Alma Mater Studiorum · Università di Bologna

SCUOLA DI SCIENZE
Corso di Laurea Magistrale in Informatica

# On Authorship Attribution

Relatore:
Chiar.mo Prof.
DANILO MONTESI

Correlatore:
Dott.
FLAVIO BERTINI

Presentata da:
Gabriele Calarota

Sessione III
Anno Accademico 2019-2020

*"When I was in college,*
*I wanted to be involved in things that would change the world"*
Elon Musk

# Sommario

# Abstract

# Contents

CHAPTER 5

# Our approach

In authorship attribution problems, there is a set of candidate authors and a set of text samples in the training set covering some of the works of the authors. In the test dataset, there are sample of texts and each of them needs to be attributed to a candidate author. In the next sections, we are going to describe the experiment we carried out taking care of the chronological path of the events. Our main focus has always been on closed set authorship attribution, training with instance-based approach (i.e. extracting features by not considering the other available text samples in the training). The three milestones can be summarized as follows:

1. Dataset selection and preparation
2. Method selection
3. Features extraction

## 5.1 Dataset preparation

In section 4.6 we have already shown the datasets we selected. In particular, in this section we are going to show the procedures done to prepare the datasets for the next steps. For the single topic authorship attribution task we decided to select the RCV1 dataset, the dataset of 45 Victorian era book authors from the GDELT project and the dataset of amazon food reviews collected in the first decade of the 2000s. Regarding the cross domain authorship attribution task, we selected the dataset extracted from The Guardian newspaper.

### 5.1.1 Reuters Corpus (RCV1)

It consists of a collection of newswire stories written in English that cover four main topics: corporate/industrial (CCAT), economics (ECAT), government/social (GCAT) and markets (MCAT). We sent a request to obtain the dataset on this webpage `https://trec.nist.gov/data/reuters/reuters.html`. After few days, we gathered the RCV1 Corpus as it contains 810,000 Reuters, English Language News stories (about 2.5 GB). First of all we had to convert the dataset, that contained folders of xml files, into a big csv with author's labels and document text. Code Listing 5.1 shows the process of documents and authors extraction, using 'xml' python library. We decided to take into account this properties of the document: *text, title, headline, byline, dateline, lang, corpus_path, corpus_subdirectory, corpus_filename.*

**Code Listing 5.1:** Extract and Parse RCV1 XML document into csv

```
import os
import xml.etree.ElementTree as ET

for f in files:
  try:
    data_path = os.sep.join([dir_path, f])
    raw_data = open(data_path).read()
    try:
      xml_parse = ET.fromstring(raw_data)
    except:
      print(D,"/",f,"failed to parse XML.")
      continue

    def get_text(tag):
      stuff = xml_parse.find(tag)
      if stuff:
        return stuff.text
      else:
        return None

  text = "\n\n".join([str(p.text) for p in xml_parse.findall(".//p")]
                                            )
  title = get_text("title")
  headline = get_text("headline")
  byline = get_text("byline")
  dateline = get_text("dateline")

  #this bit got funky in the XML parse
  lang_key = [k for k in xml_parse.attrib if "lang" in k][0]
  lang = xml_parse.attrib[lang_key]
```

```
    code_classes = [c.attrib["class"]
    for c in xml_parse.findall(".//codes")]
    codes = {cc: [c.attrib["code"] for c in
      xml_parse.findall(".//codes[@class='%s']/code"%cc)]
      for cc in code_classes}
    dcs = {d.attrib["element"]: d.attrib["value"]
      for d in xml_parse.findall(".//dc")}

    #assemble output
    output = {"text": text,
      "title": title,
      "headline": headline,
      "byline": byline,
      "dateline": dateline,
      "lang": lang,
      "corpus_path": corpus_path,
      "corpus_subdirectory": D,
      "corpus_filename": f,
    }

    # merge and flatten the other big hashmaps
    output.update(codes.items())
    output.update(dcs.items())

    result.append(output)
  except Exception as e:
    print(e)
```

The dataset was then filtered only with the documents with a *"byline"* property defined. We end up with 109'433 documents written by 2400 distinct authors. At this point, we labeled this portion of the RCV1 original dataset as the *"Full RCV1 dataset"*. In order to test and compare our approach, reproducing the testing scenario described in previous research [59], the 10 most prolific authors were chosen from the CCAT category, and then, 50 examples per author for training and 50 examples for testing were selected randomly with no overlapping between training and testing sets. We will reference to this portion of the RCV1 dataset as the *"RCV1_10"*. In previous works [22], the authors proposed another adaptation of the RCV1 corpus for the authorship attribution task. They choose the 50 most prolific authors from the Reuters Corpus, keeping 50 examples per author for training and 50 examples per author for testing with no overlapping between them. We will refer to this corpus as the *RCV1_50*.
The RCV1_10 and RCV1_50 datasets are both balanced over different authors and have their genre fixed to news. The majority of our work has been conducted on the RCV1_50,

although to compare results with previous works we will show also the same techniques applied to the RCV1_10 corpus. Table 5.1 shows the main metrics to describe these different portions of the original dataset.

