Advanced Text Document Classification Techniques: Enhancing Accuracy and Efficiency in Real-World Applications

Bachelorarbeit

zur Erlangung des akademischen Grades

Bachelor of Science in Engineering (B.Sc.)

Eingereicht bei:

Fachhochschule Kufstein Tirol Bildungs GmbH

Web Business & Technology

Verfasser/in:

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Gutachter : Prof. (FH) Dr. Michael Kohlegger

Abgabedatum:

19. May 2024

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Ich erkläre hiermit, dass ich die vorliegende Bachelorarbeit selbständig und ohne fremde Hilfe verfasst und in der Bearbeitung und Abfassung keine anderen als die angegebenen Quellen oder Hilfsmittel benutzt sowie wörtliche und sinngemäße Zitate als solche gekennzeichnet habe. Die vorliegende Bachelorarbeit wurde noch nicht anderweitig für Prüfungszwecke vorgelegt.

Kufstein, 19. May 2024

Jesse Lang

Sperrvermerk

Ich habe die Sperrung meiner Bachelorarbeit beantragt, welche von der Studiengangsleitung genehmigt wurde.

Kufstein, 19. May 2024

Jesse Lang

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HTML HyperText Markup Language

JS JavaScript

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Kurzfassung der Bachelorarbeit: **Advanced Text Document Classification Techniques: Enhancing Accuracy and Efficiency in Real-World Applications**

Verfasser: Jesse Lang
Gutachter: Prof. (FH) Dr. Michael Kohlegger

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19. May 2024

1. Introduction

The classification of text documents is essential across various applications. It demands a high accuracy and efficiency, in order to be beneficial. Traditional approaches often struggle with the diversity and complexity of modern textual data, emphasising the need for advanced techniques. Leveraging natural language processing (NLP), data mining and machine learning (ML) techniques holds promise in overcoming these challenges by enabling automated categorisation of textual documents based on their content, context and semantics. These procedures contain numerous obstacles, including defining accurate annotation of documents, the implementation of dimensionality reduction techniques to address complexities, utilizing appropriate classifier functions to obtain robust generalisation while avoiding overfitting (Aurangzeb et al., 2010).

One of the main sources for textual documents these days is the web, the amount that is available to us is constantly increasing. Unstructured textual formats, such as reports, emails, opinions, and news stories, are thought to contain approximately 80% or more of an organization's information. Studies indicate that unstructured formats contain almost 90% of the world's data. There's a clear necessity for the automatic extraction of valuable insights from vast amounts of textual data to aid human analysis (Aurangzeb et al., 2010).

This study aims to investigate how these advanced classification techniques, can enhance the accuracy and efficiency of categorizing diverse textual docu-

ments. Libraries, such as scikit-learn (Scikit-Learn, 2024), NLTK (NLTK, 2024) and Keras (Keras, 2024) and their broad spectrum of algorithms will be used to implement different approaches and exploring the interactions between these techniques. With the use of a BBC text document dataset with a ".csv" format does the research seeks to gain insights into optimizing classification performance in real-world applications.

The following research question arises from the objective: "How can advanced text document classification techniques, incorporating machine learning and natural language processing, be effectively employed to improve the accuracy and efficiency of categorizing diverse textual documents, and what factors influence the performance of such classification models in real-world applications?"

1.1 Motivation

The current state of research in text document classification techniques, with ML and NLP, showcases significant progresses towards enhancing efficiency and accuracy. Recent developments have seen the emergence of sophisticated deep learning architectures, such as CNNs and RNNs, which excel in processing complex textual data. Furthermore, has the integration of pre-trained language models like GPT and BERT revolutionized feature representation, allowing models to capture difficult semantic nuances. This dynamic landscape reflects ongoing efforts to refine classification models, making them increasingly adept at real-world applications.

2. Theory

The theoretical basis of this thesis provides the necessary background to comprehend the research discussed in the following chapters. Through an insight of relevant development in the field, various models, preprocessing methodologies, and evaluation metrics, this chapter aims to construct a theoretical framework for the thesis. Its objective is to empower the reader with the requisite understanding to contextualize the research outcomes and their significance.

