DEPARTMENT OF ENGINEERING MATHEMATICS

# Improving Text Classifier Performance through Human-in-the-Loop: Enhancing Learning from Explanations

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A dissertation submitted to the University of Bristol in accordance with the requirements of the degree of Master of Science in the Faculty of Engineering.

Sunday 13th August, 2023

Supervisor: Dr. Edwin Simpson

# Declaration

This dissertation is submitted to the University of Bristol in accordance with the requirements of the degree of MSc in the Faculty of Engineering. It has not been submitted for any other degree or diploma of any examining body. Except where specifically acknowledged, it is all the work of the Author.

Xinyang Song, Sunday 13th August, 2023

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# Abstract


Text classification utilises Natural Language Processing (NLP) techniques to analyse pre-trained texts and assign them appropriate labels. Especially in crisis situations like floods, earthquakes, etc., text classifiers are crucial in identifying key information and effectively forwarding it to relevant agencies. However, the efficacy of text classification largely depends on abundant rich training data, which may be difficult to obtain in many scenarios [3]. Relying on a vast amount of non-representative annotated data can lead to delays in project commencement and may impact the model's accuracy. Specifically, in emergencies, identifying action-related information (such as casualties or missing persons) becomes particularly challenging.

To address these issues, this paper introduces a Human-in-the-Loop (HITL) system integrated into the classifier's training process. Coupled with the representational engineering technique of natural language explanations—ExpBERT, a BERT fine-tuned on the MultiNLI natural language inference dataset is utilised to learn from explanations [4]. This optimised embedding representation is used as input to the neural network classifier, further enhancing performance. The core task of the paper revolves around improving the performance of the text classifier based on ExpBERT by combining a limited but representative set of samples with labels and explanations provided by either humans or OpenAI [1].

This paper delves deeply into the application of active learning in text classification tasks based on ExpBERT. During the iterative process, acquisition functions based on uncertainty and diversity are used to select representative unlabeled instances for annotators to process. The original small sample and newly annotated data are used for model retraining. The results indicate that this method can achieve performance similar to models trained on vast datasets within a few iterations. To substantiate this, the model's performance using different active learning strategies is compared on the CrisisNLP dataset, and the effects of an active learning system combined with Monte Carlo Dropout (MCD) are also evaluated.

The main conclusions of this paper are:

- The Human-in-the-loop framework combined with a text classifier enables the model to achieve, or even surpass, the performance of models trained with the full dataset, using only a small amount of annotated data and undergoing a limited number of iterations.
- Compared to merely annotating labels, low-quality explanations, or a limited number of explanations, annotating a certain amount of high-quality explanations can significantly boost the model's performance.
- In terms of acquisition functions, semantic diversity-based sampling and Bayesian Active Learning by Disagreement (BALD) strategies combined with Monte Carlo Dropout (MCD) can allow the model to achieve higher average performance post-training.

# Supporting Technologies

- I used Python as the development language.
- I used the *Transformers* library to introduce pre-trained models and *Pytorch* for implementing neural networks.
- I used OpenAI models as one of the annotation methods.
- I used LaTeX to format my thesis, via the online service *Overleaf*.

# Notation and Acronyms

| | | |
|---|---|---|
| NLP | : | Natural Language Processing |
| BERT | : | Bidirectional Encoder Representations from Transformers |
| ExpBERT | : | Representation Engineering with Natural Language Explanations |
| NLI | : | Natural Language Inference |
| HITL | : | Human-In-The-Loop |
| AL | : | Active Learning |
| BALD | : | Bayesian Active Learning by Disagreement |
| MCD | : | Monte Carlo Dropout |
| GPT | : | Generative Pre-trained Transformer |
| NN | : | Neural networks |

# Acknowledgements

Xinyang Song would like to extend her profound gratitude to her supervisor, Dr. Edwin Simpson, for sharing literature and implementation examples related to ExpBERT and active learning, offering countless invaluable assistance. His professional guidance and enthusiastic support helped me overcome numerous challenges, complete my dissertation, and achieve meaningful insights.

Additionally, I'd like to thank the University of Bristol and my peers for their resources and emotional support during this time. My gratitude goes out to all of you.

# Chapter 1

# Introduction

This chapter begins by introducing the research background of the text classifier based on ExpBERT integrated with Human-In-The-Loop (Section 1.1). Based on this background, the motivation for the experiment was formed in Section 1.2, emphasising the significance of this research. Furthermore, a general overview of the work will be provided, contrasting with the limitations of traditional methods. Finally, the primary objectives and challenges are briefly summarised (Section 1.3).