**Table 5.1:** Main metrics to describe different portion of the dataset

| Name | N# documents | N# authors | Avg docs length | Avg n# docs/author |
|---|---|---|---|---|
| Full RCV1 dataset | 109433 | 2400 | 3061.95 | 45.60 |
| RCV1_10 | 1000 | 10 | 3093.82 | 100 |
| RCV1_50 | 5000 | 50 | 3251.16 | 100 |

### 5.1.2 GDELT

The GDELT Project is one of the largest publicly available digitalized book database which has more than 3.5 million books published from 1800-2015. To decrease the bias and create a reliable dataset the following criteria have been chosen to filter out authors: English language writing authors, authors that have enough books available (at least 5), 19th century authors. With these criteria 50 authors have been selected and their books were queried through Big Query Gdelt database. The next task has been cleaning the dataset due to OCR reading problems in the original raw form. To achieve that, firstly all books have been scanned through to get the overall number of unique words and each words frequencies. While scanning the texts, the first 500 words and the last 500 words have been removed to take out specific features such as the name of the author, the name of the book and other word specific features that could make the classification task easier. After this step, we have chosen top 10, 000 words that occurred in the whole 50 authors text data corpus. The words that are not in top 10, 000 words were removed while keeping the rest of the sentence structure intact. Afterwards, the words are represented with numbers from 1 to 10, 000 reverse ordered according to their frequencies. The entire book is split into text fragments with 1000 words each. We separately maintained author and book identification number for each one of them in different arrays. Text segments with less than 1000 words were filled with zeros to keep them in the dataset as well. 1000 words make approximately 2 pages of writing, which is long enough to extract a variety of features from the document. The reason why we have represented top 10, 000 words with numbers is to keep the anonymity of texts and allow researchers to run feature extraction techniques faster. Dealing with large amounts of text data can be more challenging than numerical data for some feature extraction techniques. When gathering the dataset, we decided to discard 5 authors for which their writings were not consistent enough for the authorship attribution task. We ended up with a full dataset with 53'678 documents instances, each one containing 1000 words. In order to make training methods reliable across dataset, we decided to select 100 documents of each authors, with a 50/50 split (i.e. 50 documents in the training set, 50 documents in the testing set, no overlapping among them). In the following sections, we will refer to this as the *"GDELT_45"*. Table 5.2 shows the metrics that describe best this dataset.

**Table 5.2:** Main metrics to describe different portion of the GDELT dataset

| Name | N# documents | N# authors | Avg docs length | Avg n# docs/author |
|---|---|---|---|---|
| Full GDELT dataset | 53678 | 45 | 4950.61 | 1192.84 |
| GDELT_45 | 4500 | 45 | 4911.91 | 100 |

### 5.1.3 Amazon Food Reviews (AFR)

This dataset consists of reviews of fine foods from amazon. The data span a period of more than 10 years, including all 500,000 reviews up to October 2012. Reviews include product and user information, ratings, and a plain text review. It also includes reviews from all other Amazon categories. We decided to consider this dataset for our experiment, because we were missing a more "everyday" example of dataset to work with. As Table 5.3 shows, the average documents length is dramatically lower than the other two datasets presented previously, providing us with a good challenge to show consistency of our method across all these different scenarios. Moreover, in order to make training methods reliable across dataset, we decided to select 100 reviews of each customers, with a 50/50 split (i.e. 50 reviews in the training set, 50 reviews in the testing set, no overlapping among them). In the following sections, we will refer to this as the *"AFR_50"*.

**Table 5.3:** Main metrics to describe different portion of the AFR dataset

| Name | N# documents | N# authors | Avg docs length | Avg n# docs/author |
|---|---|---|---|---|
| Full AFR dataset | 568454 | 256059 | 380.70 | 2.2 |
| AFR_50 | 5000 | 50 | 990.45 | 100 |

### 5.1.4 The Guardian newspaper

Although the majority of our time and effort was focused on the first 3 single domain datasets for closed set authorship attribution task, we wanted to test our approach with a cross domain dataset. *The Guardian corpus* is composed of texts published in The Guardian daily newspaper. The majority of the corpus comprises opinion articles (comments). The newspaper describes the opinion articles using a set of tags indicating its subject. There are eight top-level tags (World, U.S., U.K., Belief, Culture, Life&Style,

Politics, Society), each one of them having multiple subtags. In order to test and compare our approach, we reproduce the testing scenario described in the previous research [60] using the Guardian corpus. The experimental scenario is as follows:

1. Select at most ten samples per author in each topic category (in Figure 5.1 we can see the distribution of the samples per author for the Politics category after considering the restriction of ten samples per author)

2. Use the samples in the Politics category as training set and train the classifier

3. Finally, test the classifier using another topic category different from Politics (four possible pairings)

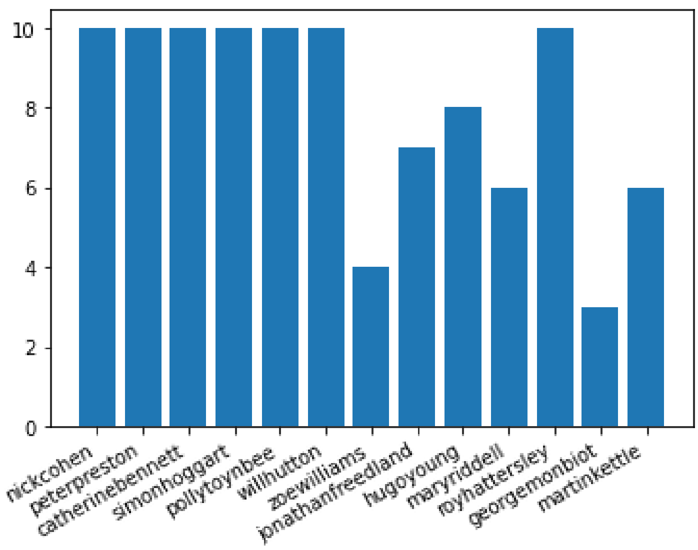


**Figure 5.1:** The Guardian samples distribution for the Politics topic

## 5.2 Method selection

At this point, we had to face the problem of deciding the classifier method that would solve best our authorship attribution task. Although in previous studies over the past decades on authorship attribution SVM has been shown to be very convincing ([10], [30], [71]), we initially wanted to construct an experimental approach that would lead us to exclude the other classifiers for our task.

