category (horror movies belong to category 6 at index position 5):

```
>>> horror = X_topics[:, 5].argsort()[:-1]
>>> for iter_idx, movie_idx in enumerate(horror[:3]):
...     print(f'\nHorror movie #{(iter_idx + 1)}:')
...     print(df['review'][movie_idx][:300], '...')

Horror movie #1:
House of Dracula works from the same basic premise as House of Frankenstein
from the year before; namely that Universal's three most famous monsters;
Dracula, Frankenstein's Monster and The Wolf Man are appearing in the movie
together. Naturally, the film is rather messy therefore, but the fact that ...
```

```
Horror movie #2:
```

```
Okay, what the hell kind of TRASH have I been watching now? "The Witches' Mountain" has got to be one of the most incoherent and insane Spanish exploitation flicks ever and yet, at the same time, it's also strangely compelling. There's absolutely nothing that makes sense here and I even doubt there ...
```

```
Horror movie #3:
```

```
<br /><br />Horror movie time, Japanese style. Uzumaki/Spiral was a total freakfest from start to finish. A fun freakfest at that, but at times it was a tad too reliant on kitsch rather than the horror. The story is difficult to summarize succinctly: a carefree, normal teenage girl starts coming fac ...
```

Using the preceding code example, we printed the first 300 characters from the top three horror movies. The reviews—even though we don't know which exact movie they belong to—sound like reviews of horror movies (however, one might argue that Horror movie #2 could also be a good fit for topic category 1: *Generally bad movies*).

Summary

In this chapter, you learned how to use machine learning algorithms to classify text documents based on their polarity, which is a basic task in sentiment analysis in the field of NLP. Not only did you learn how to encode a document as a feature vector using the bag-of-words model, but you also learned how to weight the term frequency by relevance using tf-idf.

Working with text data can be computationally quite expensive due to the large feature vectors that are created during this process; in the last section, we covered how to utilize out-of-core or incremental learning to train a machine learning algorithm without loading the whole dataset into a computer's memory.

Lastly, you were introduced to the concept of topic modeling using LDA to categorize the movie reviews into different categories in an unsupervised fashion.

So far, in this book, we have covered many machine learning concepts, best practices, and supervised models for classification. In the next chapter, we will look at another subcategory of supervised learning, *regression analysis*, which lets us predict outcome variables on a continuous scale, in contrast to the categorical class labels of the classification models that we have been working with so far.

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