2.1 Natural Language Processing

Natural Language Processing (NLP) is a branch of artificial intelligence and computer science, that deals with the interaction between computers and human language. It aims to enable machines to generate human language, process, and understand it. By employing a variety of techniques and different approaches, such as deep learning, rule-based systems, and statistical methods, is NLP capable of tackling different language-related tasks. The usage of it can be found in numerous areas, including machine translation, chatbots, text classification, and speech recognition (Helland, 2023).

2.2 Machine Learning

Machine learning refers to the development of computer programs that are learning from experience to complete and solve a certain task. The measurement of the performance is calculated by the ability to do so. A training dataset represents the "experience" that is acquired by machine learning models, which contains output and input pairs. From the analysis of these examples can the model recognize and generalise the patterns to new, unseen data. To simplify, can it be reflected to the process of human learning and adaption to new scenarios. Common applications include fraud detection, self-driving cars and personalised recommendations (Helland, 2023).

2.3 Deep Learning

Deep learning is a method that uses non-linear modules to transform the data at multiple levels of abstraction, allowing models to find patterns in the raw data. This suggests that deep learning models are discovering and learning different data features without the need for human interaction. Because of its universal learning, generalization potential, robustness, and scalability advantages, this can be used in a variety of applications without the need for precise feature engineering (Helland, 2023).

2.4 Evaluation Metrics

A machine learning model's performance is assessed using metrics. They are employed to evaluate the accuracy of the made predictions, to analyze the output of various models, and to fine-tune them for optimal performance. Different types of machine learning issues have various types of metrics avail-

able. The model selection process, the optimization procedure, and the overall understanding of the model's capabilities can all be impacted by the metrics chosen. Selecting the incorrect metrics might also result in a biased model, which aligns differently with the project's objectives (Helland, 2023).

2.4.1 Accuracy

One popular assessment metric for classification problems is accuracy. Out of all the samples in the prediction, it calculates the proportion of correctly classified samples.

Accuracy = Number of correctly classified instances/ Total number of instances

For balanced datasets, accuracy works well since it presents a realistic picture of the model's capabilities and performance. When datasets are unbalanced, accuracy might be misleading and more difficult to interpret. This may be due to a single label in the dataset that accounts for the majority of the samples; therefore, reasonable accuracy can still be obtained by projecting all samples to the dominant label. This does not imply that the model is good because it ignores the less common but no less significant labels. Accuracy in multi-label classification only takes into account samples where every label is correctly classified. Because of this, using accuracy as a multi-label classification metric to evaluate the performance of multi-label models is more strict, less informative, and less desirable (Helland, 2023).

3. Methodology

The methods used to address the research topics raised in this thesis are described in this chapter. To obtain the results that will be presented, this section provides a thorough overview of the pipeline (Figure 1), outlining the procedures for preprocessing data, extracting features, model selection and training, and assessing performance. Through the conversion of theoretical ideas into practical procedures, aiming to offer an outline of how these methods are applied in real-life situations.

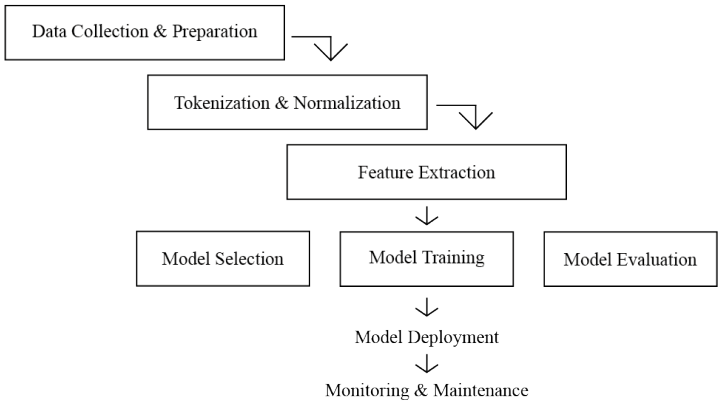

Figure 1: Implementation pipeline

3.1 Data Collection

The collection of data is a crucial step that lays the foundation for later analyses and model development. It involves gathering textual data from various

sources, which could include websites, databases, or specialized datasets for the specific domain of interest. It is important to collect a sufficiently diverse amount of data to capture the variability present in real-world text data (OpenAI, 2024). This thesis uses a BBC news dataset containing 2225 text data and five categories of documents (Text Document Classification Dataset, 2024).