### 5.2.1 Naive Approach

Our very first naive approach was to compare on different portions of the dataset (increasing number of authors) different classification methods to see which one performed best. Initially, we considered the authorship attribution study for groups of authors consisting of 6 or 10 authors. In truth, as many previous studies show, an authorship attribution model must perform well especially in situations where the group of authors is composed of several dozen candidates. The classifiers initially chosen were:

- Naive Bayes
- Multinomial Naive Bayes
- Logistic Regression
- XGBoost
- XGBoost with Neural Networks
- Random Forest

For text representation, we chose to use TFIDF and Bag Of Words, comparing the results depending on the dataset, the number of authors, and the method used. In Figure 5.2 we can see the accuracy score of the testing set of the various classifiers tested on the groups of authors increasing from right to left on the RCV1 dataset. As on the groups of "small" authors, i.e. composed of 6 authors and 10 authors, almost all the classifiers exceed the threshold of 95% accuracy that validates the approach even in non-research contexts. The classifier that seems to perform best among the various groups of authors increasing in number is RandomForest. On the other hand, it has been shown that decision tree type classifiers struggle to maintain high performance when the number of features used increases.

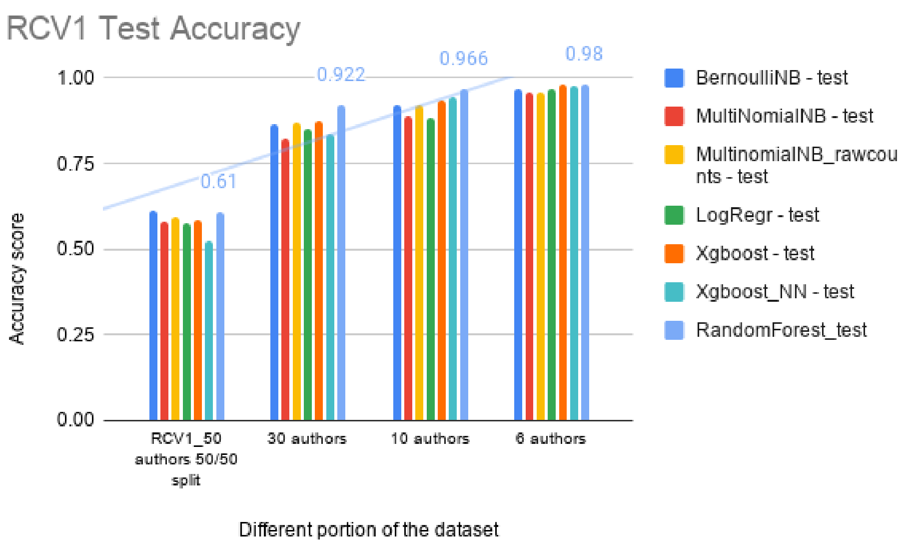


**Figure 5.2:** Accuracy scores for different groups of authors on RCV1 dataset

In fact in Figure 5.3 and 5.4 we can see that in all 3 single topic datasets the various methods proposed have a decrease in performance when the number of authors increases reaching 50 authors (or 45 in the case of the GDELT dataset). This is probably due to the fact that by keeping the number of documents per author fixed at 50 in the training test (and in the testing set), the number of features to represent grows proportionately as the number of authors increases. Therefore, we need to select a classification method that remains stable as the number of features we want to represent increases, and therefore remains valid for 6, 10, 30, 50 authors (and more).