## 1.1 Background

Emergency response systems for social platforms mainly focus on developing better text classification algorithms to learn from limited data. However, obtaining valuable annotated datasets can prove to be challenging [5]. The text classifier based on ExpBERT receives classification labels and corresponding explanations. These explanations detail which keywords led to a particular classification. ExpBERT incorporates this information into the model's training, allowing it to learn from deeper semantic insights to enhance its generalisation capabilities. Therefore, annotating with representative data and understanding the key phrases is vital for guiding the model towards accurate classification.

However, the data throughput of typical social platforms does not permit the annotation of tens of thousands of entries. Consequently, various forms of active learning that can sample high-information-value data at low costs have found extensive application in classification projects [6, 10]. Active learning emerges as an effective solution to these challenges, selecting a limited number of highly informative unannotated samples for human experts in the loop to annotate [9, 2]. The newly data, once effectively annotated, dictates the performance of the model in the next iteration. Thus, employing different acquisition functions to query the most information-rich new instances is perhaps the most popular approach in active learning. Acquisition functions have naturally become the focal point of research in the domain of active learning.

Additionally, neural network-based text classifiers are often ill-suited for early uncertainty sampling [8, 7]. This is because the weight parameters of the neural network are fixed values, causing the model to be overly confident in its predictions, both correct and incorrect. However, by employing dropout, it's possible to introduce a degree of uncertainty into the model. During training, the dropout layer randomly "turns off" a subset of input units. This randomness ensures that network weights are no longer fixed values, thus simulating weight uncertainty.

## 1.2 Motivation

In light of the aforementioned background, this section emphasises the research motivation from three aspects: accuracy, representativeness, and robustness.

### 1.2.1 Accuracy

A unified feature of social networks, exemplified by Twitter, is the vast amount of data combined with internet-specific language syntax. The ultimate goal is to precisely classify urgent messages when capturing emergent needs and to dispatch relevant departments to address those needs. However, traditional text classification systems that achieve performance improvements are primarily done through extensive supervised learning, which is costly and slow to respond. Texts with varying amounts of information are randomly distributed, and the difference in information content can significantly impact model accuracy. Consequently, the results of capturing and identifying crucial emergency information are often subpar. Therefore, employing active learning models to utilise a small amount of data and enhance accuracy is urgently needed.

### 1.2.2 Representativeness

The ability to query rich feature representations from a large pool of unannotated data can mitigate much of the bias in multi-class active learning problems for emergency scenarios. By actively selecting samples for annotation, the model can choose the most valuable and representative samples in each iteration to enhance its performance. Therefore, selecting an effective acquisition function to seek out representative data has the most profound impact on performance and offers the most significant room for improvement.

### 1.2.3 Robustness

Original models often exhibit an overconfidence bias when handling text classification tasks. When encountering unfamiliar content, they make incorrect and unreliable predictions. In many practical applications, such as disaster response and medical diagnostics, erroneous predictions can have severe consequences. Thus, introducing a certain level of uncertainty to the model to curb its overconfidence has become an essential research topic. On the other hand, we can enhance the robustness of the model without introducing excessive computational overhead. This holds significant value for neural networks in scenarios that demand highly accurate and reliable predictions.

## 1.3 Experimental Methodology

Considering the background and motivations, this paper eventually designs a pool-based Human-In-The-Loop active learning system for text classification. Unlike traditional text classification models, we train with a small amount of annotated data and then use the trained model in combination with various acquisition functions to select instances. Subsequently, preset annotations or human or OpenAI annotators observe and analyse the key features of the extracted instances in the loop, providing corresponding labels and adding a certain amount of explanations. These newly annotated instances are incorporated into the original data, and the above cycle is repeated until the performance reaches that of the full data (with the training set ratio close to 1, annotated with labels and default explanations).

The implementation will utilise uncertainty sampling based on Least Confidence, sentiment diversity sampling, and random sampling as a baseline to examine the performance under various active learning strategies. Detailed explanations of the acquisition functions will be provided in Chapter 2. Furthermore, in every iteration, the concatenated explanatory texts will be processed using a pre-trained model based on ExpBERT to generate deep semantic representations. This embedded vector will then be input into the neural network text classifier.

Lastly, structural modifications will be made to traditional neural network(NN) models. Using the dropout mechanism, the model becomes more robust to minor variations in input, thereby enhancing its generalisation performance. Additionally, dropout can address the model's overconfidence issue by introducing noise and randomness, ensuring that model predictions aren't overly deterministic. While dropout doesn't directly quantify uncertainty, the introduced randomness and noise can bolster the model's resilience and to some extent alleviate its overconfidence. Given the high computational cost of entropy calculations in the original Bayesian Active Learning by Disagreement (BALD) algorithm, we've refined the BALD algorithm. Utilising Monte Carlo Dropout (MCD), we employ Least Confidence to select samples where the model's predictive probability is most uniform (i.e., without a particularly high predictive probability for any category).