3.2 Data and Text preprocessing

Preprocessing methods are an essential step for text mining techniques and applications. The data and its columns need to be analyzed and inspected since it is often necessary to generate a new column combining the various features. Through the joint column, a better, more comprehensive, and more accurate analysis can take place. The three essential preprocessing steps — extraction, lowercase conversion, and StopWords removal — are covered in this study.

3.2.1 Tokenization

Tokenization is the process of splitting sentences into individual words, characters, and punctuation, which are referred to as tokens. The split function uses white spaces or punctuations as dividing criteria. These generated tokens are often stored in a list afterward. In later processing phases, this step aids in removing unnecessary terms (Tabassum & Patil, 2020).

For example:

“This is an example sentence for the showcase of tokenization!”

Will be split into:

“This”, “is”, “an”, “example”, “sentence”, “for”, “the”, “showcase”, “of”, “tokenization”, “!”

3.2.2 Lowercase Conversion

Text typically consists of capital letters and abbreviations. Although this stage of text preprocessing is frequently skipped, it is one of the easiest and most successful ones. NLP is case-sensitive, meaning, it interprets ’Hello’ differently than ’hello’ and leads to a different outcome. In the later phases of word embedding would it create two distinct vectors, for the same words with one in capital and one in lowercase. For this reason, the best practice in text preprocessing has been to make all words lowercase (Tabassum & Patil, 2020).

3.2.3 StopWords Removal

Simple words like "the", "are", "is", "and" and so forth have no significance except in certain particular use cases. For instance, these extra words are not given any weightage in the text classification use case. The keywords that define the topics are the only ones that are extracted. Therefore, to reach the best result of algorithms these StopWords have to be found and removed from their document. It is also important to remember that in some scenarios, such as conversational models, the inclusion of specific negation words, like “No”, “cannot”, “wont” and “not”, is crucial (Tabassum & Patil, 2020). Libraries like nltk and sklearn already offer predefined lists of StopWords which can be easily downloaded and implemented into the code.

3.3 Feature Extraction

The encoding of features in vector forms for machine comprehension is often referred to as feature extraction. After being extracted by these methods, every feature is finally represented as a vector, which is then sent to the classifier models. The most common techniques, such as Bag-of-Words (BoW), and TF-IDF will be discussed next.

3.3.1 Bag-of-Words (BoW)

A bag of words in terms of natural language processing is a collection of words based on the number of occurrences in a given text or document. It only counts the frequency of a word, regardless of its position in the text. Thus, the BoW interprets that documents or texts containing similar words share the same context. One flaw of the model is that it prioritizes words that appear more frequently, making them more significant. On the other hand, some words may occur more frequently than others but lack sufficient information to help in clustering or classification issues. Additionally, longer documents provide a greater rate than shorter ones, which reduces the accuracy of the BoW model (Tabassum & Patil, 2020).

```
Document 0: "The quick brown fox"
Document 1: "Jumped over the lazy dog"
Document 2: "The dog chased the fox"

Vocabulary:
{'the': 8, 'quick': 7, 'brown': 0, 'fox': 3, 'jumped': 4,
'over': 6, 'lazy': 5, 'dog': 2, 'chased': 1}
```

```
BoW:
    brown  chased  dog  fox  jumped  lazy  over  quick  the
0       1       0    0    1       0     0     0      1     1
1       0       0    1    0       1     1     1      0     1
2       0       1    1    1       0     0     0      0     2
```