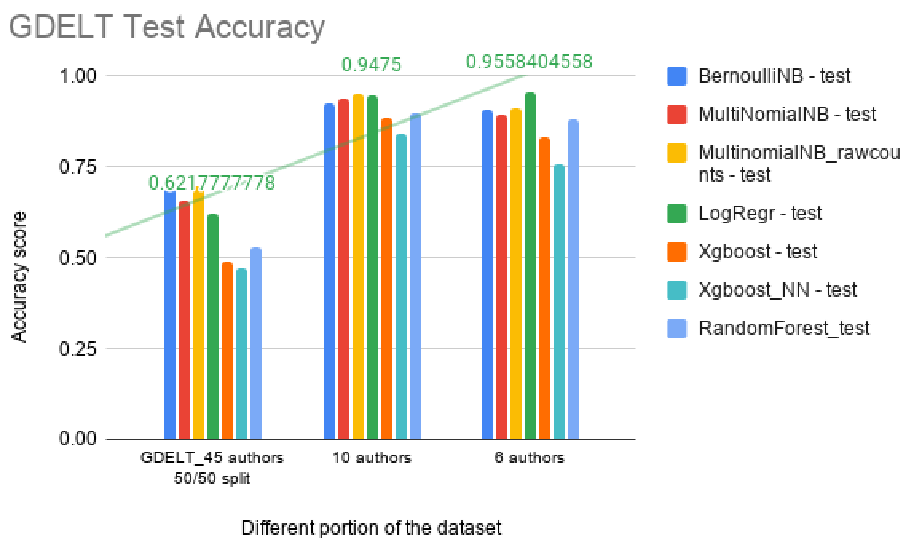


**Figure 5.3:** Accuracy scores for different groups of authors on GDELT dataset

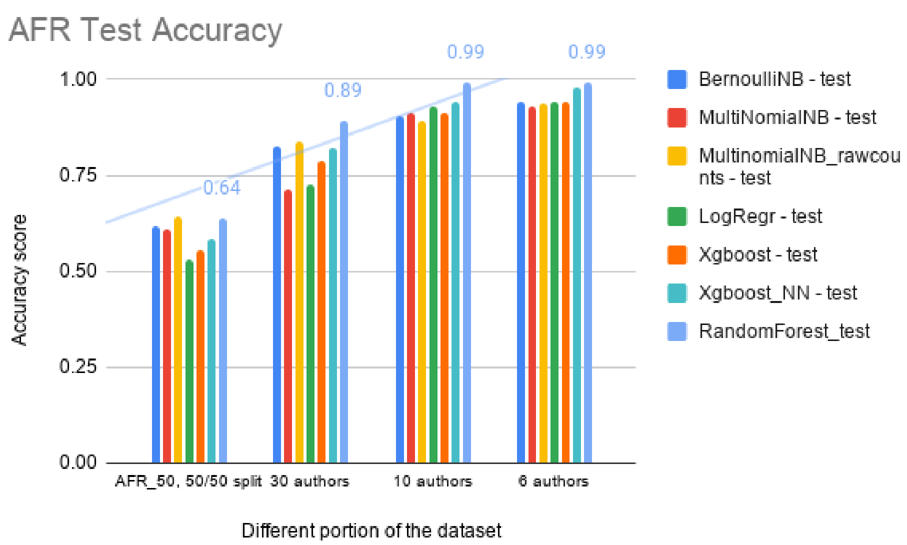


**Figure 5.4:** Accuracy scores for different groups of authors on AFR dataset

### 5.2.2 TPOT: automated method selection

Therefore, considering the more or less unsuccessful approaches of the methods presented in the previous section, we tried to find an approach that would validate our choice and those of previous works on the use of the Support Vector Machine as a classification method. Our choice fell on TPOT[1], an automated machine learning (autoML) tool in Python. In order to give the reader of what TPOT is and how it works, I'll report the first paragraph quoting the TPOT website:

> TPOT is meant to be an assistant that gives you ideas on how to solve a particular machine learning problem by exploring pipeline configurations that you might have never considered, then leaves the fine-tuning to more constrained parameter tuning techniques such as grid search.

So TPOT helps you find good algorithms. TPOT is built on the scikit learn library and follows the scikit learn API closely. It can be used for regression and classification tasks and has special implementations for medical research. TPOT is open source, well documented, and under active development. It's development was spearheaded by researchers at the University of Pennsylvania. TPOT appears to be one of the most popular autoML libraries, with more than 7,800 GitHub stars as of the moment of writing. TPOT has what its developers call a genetic search algorithm to find the best parameters and model ensembles. It could also be thought of as a natural selection or evolutionary algorithm. TPOT tries a pipeline, evaluates its performance, and randomly changes parts of the pipeline in search of better performing algorithms (An example is shown in Figure 5.5). This power of TPOT comes from evaluating all kinds of possible pipelines automatically and efficiently. Doing this manually is cumbersome and slower.

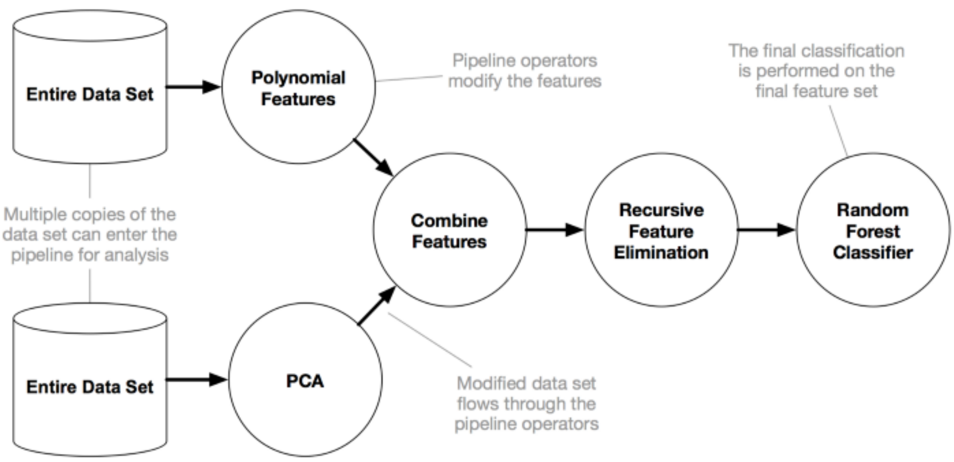


**Figure 5.5:** An example TPOT Pipeline from TPOT docs

[1] `http://epistasislab.github.io/tpot/`

In Code Listing 5.2 we show a snippet of code we used for extracting TPOT pipeline with hyper parameters and research space.

**Code Listing 5.2:** TPOT pipeline generation

```
!pip install -q tpot
from tpot import TPOTClassifier, TPOTRegressor
pipeline_optimizer = TPOTClassifier(generations=5, population_size=20
                              , cv=5,
random_state=42, verbosity=2, scoring='accuracy', config_dict='TPOT
                              sparse')
pipeline_optimizer.fit(tfidf_train, df_train['target'])
print(pipeline_optimizer.score(tfidf_test, df_test['target']))
pipeline_optimizer.export('tpot_exported_pipeline.py')
```

We chose the most appropriate hyperparameters and ran TPOT optimization pipelines on all 3 datasets with 50 authors [2]. The result is shown in Code Listing 5.3 for all 3 single domain selected datasets, thus proving that SVM is the best choice as a model classifier for this task.

**Code Listing 5.3:** TPOT pipeline extracted

```
import numpy as np
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.svm import LinearSVC

# NOTE: Make sure that the outcome column is labeled 'target' in the
                              data file
tpot_data = pd.read_csv('PATH/TO/DATA/FILE', sep='COLUMN_SEPARATOR',
                              dtype=np.float64)
features = tpot_data.drop('target', axis=1)
training_features, testing_features, training_target, testing_target
                              = \
train_test_split(features, tpot_data['target'], random_state=42)

# Average CV score on the training set was: 0.6912
exported_pipeline = LinearSVC(C=0.5, dual=True, loss="squared_hinge",
                               penalty="l2", tol=1e-05)
# Fix random state in exported estimator
if hasattr(exported_pipeline, 'random_state'):
setattr(exported_pipeline, 'random_state', 42)

exported_pipeline.fit(training_features, training_target)
results = exported_pipeline.predict(testing_features)
```

[2] 45 in the case of GDELT

## 5.3 Features extraction

After the choice of dataset and classification method, all our energies were spent on the choice of feature extraction. In order to identify the authorship of an unknown text document using machine learning the document needs to be quantified first. The simple and natural way to characterize a document is to consider it as a sequence of tokens grouped into sentences where each token can be one of the three: word, number, punctuation mark. As with the choice of classification method, we initially attempted a naive approach. In fact, many studies have focused on using methods such as TFIDF and Bag Of Words. In fact, our experiment is mainly aimed at showing that simple numerical text representation methods such as TFIDF or BOW, applied with the right hyperparameters, can somehow yield good performance in the same way as other more complex methods such as Doc2Vec or n-grams character selection.