### 1.3.1 Objectives

Based on the above experimental descriptions, the objectives of this paper can be summarised as follows:

- Develop a pool-based Human-In-The-Loop framework applied to the ExpBERT-based text classifier and investigate its effectiveness.
- Construct an annotator simulation process and design stopping criteria (e.g., terminate when reaching the performance of the full data model).
- Establish a baseline (performance of the full-data model without active learning or random sampling) and study whether active learning can enhance the performance of the text classification model. Compare the effects of different acquisition functions.
- Explore the impact of the quality and quantity of explanations on this system. For instance, providing explanations with noise or increasing the number of explanations added in each iteration.

### 1.3.2 Challenges

The main challenges of this project lie in the significant differences that may exist between various active learning strategies and how to improve the original initialisation framework of the multi-classifier based on ExpBERT and the annotation process to reduce computational costs.

- It's worth noting that there are multiple acquisition functions in active learning text classification systems. The application of different algorithms in active learning strategies significantly affects the performance of the active learning framework. The choice of strategy needs to consider both time complexity and representativeness.
- Secondly, neural networks with dropout mechanisms might increase computational costs during training algorithm execution and when using MCD for active learning. Thus, how to reduce computational costs in each iteration to improve response efficiency poses a challenge.
- Finally, regarding the framework design, determining the appropriate sampling ratio, the number of iterations, and the number of explanations provided in each iteration requires further study to achieve satisfactory performance.

# Chapter 2

# Background

This chapter introduces the relevant techniques centred around enhancing the performance of the text classifier based on ExpBERT through active learning. Firstly, the ExpBERT mechanism used in the experiment is introduced (Section 2.1). ExpBERT will be applied during dataset pre-training. The active learning-based “Human-In-The-Loop” (Section 2.2) and its main acquisition functions (Sections 2.3 and 2.4) are the focal implementation parts of this experiment, which can rapidly boost performance through this technique. Section 2.5 describes the multi-model integration method, while Section 2.6 discusses using OpenAI models to simulate the annotator role within the Human-In-The-Loop. Lastly, the feasibility of applying Bayesian theory to active learning is concerned.

## 2.1 ExpBERT

The Representation Engineering with Natural Language Explanations (ExpBERT) model proposes a method to enhance the knowledge integration ability of language models. It combines fixed explanations provided by humans or, in this experiment, annotators with tweets to learn from these explanations and improve the model’s performance [4]. Figure 2.1 intuitively shows how to combine samples with explanations with BERT fine-tuned on MultiNLI. Explanations play a key role here. The quality of the explanations has a much greater impact on the performance of ExpBERT than the quantity of explanations. By using high-quality explanations, the model’s learning can be guided.

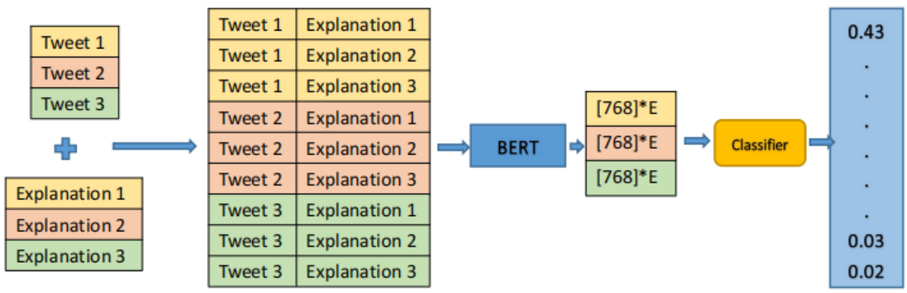


Figure 2.1: Using BERT to produce representations that form the input to the classifier

First, each tweet is fully connected with a set of pre-written explanations to generate a 3×3 set. These explanations are unrelated to specific tweets; each tweet will be connected with the same number of explanations. The preprocessed text and explanations are input into BERT to generate features that ”interpret” each explanation [new 1]. The classifier can be trained to classify the representations of the input and explanations.

After being fine-tuned on the MultiNLI dataset, the BERT model will generate a feature vector for each input sample, representing the entire input of a length of 768. The feature vectors of tweets and explanations are then connected to form an embedding with a size of 768∗E, where E is the number of explanations. This will be used as the input data for training and predicting in the classifier model. This paper will use this model as the basic pre-trained model. At the same time, the Natural Language Inference (NLI) technique will be used to reduce the number of embeddings (the size will be $768 + (3*E)$) and integrate and initialize them into the HITL system. Because this model can handle instance vectors with explanations, the optimized embedding representation as input to the classification model can improve the performance of the model.