3.3.2 Term Frequency-Inverse Document Frequency (TF-IDF)

The term frequency-inverse document frequency (tf-idf) is a numerical measure that indicates the importance of a word to a document in a collection. Its primary application is as a standard weighting factor in information retrieval and text mining. The value of tf-idf rises in direct proportion to the frequency of a word in the corpus, but this is offset by the term's frequency in the document. This can help in managing the fact that certain words are typically used more commonly than others. Stop-word filtering using Tf-IDF is effective in a variety of subject areas, such as text classification and summarization. The model is the product of the two aforementioned statistics, termed frequency and inverse document frequency. The number of occurrences with which each term appears in each document is counted and added together to further differentiate them (Vijayarani et al., 2015). By calculating the log of the ratio of all documents to all instances of a word in a given document, it essentially scales down the less important words (Tabassum & Patil, 2020).

```
Document 0: "The quick brown fox"
Document 1: "Jumped over the lazy dog"
Document 2: "The dog chased the fox"

Vocabulary:
{'the': 8, 'quick': 7, 'brown': 0, 'fox': 3, 'jumped': 4,
'over': 6, 'lazy': 5, 'dog': 2, 'chased': 1}
```

```
TF-IDF:
   brown  chased   dog   fox   jumped  lazy   over  quick   the
0   0.58    0.00  0.00  0.44    0.00  0.00   0.00   0.58   0.35
1   0.00    0.00  0.38  0.00    0.50  0.50   0.50   0.00   0.30
2   0.00    0.53  0.40  0.40    0.00  0.00   0.00   0.00   0.63
```

3.4 Train-Test-Split

Train-Test-Split is a common method provided by sklearn, used to divide a given dataset into smaller subsets. The datasets need to be divided into training and testing sets in order to fairly assess the models. By dividing the data, the model's performance on unknown data may be evaluated, revealing whether the model overfits or performs well in terms of generalization. This stage is crucial because the model's ultimate objective is to accurately predict new data.

Every dataset was split only once, and all models were trained and fine-tuned using the same split, to maintain the comparison as fair and repeatable as possible. Listing 1 displays the implementation, which divides the data into a split of 80:20, where the training set contains 80%, and the testing set 20%.

Listing 1: Train-Test-Split in Python

```
1 from sklearn.model_selection import train_test_split
2
3 X_train,X_test,y_train,y_test = train_test_split(X,y,
    test_size=0.2, random_state=42)
```

The variable X (features) is assigned to the previously created TF-IDF vector and y (target) to the labels that should be predicted.

The random_state parameter controls the randomness of the data splitting pro-

cess. When a specific random_state value is provided, the data splitting process will produce the same result every time it is executed, ensuring reproducibility. If random_state is not specified, the data splitting will be different each time the function is called.

3.5 Model Selection

Machine Learning is split into three main categories, which are supervised, unsupervised and reinforcement learning. This thesis only required supervised learning, which is about the prediction of values with regression models, as well as classifying data with predefined labels. On the other hand, there is unsupervised learning which contains the analysis of patterns and can form clusters out of unlabelled data.

3.5.1 Classification Models

There are several different classification models and each of them fits a specific use case best. The models need to be evaluated and compared to one and another, to find the optimal algorithm. This study analyses seven different models from sklearn (Logistic Regression, Decision Tree, Naive Bayes, Support Vector Machine, Random Forest, XGBoost, KNeighborsClassifier) and evaluates them based on the run time and accuracy.

K-nearest neighbour - KNN

The K-nearest neighbour algorithm is one of the finest examples of instance-based learning. Additionally, it is easy to understand and a simple method for classification problems. Despite its simplicity, it has the capability to yield

results that are highly competitive. Not only is it well suitable for classifications but it also fits the requirements for regression predictions (Sen et al., 2020).

The algorithm stores all the given data points and predicts the target based on giving attention to the similarity measurements of the surrounding neighbours in likelihood. The number of neighbours that will be taken in consideration is defined by the "k" variable. Assuming k equals 3, a circular region with the new data point at its centroid is created to encompass only the three closest neighbouring data points on the plane. The determination of the label for the new data point is then based on the distances between the data point and each of its neighbours (Sen et al., 2020).

Some of the advantages are that it handles noisy and large training data well, besides the simplicity of the implementation. A significant limitation of this algorithm arises from the necessity to recalculate the distances from K neighbours for every new instance, resulting in substantial computational time consumption. Additionally, accurately determining the value of K is crucial to achieve a lower error rate (Sen et al., 2020).

Support vector machine - SVM

Another supervised algorithm is the support vector machine. It can handle both, classification, and regression problems, though is it more seen for classification. Furthermore, it can manage numerous instances that involve both continuous and categorical data (Sen et al., 2020).