### 5.3.1 TFIDF & BOW

Once taken the route of the simple feature extraction approach via TFIDF and BOW, we had to choose the hyperparameters that would play a main role in the model performances for this task. We initially chose a classical approach to the problem, extracting features with both TFIDFVectorizer and CountVectorizer, with standard hyperparameters.

In Code Listing 5.4 we can see the initialization of the vectorizers with the chosen hyperparameters after a long process of tuning and validation.

**Code Listing 5.4:** TFIDF & BOW Vectorizer

```
tfidf_vec = TfidfVectorizer(max_df=0.75, max_features=None,
min_df=0.02, use_idf=False, tokenizer=custom_tokenizer,
ngram_range=(1, 4))
counter_vect = CountVectorizer(max_df=0.8, max_features=10000,
min_df=0.02, tokenizer=custom_tokenizer, ngram_range=(1, 2))
```

After that, we shifted our focus to the tokenizer that instead of choosing to use the standard one, we preferred to use a ”custom” one. We initially used a robust tokenizer for text categorization tasks, but we realized that for this kind of authorship attribution problem, some approaches valid for many text categorization problems would not work. In fact, in Code Listing 5.5 shows the choice of the three tokenizers we tried experimentally and which sequentially showed better and better results. The first one we tried was a custom tokenizer with classical approaches to text categorization. In fact, we used a ”snowball” type stemmer for the English language and applied it to all the filtered words. We also converted all words to lowercase and removed the words from the English stopwords group. This type of tokenizer proved to be the weakest of the three because it removes too many features that best distinguish and characterize a text with respect to the author of the document itself.

**Code Listing 5.5:** Custom tokenizer for TFIDF and BOW

```
def tokenize_and_stem(text):
    """
    Below function tokenizes and lemmatizes the texts. It also does
                                     some cleaning by removing non
                                     dictionary words
    This can be used to replace default tokenizer provided by feature
                                     extraction api of sklearn.
    :param text: str
    :return: list
    """
    stemmer = SnowballStemmer("english")
    stop_words = stopwords.words("english")
    tokens = [word.lower() for sent in nltk.sent_tokenize(text) for
                                     word in nltk.word_tokenize(sent)]
    filtered_tokens = []
    for token in tokens:
      if re.search(r'[a-zA-Z-]{4,}', token) and token not in stop_words
                                      and len(wn.synsets(token)) > 0:
        token.strip()
        filtered_tokens.append(token)
    filtered_tokens = [stemmer.stem(token) for token in filtered_tokens
                                     ]
return filtered_tokens

def simple_tokenizer(text):
    text = re.sub('"([^"]*)"', '', text)
    tokens = [word.lower() for sent in nltk.sent_tokenize(text) for
                                     word in nltk.word_tokenize(sent)]
    filtered_tokens = []
    for token in tokens:
      if len(wn.synsets(token)) > 0:
        token.strip()
        filtered_tokens.append(token)
    return filtered_tokens

def only_remove_quoting_tokenizer(text):
    text = re.sub('"([^"]*)"', '', text)
    tokens = [word.lower() for sent in nltk.sent_tokenize(text) for
                                     word in nltk.word_tokenize(sent)]
    return tokens
```

In fact, the approach of purposely modifying words and removing stopwords, in the literature on authorship attribution has proven to be a wrong one. The most frequent words defined as "non-content" categorize worse a text in the sense of content and introduce noise, but better classify a text in respect of the author who wrote it, especially in cross domain contexts in which are precisely the content words that go to introduce noise. After evaluating our results with the available datasets, we agreed to change our approach regarding the tokenizer. We tried to build a simpler tokenizer called *"simple_tokenizer"* that would remove only the words between double-quotes because they were considered as phrases or quotation words and therefore would not classify well the text in respect of the author who reported them, after which we only removed those words that, after transforming them into lowercase, were not found as synonyms of an English dictionary (and therefore words that do not conform to the dictionary). This second approach showed better results than the first, but once again we wondered if the approach of removing words that did not conform to the dictionary was a correct approach for author attribution analysis. With these premises in fact, in the third and last approach we thought to remove only the words or phrases contained in quotation marks, without removing the words therefore wrong or not present in the official dictionary of the English language. This last approach, called *"only_remove_quoting_tokenizer"* proved to be the best of the three, thus underlining the importance of stopwords and common mistakes or words commonly used by the author and not present in the official English dictionary, in the face of this specific task of authorship attribution. Just for the purpose of making the reader aware, as a tokenizer we tried two additional approaches but they did not show the desired results. Along the lines of thinking that the content words of a text are the ones that litter the numerical representation of a text the most in an authorship attribution context, one of the approaches attempted was text distortion. In fact as also shown in some previous articles [61], using text distortion for autorship attribution tasks, especially in cross domain contexts could be very effective. The concept behind text distortion is to obfuscate and hide words in a document based on their frequency, so as not to create noise during feature extraction and focus only on the most relevant words. In the case of authorship attribution, the opposite is applied, i.e. less frequent words in a text are obfuscated (i.e. replaced by symbols like $*$ and #) and the same applies to numbers. This approach can be divided into two: an approach that is length-preserving and an approach that particularly shortens the length of the text in order to make feature extraction even easier. In the first case we replace all letters of the selected target word with $*$ or # symbols for numbers, in the second case we replace the selected word with only one $*$ or # symbol for numbers, shortening the resulting text. We applied both of these two approaches as tokenizers of TFIDF and BOW, but the results obtained did not even pass the threshold of mention as they were considered completely unsuccessful.

