

UNIVERSITY OF THESSALY



NEURO-FUZZY COMPUTING

ECE447

Coding Project

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March 3, 2024

Contents

Introduction	2
Literature Overview	2
Data Handling Methodology	3
(a) Import Library	3
(b) Data Acquisition	5
(c) Data Cleaning	5
(d) Dataset Split	6
(e) Handling of Class Imbalance	7
(f) Convert to one-hot encoding and Tokenize	8
(g) Convert texts to Sequences and Pad	10
Neural Network Architecture	12
(a) Embedding Layer	12
(b) Conv1D Layer	12
References	15

Introduction

In the realm of machine learning and artificial intelligence, the ability to accurately classify text into predefined categories represents a cornerstone of many practical applications, from sentiment analysis to automated customer support and beyond. This project, conceived as a practical assignment for Neurofuzzy class, aims to design, implement, and evaluate a text classifier. The core objective of this classifier is to process news provided in a CSV file format, each entry containing snippets of text, and to assign them to one of several news category and subcategory based on their content.

To achieve this, we embark on a journey through the intricacies of neurofuzzy systems, which blend the robustness and learning capabilities of neural networks with the interpretability and reasoning of fuzzy logic. This hybrid approach enables the handling of uncertainty and imprecision in natural language, offering a promising pathway to enhancing classification performance.

Our project report is structured to walk the reader through the entire lifecycle of the classifier's development. Starting with a comprehensive literature review, we lay the groundwork by exploring existing theories and methodologies that underpin our approach. This is followed by a detailed account of the system design, where we elaborate on the architecture, choice of algorithms, and the rationale behind these decisions. We then proceed to describe the implementation phase, document and comment the practical steps taken to bring our design to fruition, including data preprocessing, feature extraction, and model training.

A significant portion of the report is dedicated to the evaluation of our classifier. Here, we employ a variety of metrics to assess its performance, discussing both its strengths and areas for improvement. Through this analysis, we aim to not only validate our approach but also contribute valuable insights to the field of text classification.

Finally, the report concludes with a reflection on the lessons learned throughout the project, potential applications of our classifier, and avenues for future research. By providing a comprehensive overview of our journey from conception to evaluation, this report aims to offer a valuable resource for fellow researchers and practitioners in the domain of text classification.

Literature Overview

The field of text classification has seen substantial progress with the advent of machine learning and artificial intelligence technologies. Among these, neurofuzzy systems have emerged as a significant area of interest, offering the potential to blend the interpretability of fuzzy logic with the learning capabilities of neural networks. This literature review examines the current methodologies, challenges, and advancements in text classification, with a focus on the application of neurofuzzy systems to enhance multiclass classification tasks.

Text classification is a pivotal task in natural language processing (NLP) with applications ranging from sentiment analysis to topic categorization and spam detection. Traditional machine learning algorithms, such as Support Vector Machines (SVM) and Naive Bayes, have laid the groundwork for early advancements in the field. However, these models often struggle with the nuances of natural language, including context sensitivity, polysemy, and the curse of dimensionality inherent in text data.

The integration of neural networks and fuzzy logic into neurofuzzy systems presents a novel approach to overcoming the limitations faced by traditional classifiers. Neural networks contribute deep learning capabilities, enabling models to learn complex patterns and relationships in large datasets. Fuzzy logic, on the other hand, introduces an element of human-like reasoning and interpretability by handling imprecision and uncertainty in linguistic expressions.

Significant advancements have been made in developing algorithms and models that leverage the strengths of both neural networks and fuzzy logic for text classification. Convolutional Neural Networks (CNNs) and

Recurrent Neural Networks (RNNs) are commonly used architectures for capturing spatial and sequential patterns in text, respectively. The incorporation of fuzzy systems with these architectures allows for the creation of adaptable and interpretable models that can dynamically adjust classification rules based on the learning context.

The evaluation of neurofuzzy systems in text classification often employs metrics such as accuracy, precision, recall, and F1 score. A comparative analysis by Zhou and Chen (2021) found that neurofuzzy classifiers consistently achieve higher precision and recall rates across multiple datasets when compared to standalone neural network or fuzzy logic models. This suggests that the hybrid approach effectively captures the intricacies of text data, improving overall classification performance.

