Deciphering Multi-task Learning: Comparative Insights for Similar and Dissimilar Tasks

Anonymous ACL submission

Abstract

Multi-task learning (MTL), which emerged as a powerful concept in the era of machine learning, employs a shared model trained to handle multiple tasks at the same time. Numerous advantages of this novel approach inspire us to investigate the insights of various tasks with similar (Identification of Sentiment, Emotion, Sarcasm, Irony, Hate and Offensive) and dissimilar (Identification of Sentiment, Claim, Language) genres and to analyze the change in their performances with respect to long and short head approaches. We shed light on the methods employed and critical observations to promote a more efficient learning paradigm across similar and dissimilar tasks.

1 Introduction

The popularity of internet and social media not only allows users to express their opinions, sentiments, emotions or sarcasm but at the same time, such social media posts can also contain hateful and offensive contents that are vulnerable for teenagers. In the past decades, most of the researchers have worked on single tasks such as classification of sentiment, sarcasm, emotion, hateful sentences etc. while a few researchers have emphasized on two or multiple classification tasks e.g., sentiment and sarcasm (Majumder et al., 2019a; El Mahdaouy et al., 2021; Tan et al., 2023), sentiment and emotion (Akhtar et al., 2019; Singh et al., 2022) etc.

Multi-task learning (MTL) as the name suggests, refers to a single shared machine-learning model that can perform multiple different tasks simultaneously (Kundu, 2023). The MTL provides three advantages over single-task learning - i) it helps in achieving generalization for multiple tasks; ii) each task improves its performance in association with the other participating tasks; and iii) it offers reduced complexity (Akhtar et al., 2019).

In the present article, we proposed two schemes of multi-task learning: First, a MTL model that classifies six related tasks of similar genre: sentiment, sarcasm, emotion, irony, hate speech and offensive and Second, a similar multi-task learning model working on relatively dissimilar tasks: claim detection, language identification, and sentiment analysis. The main objectives of our work is 1) to analyze whether adding different classification tasks (similar or dissimilar) into a MTL model can improve the overall performance of each classification over single-task or not; 2) to identify whether and how a task can gain out of MTL with respect to the tasks of similar and different flavours. Besides, we performed various combinations of tasks in MTL such as emotion and sarcasm classification, sentiment and hate speech classification, etc. to analyze the performance in a different scenario.

2 Related Work

The concept of MTL was first proposed by Caruana (1997). Liu et al. (2016) and Liu et al. (2017) proposed MTL frameworks using LSTM and BiLSTM for text classification.

Majumder et al. (2019b), Tan et al. (2023) and Savini and Caragea (2020) proposed MTL frameworks for sentiment and sarcasm classification. Majumder et al. (2019b) used GRU-based architecture and attention mechanism to classify sentiment and sarcasm whereas Tan et al. (2023) and Savini and Caragea (2020) used BiLSTM in their study. In addition, Savini and Caragea (2020) used a non-contextual pre-trained embedding FastText (Bojanowski et al., 2016), which elevates their performance. Another sentiment and sarcasm analysis MTL work was proposed by El Mahdaouy et al. (2021) using the pre-trained BERT model where the authors focused only on Arabic languages.

In this present article, we focused on a comparative analysis for multi-task learning framework for similar and dissimilar tasks.

	Dataset	#Texts
Similar Tasks	Sentiment	59899^a + 14640^b
	Sarcasm	55328^c + 690^d
	Emotion	5052^a
	Irony	4601^a
	Hate	12962^a
	Offensive	14100^a
Dissimilar Tasks	Claim	2190^e
	Claim	2197^f
	Language	21859^g

Table 1: Datasets and number of texts in those datasets (^{a}:Tweet_Eval; ^{b}:twitter-airline-sentiment; ^{c}:Sarcasm_News_Headline; ^{d}:MUStARD; ^{e}:LiveJournal; ^{f}:Wikipedia; ^{g}:WiLI-2018)

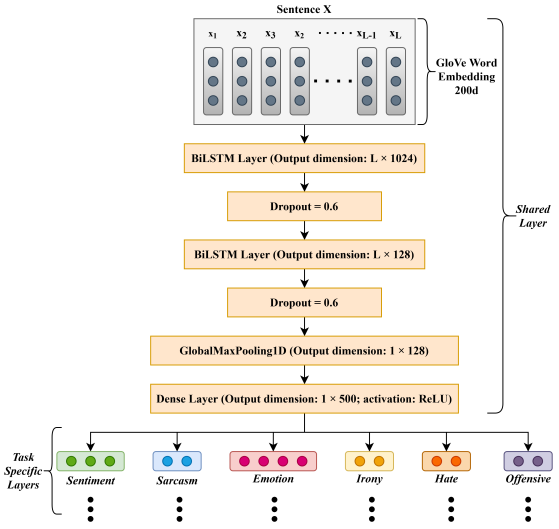

Figure 1: Proposed model architecture

3 Dataset Preparation

In order to accomplish our first task, to the best of our knowledge, no publicly available dataset includes all the class labels together. Thus, we collected different task datasets from various sources with single labels and identify other labels using some pre-trained models[1][2]. For example, in case of sentiment dataset, the sarcasm, emotion, irony, hate, and offensive labels were identified; for the sarcasm dataset, the sentiment, emotion, irony, hate, and offensive labels were calculated, and so on. For the sentiment, irony, emotion, hate, and offensive sentences, we use the Tweet_Eval (Barbieri et al., 2020). In order to develop MTL model for dissimilar tasks, we collect another sentiment dataset from Kaggle known as the airline_tweet_sentiment[3] dataset. For sarcasm, the Sarcasm_News_Headline[4] dataset and the MUStARD (Castro et al., 2019) dataset were used. The number of texts in each dataset is given in Table 1 (Similar Tasks).