### 5.3.2 GridSearchCV

In almost any Machine Learning project, we train different models on the dataset and selecting the one with the best performance. However, there is almost a room for improvement as we cannot say for sure that this particular model is best for the problem at hand, hence our aim is to improve the model in any way possible. One important factor in the performances of these models are their hyperparameters, once we set appropriate values for these hyperparameters, the performance of a model can improve significantly. At the state of the art, we can say that one of the well-established approaches is to optimize the values of the hyperparameters of a model using GridSearchCV. Note that there is no way to know in advance the best values for hyperparameters so ideally, we need to try all possible values to know the optimal values. Doing this manually could take a considerable amount of time and resources and thus we use GridSearchCV to automate the tuning of hyperparameters. GridSearchCV is a function that comes in Scikit-learn's(or SK-learn) model_selection package. This function helps to loop through predefined hyperparameters and fit your estimator (model) on your training set. So, in the end, we can select the best parameters from the listed hyperparameters. As mentioned above, we pass predefined values for hyperparameters to the GridSearchCV function. We do this by defining a dictionary in which we mention a particular hyperparameter along with the values it can take.

**Code Listing 5.6:** GridSearchCV with BOW, TFIDF and SGD

```
pipeline = Pipeline([
('vect', CountVectorizer()),
('tfidf', TfidfTransformer()),
('clf', SGDClassifier()),
])

# uncommenting more parameters will give better exploring power but
                                            will
# increase processing time in a combinatorial way
parameters = {
  'vect__max_df': (0.5, 0.75, 1.0),
  'vect__max_features': (None, 5000, 10000, 50000),
  'vect__ngram_range': ((1, 1), (1, 2)),  # unigrams or bigrams
  'tfidf__use_idf': (True, False),
  'tfidf__norm': ('l1', 'l2'),
  'clf__max_iter': (20,),
  'clf__alpha': (0.00001, 0.000001),
  'clf__penalty': ('l2', 'elasticnet'),
  'clf__max_iter': (10, 50, 80,),
}
```

```
# find the best parameters for both the feature extraction and the
# classifier
grid_search = GridSearchCV(pipeline, parameters, n_jobs=-1, verbose=1
                                  )

print("Performing grid search...")
print("pipeline:", [name for name, _ in pipeline.steps])
print("parameters:")
print(parameters)
t0 = time.time()
grid_search.fit(dataset['articles'], dataset['author'])
print("done in %0.3fs" % (time.time() - t0))
print()

print("Best score: %0.3f" % grid_search.best_score_)
print("Best parameters set:")
best_parameters = grid_search.best_estimator_.get_params()
for param_name in sorted(parameters.keys()):
print("\t%s: %r" % (param_name, best_parameters[param_name]))
```

In Code Listing 5.6 we can see an example of GridSearchCV applied to the datasets with a simple pipeline with: CountVectorizer, TfidfTransformer and SGDClassifier. The pool of parameters we choose were based on previous research on same datasets. GridSearchCV tries all the combinations of the values passed in the dictionary and evaluates the model for each combination using the Cross-Validation method. Hence after using this function we get accuracy/loss for every combination of hyperparameters and we can choose the one with the best performance. The result of this first attempt at GridSearchCV was shown in Code Listing 5.4, the picture of the final hyperparameter tuning we mentioned earlier in the section.

### 5.3.3 Doc2Vec

# Bibliography


[1] Ahmed Abbasi and Hsinchun Chen. Applying authorship analysis to extremist-group web forum messages. *IEEE Intelligent Systems*, 20(5):67–75, 2005.

[2] Shlomo Argamon and Shlomo Levitan. Measuring the usefulness of function words for authorship attribution. In *Proceedings of the 2005 ACH/ALLC Conference*, pages 4–7, 2005.

[3] Harald Baayen, Hans van Halteren, Anneke Neijt, and Fiona Tweedie. An experiment in authorship attribution. In *6th JADT*, volume 1, pages 69–75. Citeseer, 2002.

[4] Sarkhan Badirli, Mary Borgo Ton, Abdulmecit Gungor, and Murat Dundar. Open set authorship attribution toward demystifying victorian periodicals. *arXiv preprint arXiv:1912.08259*, 2019.

[5] John Burrows. 'delta': a measure of stylistic difference and a guide to likely authorship. *Literary and linguistic computing*, 17(3):267–287, 2002.

[6] JK Chambers, P Trudgill, and Natalie Schilling-Estes. The handbook of language variation and change (2nd). *Victoria: Blackwell Publishing*, 2004.

[7] Carole E Chaski. Who's at the keyboard? authorship attribution in digital evidence investigations. *International journal of digital evidence*, 4(1):1–13, 2005.

[8] Na Cheng, Rajarathnam Chandramouli, and KP Subbalakshmi. Author gender identification from text. *Digital Investigation*, 8(1):78–88, 2011.

[9] Cindy Chung and James W Pennebaker. The psychological functions of function words. *Social communication*, 1:343–359, 2007.

[10] Joachim Diederich, Jörg Kindermann, Edda Leopold, and Gerhard Paass. Authorship attribution with support vector machines. *Applied intelligence*, 19(1):109–123, 2003.

[11] Harris Drucker, Donghui Wu, and Vladimir N Vapnik. Support vector machines for spam categorization. *IEEE Transactions on Neural networks*, 10(5):1048–1054, 1999.

[12] Susan Dumais, John Platt, David Heckerman, and Mehran Sahami. Inductive learning algorithms and representations for text categorization. In *Proceedings of the seventh international conference on Information and knowledge management*, pages 148–155, 1998.

[13] Neal Fox, Omran Ehmoda, and Eugene Charniak. Statistical stylometrics and the marlowe-shakespeare authorship debate. *Proceedings of the Georgetown University Roundtable on Language and Linguistics (GURT), Washington, DC, USA*, 2012.