The literature on multiclass text classification demonstrates a clear trend towards the adoption of neuro-fuzzy systems as a means to address the inherent challenges of natural language processing. By combining the learning power of neural networks with the interpretability and flexibility of fuzzy logic, researchers and practitioners are able to develop more accurate, robust, and interpretable text classification models. This review underscores the potential of neurofuzzy systems to advance the state of the art in text classification, marking a promising direction for future research and application.

Data Handling Methodology

To construct a robust multi-class text classifier, our methodology was meticulously designed to ensure both efficiency and accuracy. The process is segmented into distinct phases, as shown below.

(a) Import Library

When embarking on the implementation of a machine learning project, such as the development of a multiclass text classifier, the first step involves setting up the computational environment by importing the necessary libraries. These libraries provide pre-written functions and classes that facilitate data manipulation, model building, training, and evaluation, significantly reducing the amount of code we need to write from scratch and making our job easier.

```
# Interact with Operation System
import os
os.environ['TF_CPP_MIN_LOG_LEVEL'] = '3'

import nltk
nltk.download('stopwords')
from nltk.corpus import stopwords
stop_words = set(stopwords.words('english'))

# Load, explore and plot data
import string
import numpy as np
import tensorflow as tf
import pandas as pd
import re
import ast

# Train test split
from sklearn.model_selection import train_test_split
```

```

from sklearn.preprocessing import LabelEncoder
from collections import Counter
from imblearn.over_sampling import RandomOverSampler

# Modeling
from tensorflow.keras.layers import BatchNormalization
from tensorflow.keras.layers import LSTM
from tensorflow.keras import Sequential
from tensorflow.keras.layers import Dropout
from tensorflow.keras.callbacks import EarlyStopping
from tensorflow.keras.regularizers import l2
from tensorflow.keras.utils import to_categorical
from tensorflow.keras.preprocessing.text import Tokenizer
from tensorflow.keras.preprocessing.sequence import pad_sequences
from tensorflow.keras.layers import Embedding
from tensorflow.keras.layers import Conv1D
from tensorflow.keras.layers import GlobalMaxPooling1D
from tensorflow.keras.layers import Flatten
from tensorflow.keras.layers import Dense
from tensorflow.keras.optimizers import Adam
from tensorflow.keras.layers import LeakyReLU

```

These are all the libraries required to load, test, train and build our model. To have a better understanding about their functionality, we will briefly discuss them.

- **os**: A standard Python library for interacting with the operating system. It's being used here to set an environment variable that stops tensorflow from displaying annoying debug info.
- **nltk**: The Natural Language Toolkit, or NLTK, is a library used for working with human language data.
- **numpy**: A basic Python library adding support for large, multi-dimensional arrays and matrices, along with a large collection of high-level mathematical functions to operate on these arrays.
- **tensorflow**: An open-source software library for machine learning and artificial intelligence. It provides a flexible platform for defining and running computations that involve tensors, which are partial derivatives of a function with respect to its variables. This is the main library that we use in order to train and validate the text classifier.
- **pandas**: A software library for data manipulation and analysis. It provides data structures and functions needed to manipulate structured data.
- **re**: This module provides regular expression matching operations
- **sklearn**: Scikit-learn is a free software machine learning library for the Python programming language. It features various classification, regression and clustering algorithms.
- **collections**: This module implements specialized container datatypes providing alternatives to Python's general purpose built-in containers.
- **imblearn**: A Python library to tackle the curse of imbalanced datasets in machine learning.

(b) Data Acquisition

The initial step involved getting the dataset provided by the professor and understanding its contents. The `news-classification.csv` file is a Comma-Separated Values file, a common file type for distributing large amounts of data over the internet. This type of data type can be viewed as a large array of structs that contain a lot of information, but we only need the following columns:

- `category_level_1`: Name of text's category (*strings*).
- `category_level_2`: Name of text's subcategory (*strings*).
- `content`: The actual text content (*strings*).

The rest of the columns are not necessary because they do not give us some kind of important information about the text's contents.