The algorithm can be defined like following. Items of the dataset with "n" features will be characterised and plotted as points in an n-dimensional space split into classes by a hyperplane with the widest possible margin. The data points are then mapped into the previous defined space to predict their label based on their position relative to the hyperplane (Sen et al., 2020).

A significant performance boost can be seen, when the variable "n" exceeds the total size of sample set. Therefore, is this algorithm mostly taken under consideration for high-dimensional data. Further improvements in performance can be achieved by having a well-constructed hyperplane. Despite its advantages, is a relatively high training time one of its drawbacks. Which leads to slower predictions, especially with large datasets (Sen et al., 2020).

Decision Tree - DT

Decision trees are a type of supervised learning technique used for regression and classification. Building a model with the ability to forecast the value of a target variable using fundamental decision rules inferred from the data features is the goal. A piecewise constant approximation can be thought of as a tree. For instance, decision trees estimate a sine curve depending on inputs by combining a set of if-then-else decision rules. As the tree goes deeper, the model fits the data better and the decision criteria get increasingly complex (Sklearn, 2024).

The ease of use and interpretability of decision trees is one of its main benefits. It is possible to visualise and comprehend the tree structure, so even non-experts may use it. Furthermore, because decision trees can handle both numerical and categorical data without requiring a lot of preprocessing, they also require less preparation of the data. They also have the benefit of handling multi-output issues and offering a white box approach, in which a decision's logic may be simply described using boolean logic (Decision Trees, 2024).

Nevertheless, decision trees can overfit, especially if they get too complicated. To avoid this problem, measures like trimming and imposing tree growth restrictions are required. Decision trees can also be unstable since slight changes in the data might produce noticeably different tree architectures. Despite these drawbacks, is it a useful tool in machine learning, even with these limitations,

especially where simplicity and interpretability are top priorities (Decision Trees, 2024).

3.5.2 Deep Learning

Deep learning (DL) is a specific category within machine learning (ML) methodologies that utilizes artificial neural networks (ANN). These networks are loosely inspired by the structure of neurons found in the human brain. Informally, the term "deep" originally referred to the presence of numerous layers in the artificial neural network. However, this definition has evolved over time. While just four years ago, having 10 layers was considered sufficient to qualify a network as deep, today it is more commonplace to characterize a network as deep when it comprises hundreds of layers (Gulli & Pal, 2017).

Keras serves as a user-friendly high-level deep learning library in Python, providing a convenient interface for building neural networks. The Sequential model in Keras is a linear stack of layers, allowing the straightforward construction of neural networks by sequentially adding layers. Each layer, often employing activation functions like Rectified Linear Unit (ReLU), introduces non-linearity to the model, enabling it to capture complex patterns and relationships within the data (Gulli & Pal, 2017).

4. Results

The results presented in this chapter are the outcomes obtained by applying pre-processing techniques and machine learning models to the dataset for multi-class classification. Chapter 5 goes into further depth about the findings. Each of the model's runtimes, performance metrics (accuracy), and findings of the data pre-processing steps are included in the results.

4.1 Data Pre-processing

4.1.1 Label Distribution

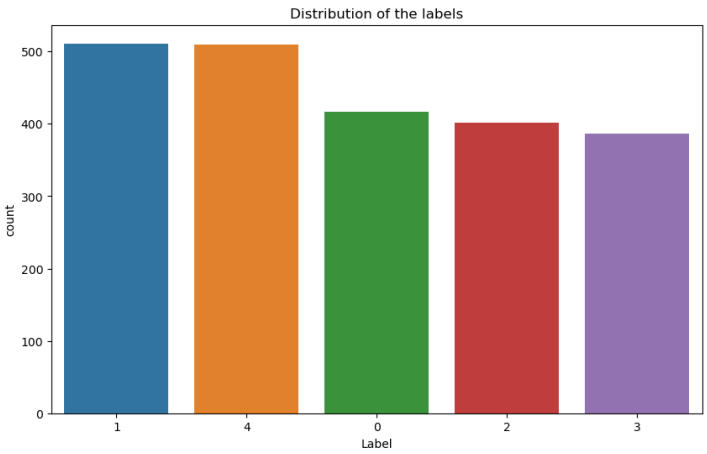

Figure 2: Distributon of the labels

Figure 2 shows the distribution of the labels in the BBC dataset. The labels

represent the categories 0: politics, 1: sport, 2: technology, 3: entertainment, 4: business. The distribution is measured in the total amount of documents per label.