[14] Georgia Frantzeskou, Efstathios Stamatatos, Stefanos Gritzalis, and Sokratis Katsikas. Effective identification of source code authors using byte-level information. In *Proceedings of the 28th international conference on Software engineering*, pages 893–896, 2006.

[15] Helena Gómez-Adorno, Juan-Pablo Posadas-Durán, Grigori Sidorov, and David Pinto. Document embeddings learned on various types of n-grams for cross-topic authorship attribution. *Computing*, 100(7):741–756, 2018.

[16] Jack Grieve. Quantitative authorship attribution: An evaluation of techniques. *Literary and linguistic computing*, 22(3):251–270, 2007.

[17] Abdulmecit Gungor. *Benchmarking authorship attribution techniques using over a thousand books by fifty Victorian era novelists.* PhD thesis, 2018.

[18] H van Halteren. Linguistic profiling for authorship recognition and verification. 2004.

[19] Graeme Hirst and Ol'ga Feiguina. Bigrams of syntactic labels for authorship discrimination of short texts. *Literary and Linguistic Computing*, 22(4):405–417, 2007.

[20] David I Holmes. The evolution of stylometry in humanities scholarship. *Literary and linguistic computing*, 13(3):111–117, 1998.

[21] David I Holmes and Fiona J Tweedie. Forensic stylometry: A review of the cusum controversy. *Revue Informatique et Statistique dans les Sciences Humaines*, 31(1): 19–47, 1995.

[22] John Houvardas and Efstathios Stamatatos. N-gram feature selection for authorship identification. In *International conference on artificial intelligence: Methodology, systems, and applications*, pages 77–86. Springer, 2006.

[23] Thorsten Joachims. Making large-scale svm learning practical. Technical report, Technical report, 1998.

[24] Thorsten Joachims et al. Transductive inference for text classification using support vector machines. In *Icml*, volume 99, pages 200–209, 1999.

[25] Patrick Juola. *Authorship attribution*, volume 3. Now Publishers Inc, 2008.

[26] Brett Kessler, Geoffrey Nunberg, and Hinrich Schütze. Automatic detection of text genre. *arXiv preprint cmp-lg/9707002*, 1997.

[27] Mike Kestemont, Efstathios Stamatatos, Enrique Manjavacas, Walter Daelemans, Martin Potthast, and Benno Stein. Overview of the cross-domain authorship attribution task at pan 2019. In *CLEF (Working Notes)*, 2019.

[28] Dmitry V Khmelev and William J Teahan. A repetition based measure for verification of text collections and for text categorization. In *Proceedings of the 26th annual international ACM SIGIR conference on Research and development in informaion retrieval*, pages 104–110, 2003.

[29] Moshe Koppel and Jonathan Schler. Exploiting stylistic idiosyncrasies for authorship attribution. In *Proceedings of IJCAI'03 Workshop on Computational Approaches to Style Analysis and Synthesis*, volume 69, pages 72–80, 2003.

[30] Moshe Koppel, Jonathan Schler, and Kfir Zigdon. Determining an author's native language by mining a text for errors. In *Proceedings of the eleventh ACM SIGKDD international conference on Knowledge discovery in data mining*, pages 624–628, 2005.

[31] Moshe Koppel, Jonathan Schler, Shlomo Argamon, and Eran Messeri. Authorship attribution with thousands of candidate authors. In *Proceedings of the 29th annual international ACM SIGIR conference on Research and development in information retrieval*, pages 659–660, 2006.

[32] Moshe Koppel, Jonathan Schler, and Shlomo Argamon. Computational methods in authorship attribution. *Journal of the American Society for information Science and Technology*, 60(1):9–26, 2009.

[33] Moshe Koppel, Jonathan Schler, and Shlomo Argamon. Authorship attribution in the wild. *Language Resources and Evaluation*, 45(1):83–94, 2011.

[34] Moshe Koppel, Jonathan Schler, Shlomo Argamon, and Yaron Winter. The "fundamental problem" of authorship attribution. *English Studies*, 93(3):284–291, 2012.

[35] Robert Layton, Paul Watters, and Richard Dazeley. Authorship attribution for twitter in 140 characters or less. In *2010 Second Cybercrime and Trustworthy Computing Workshop*, pages 1–8. IEEE, 2010.

[36] Quoc Le and Tomas Mikolov. Distributed representations of sentences and documents. In *International conference on machine learning*, pages 1188–1196. PMLR, 2014.

[37] David D Lewis and Marc Ringuette. A comparison of two learning algorithms for text categorization. In *Third annual symposium on document analysis and information retrieval*, volume 33, pages 81–93, 1994.

[38] David Madigan, Alexander Genkin, David D Lewis, Shlomo Argamon, Dmitriy Fradkin, and Li Ye. Author identification on the large scale. In *Proceedings of the 2005 Meeting of the Classification Society of North America (CSNA)*, 2005.

[39] Ilia Markov, Efstathios Stamatatos, and Grigori Sidorov. Improving cross-topic authorship attribution: The role of pre-processing. In *International Conference on Computational Linguistics and Intelligent Text Processing*, pages 289–302. Springer, 2017.

[40] Yuval Marton, Ning Wu, and Lisa Hellerstein. On compression-based text classification. In *European Conference on Information Retrieval*, pages 300–314. Springer, 2005.

[41] S Michaelson and A Morton. The qsum plot. Technical report, Internal Report CSR-3, 1990.

[42] Tomáš Mikolov, Martin Karafiát, Lukáš Burget, Jan Černockỳ, and Sanjeev Khudanpur. Recurrent neural network based language model. In *Eleventh annual conference of the international speech communication association*, 2010.

[43] Tomas Mikolov, Kai Chen, Greg Corrado, and Jeffrey Dean. Efficient estimation of word representations in vector space. *arXiv preprint arXiv:1301.3781*, 2013.

[44] Tomáš Mikolov, Wen-tau Yih, and Geoffrey Zweig. Linguistic regularities in continuous space word representations. In *Proceedings of the 2013 conference of the north american chapter of the association for computational linguistics: Human language technologies*, pages 746–751, 2013.