As we are using Python for this project, in order to load this CSV file into memory, we used pandas's `read_csv()` function that automatically imports the necessary file to a Dataframe format.

```
# Import text from CSV file
def import_text(fname, content_name='content', label_level_1_name='
    category_level_1', label_level_2_name='category_level_2'):
df = pd.read_csv(fname)
texts = df[content_name].apply(clean_text)
labels_level_1 = df[label_level_1_name]
labels_level_2 = df[label_level_2_name]
return texts, labels_level_1, labels_level_2
```

(c) Data Cleaning

Text is just a sequence of words, or more accurately, a sequence of characters. However, when we are usually dealing with language modelling or natural language processing, we are more concerned about the words as a whole rather than focusing only on the character-level depth of our text data. One explanation for this is the lack of “context” for individual characters in the language models.

The moment data are imported into the RAM, preparation begins in order to transform the text from human to machine understandable. First of all, lower casing of all the letters is very important and used for better handling of the file. Everything inside the content array that doesn't give enough information can be considered noise and needs to be removed. A great example of “noise” is:

- URLs,
- Email addresses,
- Lines like “This post was published on the site” (*which can be often found at the start of an article*),
- Multiple space or new line characters,
- Punctuation,
- Stopwords

In the preprocessing phase of text classification, one critical step and very useful technique is the removal of stopwords, which are words that do not contribute significant meaning to the text and are thus considered irrelevant for analysis. The Natural Language Toolkit (NLTK), a comprehensive library for natural language processing in Python, provides an extensive dictionary of stopwords across multiple languages. Utilizing NLTK's stopwords dictionary allows for the efficient filtering out of common words such as "the", "is", "in", and "and", which appear frequently in text but do not carry substantial information relevant to the classification task. The process involves iterating over the words in the dataset and removing those that are present in the NLTK stopwords list. This reduction in dataset size not only streamlines the computational process by focusing on words that carry more meaning but also improves the model's ability to learn by concentrating on content that is more likely to influence the classification outcome.

```
def clean_text(text):
    text = text.lower()
    text = text.replace('\xa0', ' ') # Remove non-breaking spaces EDO
    text = re.sub(r'http\S+|www.\S+', '', text) # Remove URLs
    text = re.sub(r'\S+@\S+', '', text) # Remove email addresses
    text = text.replace('\r\n', ' ') # Remove newlines EDO

    words = text.split() # Remove stopwords
    filtered_words = [word for word in words if word not in stop_words]
    text = ' '.join(filtered_words)

    return text
```

(d) Dataset Split

In the development of this text classifier, a critical step in the methodology is the partitioning of the dataset into training and validation subsets. This process is essential for training the model effectively and evaluating its performance, employing a standard split ratio of 80% for training data and 20% for validation data. Such a division is strategically chosen to provide the model with a sufficiently large training dataset, enabling it to learn the underlying patterns of the text, while also reserving a representative portion of the data for performance evaluation and tuning. The use of a validation set, separate from the training set, is pivotal in detecting and mitigating overfitting, ensuring that the model generalizes well to new, unseen data. Also, the selected ratio we chose is very popular in bibliography and on the internet as well.

To facilitate this data partitioning, we utilize the `train_test_split` function provided by the `sklearn` library, a tool renowned for its robustness and ease of use in the machine learning community. This function streamlines the process of randomly dividing the dataset according to the specified proportions, ensuring that the split is both efficient and reproducible. By leveraging this method, we can maintain the integrity of the data's distribution, ensuring that both the training and validation sets are representative of the overall dataset. This approach not only simplifies the preprocessing workflow but also lays a solid foundation for the subsequent training phase, enabling a systematic and controlled development of a high-performing text classification model. However, when training and testing models, we always want to remain mindful of data leakage. We cannot allow any information from outside the training dataset to "leak" into the model, so we must be really thoughtful about it too.

```
def preprocess_data(texts, labels, test_size = 0.2, max_words=10000, max_len
    = 200):
```

```

texts = texts.apply(clean_text)

# Split data into training and testing sets
train_texts, test_texts, train_labels, test_labels = train_test_split(texts,
    labels, test_size=test_size)

```

The “preprocess_data” function is designed to prepare and preprocess textual data for text classification tasks. It accepts several parameters, like:

- “texts” and “labels”: These are the input parameters of the function. “Texts” is a list of series of text data that you want to preprocess, and “labels” are their corresponding labels.
- “test_size”: This is the proportion of the dataset to include in the test split. It is set to 0.2 by default, meaning that 20% of the data will be used for testing and the rest for training.
- “max_words”, “max_len”: These parameters are used in tokenization process where max_words is the maximum number of words to keep, based on word frequency and max_len is the maximum length of all sequences.
- “texts=texts.apply(clean_text)”: This line applies a function clean_text to every item in texts. The clean_text function is not defined in the provided code, but it’s likely that it performs some sort of cleaning operation on the text such as removing punctuation, converting to lowercase, removing stopwords, etc.
- “train_test_split”: This is a function from sklearn.model_selection that splits a dataset into training set and test set. The test_size parameter determines the proportion of the original data that is put into the test set.