As can be seen in Figure 2, there is an unequal distribution of the categories, where the sports and business sections carry the most weight. Whereas the other three labels have around 20% less data available.

4.1.2 Token length distribution

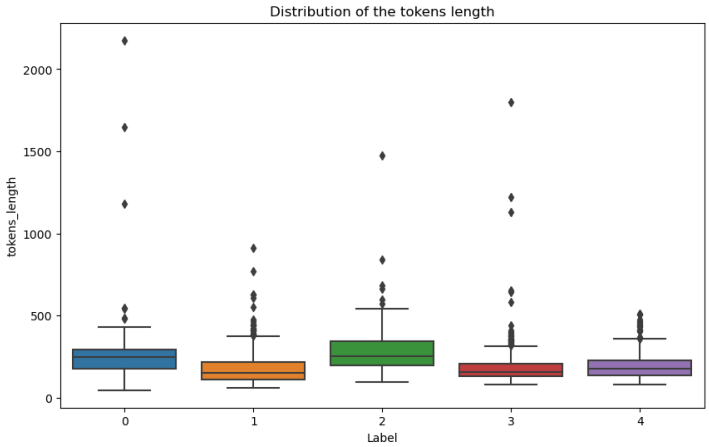

Figure 3: Distributon of the token length

Figure 3 illustrates the distribution of token lengths per label within the dataset using box plots with outliers. Each box plot represents the distribution of token lengths, with the box indicating the interquartile range and the median, while the outer ends extend to the minimum and maximum values.

This visualization provides a comprehensive view of the variability in token lengths present in the textual data. By examining the box plots, we can discern the typical range of token lengths as well as the presence of outliers or extreme values.

4.1.3 Label insights

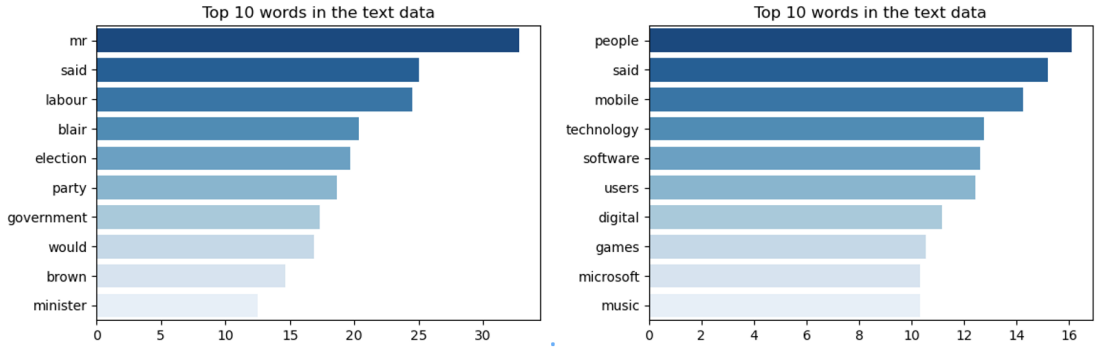

Figure 4: Top 10 words of the politics and technology category

Figure 4 presents the top 10 words for each of the two labels, "politics" and "technology." This visualization offers a concise representation of the most frequent words associated with each category, providing a quick overview of the predominant themes within the dataset.

By presenting the most commonly occurring words, this figure aids in understanding the lexical characteristics of the politics and technology categories, serving as a useful reference for subsequent analysis and interpretation of the textual data.

4.2 Model Performance

By analyzing key metrics like accuracy and runtime, it provides important insights into each model's effectiveness and computational efficiency. This evaluation process guides our decisions in selecting the most suitable models for practical applications.