[45] Leonid A Mironovsky, Alexander V Nikitin, Nina N Reshetnikova, and Nikolay V Soloviev. Graphological analysis and identification of handwritten texts. In *Computer Vision in Control Systems-4*, pages 11–40. Springer, 2018.

[46] Tom M Mitchell. Artificial neural networks. *Machine learning*, 45:81–127, 1997.

[47] Frederick Mosteller and David L Wallace. *Inference and disputed authorship: The Federalist*. Stanford Univ Center for the Study, 2007.

[48] Rebekah Overdorf and Rachel Greenstadt. Blogs, twitter feeds, and reddit comments: Cross-domain authorship attribution. *Proceedings on Privacy Enhancing Technologies*, 2016(3):155–171, 2016.

[49] Spyridon Plakias and Efstathios Stamatatos. Tensor space models for authorship identification. In *Hellenic Conference on Artificial Intelligence*, pages 239–249. Springer, 2008.

[50] Juan-Pablo Posadas-Durán, Helena Gómez-Adorno, Grigori Sidorov, Ildar Batyrshin, David Pinto, and Liliana Chanona-Hernández. Application of the distributed document representation in the authorship attribution task for small corpora. *Soft Computing*, 21(3):627–639, 2017.

[51] Martin Potthast, Sarah Braun, Tolga Buz, Fabian Duffhauss, Florian Friedrich, Jörg Marvin Gülzow, Jakob Köhler, Winfried Lötzsch, Fabian Müller, Maike Elisa Müller, et al. Who wrote the web? revisiting influential author identification research applicable to information retrieval. In *European Conference on Information Retrieval*, pages 393–407. Springer, 2016.

[52] Joseph Rudman. The state of authorship attribution studies: Some problems and solutions. *Computers and the Humanities*, 31(4):351–365, 1997.

[53] Conrad Sanderson and Simon Guenter. Short text authorship attribution via sequence kernels, markov chains and author unmasking: An investigation. In *Proceedings of the 2006 conference on empirical methods in natural language processing*, pages 482–491, 2006.

[54] Upendra Sapkota, Thamar Solorio, Manuel Montes, Steven Bethard, and Paolo Rosso. Cross-topic authorship attribution: Will out-of-topic data help? In *Proceedings of COLING 2014, the 25th International Conference on Computational Linguistics: Technical Papers*, pages 1228–1237, 2014.

[55] Upendra Sapkota, Steven Bethard, Manuel Montes, and Thamar Solorio. Not all character n-grams are created equal: A study in authorship attribution. In *Proceedings of the 2015 conference of the North American chapter of the association for computational linguistics: Human language technologies*, pages 93–102, 2015.

[56] Roy Schwartz, Oren Tsur, Ari Rappoport, and Moshe Koppel. Authorship attribution of micro-messages. In *Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing*, pages 1880–1891, 2013.

[57] Fabrizio Sebastiani. Machine learning in automated text categorization. *ACM computing surveys (CSUR)*, 34(1):1–47, 2002.

[58] Efstathios Stamatatos. Author identification: Using text sampling to handle the class imbalance problem. *Information Processing & Management*, 44(2):790–799, 2008.

[59] Efstathios Stamatatos. A survey of modern authorship attribution methods. *Journal of the American Society for information Science and Technology*, 60(3):538–556, 2009.

[60] Efstathios Stamatatos. On the robustness of authorship attribution based on character n-gram features. *Journal of Law and Policy*, 21(2):421–439, 2013.

[61] Efstathios Stamatatos. Authorship attribution using text distortion. In *Proceedings of the 15th Conference of the European Chapter of the Association for Computational Linguistics: Volume 1, Long Papers*, pages 1138–1149, 2017.

[62] Sean Stanko, Devin Lu, and Irving Hsu. Whose book is it anyway? using machine learning to identify the author of unknown texts. *Machine Learning Final Projects*, 2013.

[63] Andrew Tausz. Predicting the date of authorship of historical texts. *CS224N project*, 2011.

[64] Antônio Theóphilo, Luís AM Pereira, and Anderson Rocha. A needle in a haystack? harnessing onomatopoeia and user-specific stylometrics for authorship attribution of micro-messages. In *ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 2692–2696. IEEE, 2019.

[65] Chris van der Lee and Antal van den Bosch. Exploring lexical and syntactic features for language variety identification. In *Proceedings of the Fourth Workshop on NLP for Similar Languages, Varieties and Dialects (VarDial)*, pages 190–199, 2017.

[66] Vladimir N Vapnik. An overview of statistical learning theory. *IEEE transactions on neural networks*, 10(5):988–999, 1999.

[67] Carrington B Williams. Mendenhall's studies of word-length distribution in the works of shakespeare and bacon. *Biometrika*, 62(1):207–212, 1975.

[68] Lili Yang, Chunping Li, Qiang Ding, and Li Li. Combining lexical and semantic features for short text classification. *Procedia Computer Science*, 22:78–86, 2013.

[69] G Udny Yule. A test of tippett's random sampling numbers. *Journal of the Royal Statistical Society*, 101(1):167–172, 1938.

[70] Ying Zhao and Justin Zobel. Effective and scalable authorship attribution using function words. In *Asia Information Retrieval Symposium*, pages 174–189. Springer, 2005.

[71] Rong Zheng, Jiexun Li, Hsinchun Chen, and Zan Huang. A framework for authorship identification of online messages: Writing-style features and classification techniques. *Journal of the American society for information science and technology*, 57(3): 378–393, 2006.

[72] George Kingsley Zipf. Selected studies of the principle of relative frequency in language. 1932.

[73] Sven Meyer Zu Eissen, Benno Stein, and Marion Kulig. Plagiarism detection without reference collections. In *Advances in data analysis*, pages 359–366. Springer, 2007.