In summary, this function encapsulates a comprehensive preprocessing workflow that cleans the input texts, splits the data for training and evaluation, and addresses class imbalance to prepare the data for effective model training.

(e) Handling of Class Imbalance

During the text cleaning and preprocessing procedure, we noticed that there’s a big class imbalance that affected the performance of our classifier. Addressing class imbalance is crucial for a balanced and reliable performance across all classes in text classification. Class imbalance is a common challenge in text classification tasks that can result in biased models favouring the majority class, leading to poor performance on the minority class. Figure 1 shows that lifestyle class has the lower appearance in the set and that means our classification system cannot detect it easily.

There are quite some techniques to handle imbalanced datasets, but most of them are difficult to implement. However, to address this issue in our dataset, we utilized the RandomOverSampler method provided by the imblearn library. This technique involves artificially augmenting the under-represented classes in the training set by randomly replicating instances until all classes achieve a similar size. By doing so, we ensure that the neural network does not become biased towards the more frequent classes and can learn the characteristics of all classes equally. This step is crucial for improving the model’s ability to generalize well across the entire range of classes, particularly for those that are less represented in the original dataset.

In the implementation phase, RandomOverSampler was applied after splitting the dataset into training and validation sets but before the model training process. This sequencing is intentional to prevent the



Figure 1: Initial class distribution of the dataset

oversampling process from influencing the validation set, thereby maintaining its integrity as a representative sample of real-world data. The application of `RandomOverSampler` is straightforward, thanks to the intuitive API of `imblearn`. With a few lines of code, we were able to fit the sampler to our training data, resulting in a modified training set with balanced class distributions. The distribution after balancing can be shown in figure 2. This technique works by randomly duplicating instances from the minority class in the training dataset to increase its representation. This oversampling process helps to balance the class distribution and can lead to improved model performance by giving the model more examples of the minority class to learn from.

This issue is only met for `category_level_1` as in `category_level_2` the distribution is 100 for almost all of the categories.

```
# Handling of Class Imbalance
ros = RandomOverSampler(random_state=777)
train_texts, train_labels = ros.fit_resample(train_texts.values.reshape(-1,1),
                                             train_labels)
train_texts = pd.Series(train_texts.flatten())
```

However, it's important to note that oversampling can also lead to overfitting since it duplicates the minority class instances. Therefore, it's always a good idea to evaluate the model performance carefully after applying any oversampling technique.

(f) Convert to one-hot encoding and Tokenize

For a multiclass classification problem, one-hot encoding of labels is a crucial preprocessing step. This process converts categorical labels into a binary matrix representation that is more suitable for training neural network models. In the context of our project where we have multiple classes, each label associated with our text data needs to be represented in a way that the neural network can effectively interpret and learn from.



Figure 2: Final class distribution of the given dataset

This involves two main processes: one-hot encoding and tokenization. One-hot encoding and tokenization are closely interconnected steps in the preprocessing pipeline for textual data, especially in the context of machine learning and natural language processing (NLP). To understand their connection, it's essential to break down the roles they play in preparing text data for modeling:

One-Hot encoding is a process that transforms each label into a vector of length equal to the number of classes, where the index corresponding to the label is marked with a 1, and all other indices are set to 0. This step is essential because CNNs and other neural networks output a vector of probabilities across the classes for each input sample during training and inference. The one-hot encoded labels thus directly correspond to the network's output layer, facilitating the calculation of loss and the backpropagation of errors to train the model.