4.2.1 Accuracy

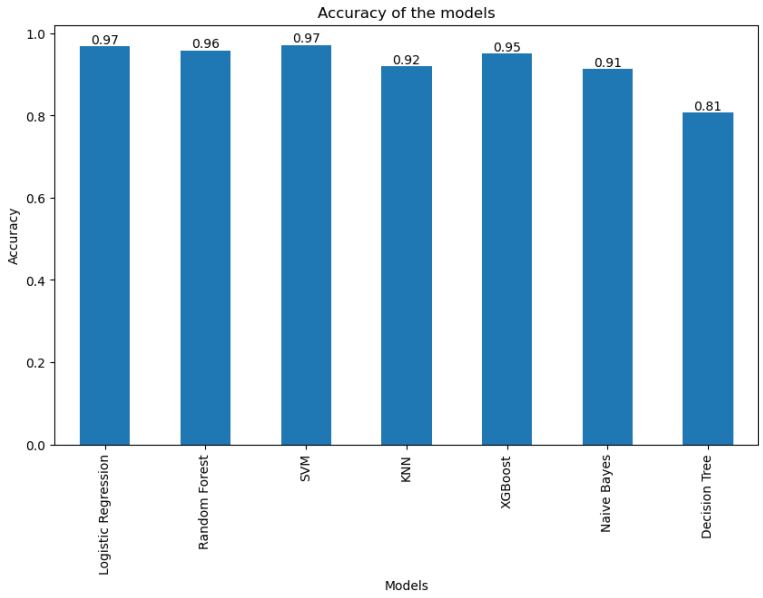

Figure 5: Accuracy of the models

Figure 5 displays the evaluation of different classification models. In this visualization, each model's accuracy score is shown, providing a clear comparison of their performance in classifying textual documents across different categories or classes. Logistic Regression and Support Vector Machine provided the most precise score with 0.97 accuracy, followed by Random Forest (0.96) and K-Nearest-Neighbour (0.92). Whereas the Decision Tree model came out as the least accurate model (0.81).

This information is crucial for determining the effectiveness and reliability of the classification algorithms employed in the study, aiding in model selection and optimization strategies.

4.2.2 Runtime

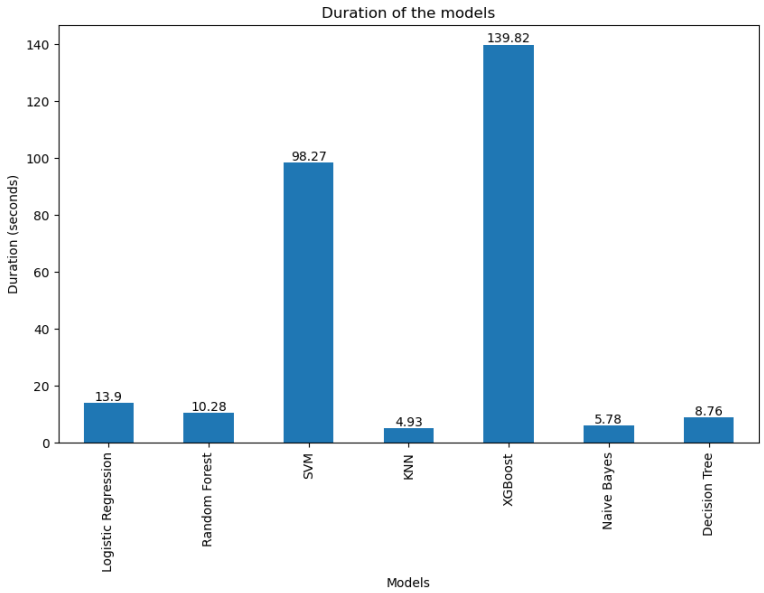

Figure 6: Runtime of the models

Figure 6 displays the runtime of the classification models utilized in this study. Runtime refers to the time taken by each model to complete the classification task, from training to prediction, on the given dataset. The faster the model's runtime is the more efficient it will be in production. Therefore is KNN (4.93 s) the quickest, Naïve Bayes (5.78 s) second, and Decision Tree (8.76 s) third. At the bottom of the ranking are the following models, SVM (98.27 s) and XGBoost (139.82 s).

This information is important for assessing the practical probability and scalability of the classification algorithms, particularly in real-world applications where computational efficiency is a significant consideration.

5. Discussion

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Bibliography

A. List of Interview Partners

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