# Chapter 3

# Execution

**A topic-specific chapter, roughly 30% of the total page-count**

This chapter is intended to describe what you did: the goal is to explain the primary activity or activities of any type which constituted your work during the project. The content is highly topic-specific. For some projects it will make sense to split the content into two main sections or maybe even into two separate chapters: one will discuss the design of something, including any rationale or decisions made, and the other will discuss how this design was realised via some form of implementation. You could instead give this chapter the title “Design and Implementation”; or you might split this content into two chapters, one titled “Design” and the other “Implementation”.

Note that it is common to include evidence of “best practice” project management (e.g., use of version control, choice of programming language and so on). Rather than simply a rote list, make sure any such content is valuable and informative in some way: for example, if there was a decision to be made then explain the trade-offs and implications involved.

## 3.1 Example Section

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Figure 3.1: This is an example figure.

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Table 3.1: This is an example table.

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### 3.1.1 Example Sub-section

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**for** $i = 0$ **upto** $n$ **do**
  $t_i \leftarrow 0$
**end**

**Algorithm 3.1:** This is an example algorithm.

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for( i = 0; i < n; i++ ) {
  t[ i ] = 0;
}
```

Listing 3.1: This is an example listing.

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# Chapter 4

# Critical Evaluation

**A topic-specific chapter, roughly 30% of the total page-count**

This chapter is intended to evaluate what you did. The content is highly topic-specific, but for many projects will have flavours of the following:

1. functional testing, including analysis and explanation of failure cases,
2. behavioural testing, often including analysis of any results that draw some form of conclusion wrt. the aims and objectives, and
3. evaluation of options and decisions within the project, and/or a comparison with alternatives.

This chapter often acts to differentiate project quality: even if the work completed is of a high technical quality, critical yet objective evaluation and comparison of the outcomes is crucial. In essence, the reader wants to learn something, so the worst examples amount to simple statements of fact (e.g., "graph X shows the result is Y"); the best examples are analytical and exploratory (e.g., "graph X shows the result is Y, which means Z; this contradicts [1], which may be because I use a different assumption"). As such, both positive *and* negative outcomes are valid *if* presented in a suitable manner.

# Chapter 5

# Conclusion

**A compulsory chapter, roughly 10% of the total page-count**

The concluding chapter(s) of a dissertation are often underutilized because they're too often left too close to the deadline: it is important to allocate enough time and attention to closing off the story, the narrative, of your thesis.

Again, there is no single correct way of closing a thesis.

One good way of doing this is to have a single chapter consisting of three parts:

1. (Re)summarise the main contributions and achievements, in essence summing up the content.
2. Clearly state the current project status (e.g., "X is working, Y is not") and evaluate what has been achieved with respect to the initial aims and objectives (e.g., "I completed aim X outlined previously, the evidence for this is within Chapter Y"). There is no problem including aims which were not completed, but it is important to evaluate and/or justify why this is the case.
3. Outline any open problems or future plans. Rather than treat this only as an exercise in what you *could* have done given more time, try to focus on any unexplored options or interesting outcomes (e.g., "my experiment for X gave counter-intuitive results, this could be because Y and would form an interesting area for further study" or "users found feature Z of my software difficult to use, which is obvious in hindsight but not during at design stage; to resolve this, I could clearly apply the technique of Bloggs *et al.*.

Alternatively, you might want to divide this content into two chapters: a penultimate chapter with a title such as "Further Work" and then a final chapter "Conclusions". Again, there is no hard and fast rule, we trust you to make the right decision.

And this, the final paragraph of this thesis template, is just a bunch of citations, added to show how to generate a BibTeX bibliography. Sources that have been randomly chosen to be cited here include:

# Bibliography


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[10] Devis Tuia, Michele Volpi, Loris Copa, Mikhail Kanevski, and Jordi Munoz-Mari. A survey of active learning algorithms for supervised remote sensing image classification. *IEEE Journal of Selected Topics in Signal Processing*, 5(3):606–617, 2011.

# Appendix A

# An Example Appendix

Content which is not central to, but may enhance the dissertation can be included in one or more appendices; examples include, but are not limited to

- lengthy mathematical proofs, numerical or graphical results which are summarised in the main body,
- sample or example calculations, and
- results of user studies or questionnaires.

Note that in line with most research conferences, the examiners are not obliged to read such appendices.