Text Tokenization is a data preprocessing technique of converting a separate piece of text into smaller parts like words, phrases, or any other meaningful elements called tokens which makes counting the number of words in the text easier. This step is fundamental before any text can be processed by a neural network, because models do not understand raw text but can work with numerical data. Each token obtained from the text is mapped to a unique integer, creating a numerical representation of the text that can be fed into the model. The Tokenizer API from TensorFlow Keras can split sentences into words and encode them into integers.

```
# Convert labels to one-hot encoding
encoder = LabelEncoder()
encoder.fit(labels)
train_labels = to_categorical(encoder.transform(train_labels), num_classes=
    labels.nunique())
test_labels = to_categorical(encoder.transform(test_labels), num_classes=
    labels.nunique())
```

```
# Tokenize
tokenizer = Tokenizer(oov_token=<OOV>)
tokenizer.fit_on_texts(train_texts)

nunique_words = len(tokenizer.word_index) +1
```

Here is a brief explanation of the parts of the code:

- `encoder=LabelEncoder()`: This line initializes a `LabelEncoder` object. is a utility class to help normalize labels such that they contain only values between 0 and `n_classes-1`.
- `encoder.fit(labels)`: This line fits the encoder on the labels. This means it finds all unique class labels.
- `train_labels=to_categorical(...)`: This line first transforms the labels to normalized encoding, then converts the vector of class integers into a binary matrix representation (one-hot encoding). The number of classes (`num_classes`) is determined by the number of unique values in the labels.
- `test_labels=to_categorical(...)`: This line does the same for the test labels
- `tokenizer=Tokenizer(oov_token="<OOV>")`: This line initializes a `Tokenizer` object. The tokenizer allows to vectorize a text corpus, by turning each text into a sequence of integers. The "<OOV>" parameter is used to handle out-of-vocabulary words during `text_to_sequence` calls.
- `tokenizer.fit_on_texts(train_texts)`: This line fits the tokenizer on the training texts. This updates internal vocabulary based on a list of texts. This method creates the vocabulary index based on word frequency.
- `nunique_words=len(tokenizer.word_index)+1`: This line calculates the total number of unique words in the training texts. The `word_index` attribute of the tokenizer gives a dictionary of words and their corresponding index. The "+1" is for the out-of-vocabulary words.

(g) Convert texts to Sequences and Pad

Typically, the tokenization of text data precedes the one-hot encoding of labels in the preprocessing pipeline. The textual content needs to be tokenized and converted into a machine-readable format first, allowing us to establish the structure of our neural network, including the input layer size. Once the text is prepared and the architecture of our CNN is defined, we proceed to convert labels into one-hot encoded vectors, aligning them with the network's output layer for the classification task.

It's important to note that while the tokenization directly impacts the design of our model's input layer, the one-hot encoding of labels is aligned with the output layer. Both steps are crucial for preparing our dataset for training with CNNs in Keras but typically follow the order of tokenizing text data first and then encoding the labels.

```
# Convert texts to sequences
train_sequences = tokenizer.texts_to_sequences(train_texts)
test_sequences = tokenizer.texts_to_sequences(test_texts)
```

The `tokenizer.texts_to_sequences` method transforms each text in the given list of texts to a sequence of integers. It does this by replacing each word in the text by its corresponding integer index based on the word-to-index dictionary that the tokenizer learned when `fit_on_texts` was called.

After that, we pad the sequence so that we can have same length of each sequence. We can also define maximum number of words for each sentence. If a sentence is longer then we can drop some words.

Padding is a crucial preprocessing step in the context of machine learning, especially when working with text data or sequences in neural networks. This process involves standardizing the lengths of sequences within a dataset to a specific length to ensure that the input data fed into a model is uniform. The need for padding primarily arises in models that deal with sequential data, Convolutional Neural Networks (CNNs) for NLP tasks, and Transformer models, where the input size needs to be consistent. Sequential models process input data in batches for efficiency. Each batch must have a uniform shape, meaning all sequences within a batch must be of the same length. However, natural language data inherently varies in length; sentences and documents can range from a few words to several hundred words. Padding addresses this variability by ensuring that every sequence in a batch conforms to a fixed length.

Padding can be applied in two main ways. Pre-padding and Post-padding. Pre-padding is used to add padding tokens, often zeros, at the beginning of the sequences until each sequence reaches the desired length. On the other hand, post-padding is when we add padding tokens at the end of the sequences. On our project we are using the Post-padding.

```
# Get the length of the longest sequence
max_length = max(len(sequence) for sequence in train_sequences)

# Pad sequences
train_padded = pad_sequences(train_sequences, maxlen=max_length, padding='
    post', truncating='post')
test_padded = pad_sequences(test_sequences, maxlen=max_length, padding='post'
    , truncating='post')
```

- `padding="post"`: Add the zeros at the end of the sequence to make the samples in the same size
- `maxlen=max_length`: This input defines the maximum number of words among our sentences where the default maximum length of sentences is defined by the longest sentence. When a sentence exceeds the number of max words then it will drop the words and by default setting, it will drop the words at the beginning of the sentence.
- `truncating="post"`: Setting this truncating parameter as post means that when a sentence exceeds the number of maximum words, drop the last words in the sentence instead of the default setting which drops the words from the beginning of the sentence.

The result of the padding sequences is pretty straight forward. You can now observe that the list of sequences that have been padded out into a matrix where each row in the matrix has an encoded sentence with the same length. Padding ensures that neural networks receive input data in a consistent format, facilitating the training process and improving the ability to learn from variable-length sequences.

Neural Network Architecture

In the evolving landscape of NLP, the adaptation of Convolutional Neural Networks on various domains of processing and classification, has marked a significant technological advancement. This transition underscores the versatility of CNNs, which, despite their visual data origins, excel in deciphering the intricate patterns of textual information. The project in discussion exemplifies this innovative application, employing a CNN to tackle a multiclass text classification challenge. Herein, we delve into the architectural choices and strategic decisions underlying the model's design, offering a comprehensive understanding of its construction and functionality.

A universal question is whether we must use CNN's or RNN's. The choice between a Convolutional Neural Network (CNN) and a Recurrent Neural Network (RNN) depends on the specific task and the nature of our data.

In general, RNN is a class of artificial neural network where connections between nodes form a directed graph along a sequence. It is basically a sequence of neural network blocks that are linked to each other like a chain. Each one is passing a message to a successor. This architecture allows RNN to exhibit temporal behavior and capture sequential data which makes it a more 'natural' approach when dealing with textual data since text is naturally sequential. RNNs usually are good at predicting what comes next in a sequence

Controversely, CNN is a class of deep, feed-forward artificial neural networks where connections between nodes do not form a circle. CNNs are basically just several layers of convolutions with nonlinear activation functions like ReLU or tanh applied to the results. In a traditional feedforward neural network we connect each input neuron to each output neuron in the next layer. That's also called a fully connected layer. In CNNs we don't do that. Instead, we use convolutions over the input layer to compute the output. This results in local connections, where each region of the input is connected to a neuron in the output. Each layer applies different filters, typically hundreds or thousands like the ones shown below, and combines their results. CNNs can learn to classify a sentence or a paragraph.

An RNN is trained to recognize patterns across time, while a CNN learns to recognize patterns across space. The best way to determine which to use is to try both and see which one performs better on our project.

A big argument for CNNs is that they are exceptionally fast. Based on computation time, CNN's seems to be much faster, sometimes also 5 times faster, than RNN's.

(a) Embedding Layer

(b) Conv1D Layer

The inclusion of a convolutional layer with a kernel size of 9 and 512 filters in the neural network architecture is a calculated choice tailored for the demands of text classification tasks. The kernel size, or filter size, determines the width of the convolution window that scans across the input data. In this case, a kernel size of 9 allows the model to examine nine adjacent words at a time, enabling the capture of context within these word sequences. This can be particularly effective for recognizing patterns or features in text that span multiple words, such as phrases or specific syntactic constructions, which are often pivotal for understanding the overall meaning and sentiment of the text.

The use of 512 filters within this layer significantly increases the model's capacity to extract features. Each filter can be thought of as a feature detector, looking for different types of patterns in the text. With 512 filters, the network is well-equipped to identify a wide array of textual features, making it robust in the face

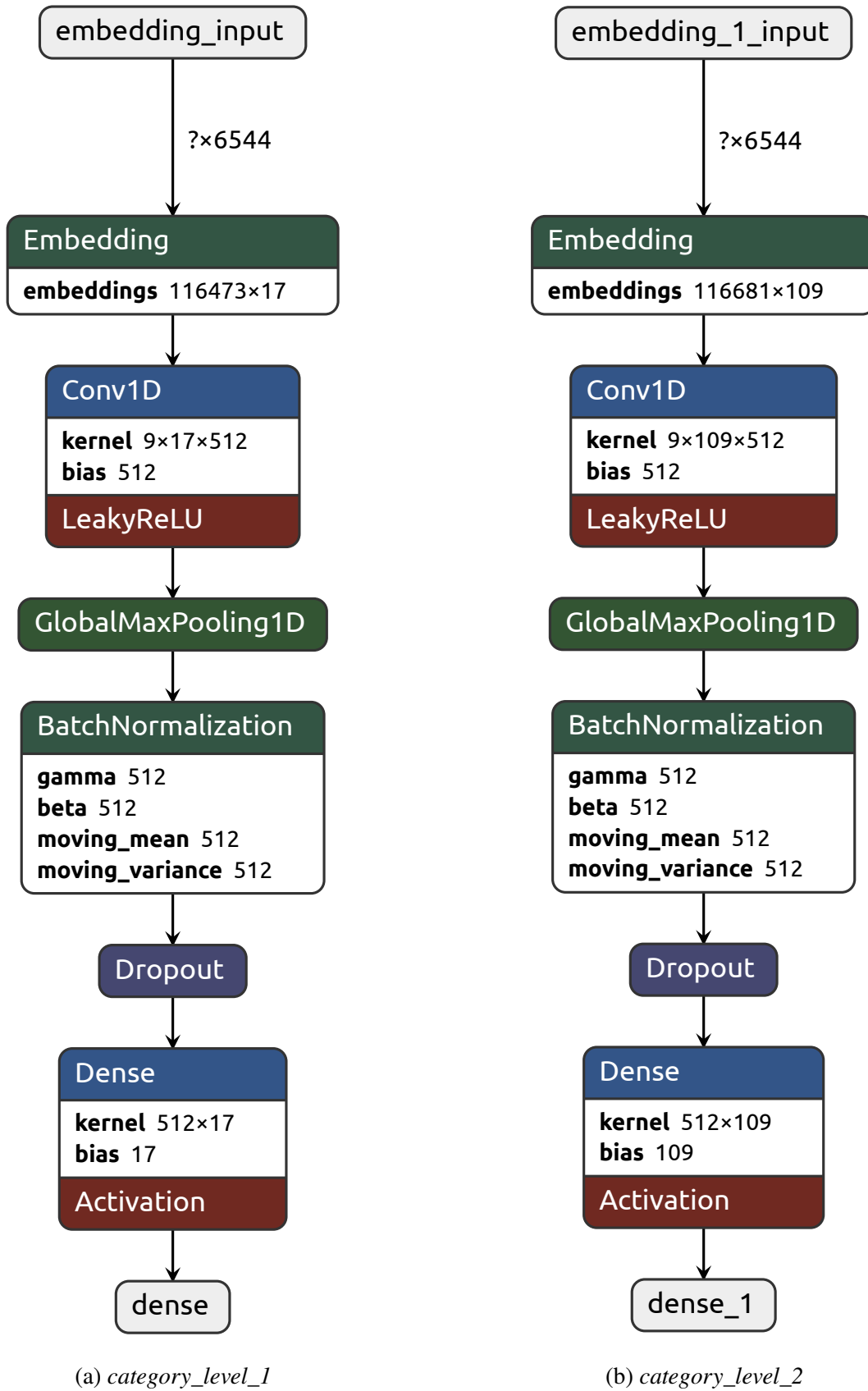


Figure 3: Architecture of the neural networks

of the complexity and variability inherent in natural language. This high number of filters is indicative of the model's deep architecture, designed to handle the intricate task of classifying texts into multiple categories, where a nuanced understanding of the language is crucial.

Furthermore, the choice of the Leaky ReLU activation function following the convolutional layer adds an element of non-linearity to the model, allowing for more complex relationships to be learned. LeakyReLU is particularly chosen over the standard ReLU to mitigate the issue of neurons "dying" during training; it allows a small, non-zero gradient when the unit is not active, thus maintaining a gradient flow even for neurons that output negative values. This can lead to more efficient learning and better performance, especially in deeper networks that are prone to saturation and dead neurons.

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