For validation, 10% of the data was preserved while the remaining data was used for training and testing purposes. After that, we merged all the datasets into a single dataset. For the second task, we have used the datasets used by (Rosenthal and McKeown, 2012) in their paper. These datasets contain sentences from LiveJournal weblogs and Wikipedia talk pages annotated for opinionated claims. In these datasets, we have 2190 instances, from LiveJournal and 2197 from Wikipedia. We have collected another dataset which is a preprocessed version of WiLI-2018[5], the Wikipedia language identification benchmark dataset. The number of texts in each dataset is given in Table 1 (Dissimilar Task).

After collecting this dataset, the sentiment labels for claim datasets were identified using some pre-trained model[6].

4 Methods

In this section, we describe our proposed methodology. We aim to develop a single multi-task learning model that can classify six similar types of tasks (sentiment, sarcasm, emotion, irony, hate, and offensive) in the first case and three dissimilar types of tasks (claim, language, and sentiment) in the second case. The overall model architecture is depicted in Figure 1.

For each sentence S, first, we conducted some basic preprocessing in S such as — i) Removal of HTML tags, ii) Convert S into a lowercase sentence, iii) Removal of punctuations and multiple spaces, iv) If S has any username that starts with the character '@' then convert that into '@user', v) If S has any website links, then convert that link into 'http'.

Then we converted S into a sequence of tokens $[k_1, k_2, k_3, ..., k_n]$. Since every sentence gives a variable length token, we convert every sentence into a fixed-sized sequence of tokens by padding 0 at the end. So, after padding 0, S now becomes in

[1] https://huggingface.co/cardiffnlp
[2] https://bit.ly/english-sarcasm-detector
[3] https://bit.ly/twitter-airline-sentiment
[4] https://bit.ly/sarcasm_news_headline
[5] https://bit.ly/language-identification-datasst
[6] https://bit.ly/multilingual-cased-sentiments-student

the form of $[k_1, k_2, k_3, ..., k_L]$ where $L = 200$.

Word Embedding: For word embedding, we have used the pre-trained "GloVe"(Pennington et al., 2014) word embedding with dimension D = 200, to convert each token k_i of sentence X into a sequence of vector x_i of length D. Thus, from a tokenized sentence $X = [k_1, k_2, k_3, ..., k_L]$ we get $X_{L\times D} = [x_1, x_2, x_3, ..., x_L]$. Then, $X_{L\times D}$ is fed into a BiLSTM layer as depicted in Figure 1.

BiLSTM Layer : A variant of recurrent neural network (RNN) is bidirectional long-sort term memory commonly known as BiLSTM. In traditional neural networks, there are short-term memory problems. Also, the vanishing gradient problem is one of the major drawbacks of those models. The LSTMs effectively enhance performance by identifying patterns, retaining important information and eliminating the vanishing gradient problem. The BiLSTMs are more powerful than normal unidirectional LSTMs by the capable of analysing the inputs from the beginning as well as from the end. Since it analyses inputs from both ends so, it has the capability of utilising features from the past as well as from the future. This gives a better language understanding over unidirectional LSTMs.

GlobalMaxPooling: We integrated two BiLSTM layers followed by a dropout layer of 0.6 (Figure 1) and used a "GlobalMaxPooling" layer. The "GlobalMaxPooling1D" gives the maximum value from the hidden output vectors. So, if the output of the 2nd dropout layer is $[\hat{y_1}, \hat{y_2}, \hat{y_3}, ..., \hat{y_M}]_{L\times M}$ where $\hat{y_i}$'s are vectors of length L and M is the number of hidden units of a BiLSTM layer then,

$$Z_{GlobalMaxPooling1D} = [Max(\hat{y_1}), Max(\hat{y_2}), Max(\hat{y_3}), ..., Max(\hat{y_M})]_{[1\times M]}$$

After that, $Z_{GlobalMaxPooling1D}$ fed into a dense layer with 500 neurons:

$$Z_* = ReLU(Z_{GlobalMaxPooling1D})$$

However, we have also done our experiments without the GlobalMaxPooling layer to check the performances in different scenarios. For the model without the GlobalMaxPooling layer, the output of the 2^{ns} BiLSTM layer is fed into the dense layer of 500 neurons.

$$Z_* = ReLU(Z_{BiLSTM_2})$$

BERT-based approach: Along with BiLSTM models, we also performed our experiments with the recent transformer-based pre-trained model BERT(Devlin et al., 2018) where instead of using BiLSTM and GlobalMaxPooling layers we just used BERT model and keep the remaining frameworks same for similar and dissimilar tasks.

Classification:

Short-Head Approach: In the case of similar tasks, for six classification tasks, we use six different dense layers. We fed Z_* as an input in each of six dense layers.

$$P_* = softmax(Z_*)$$

where P_* means probability values for either sentiment, sarcasm, emotion, irony, hate, or offensive classes, respectively.

Long-Head Approach: In the case of dissimilar tasks, for each of the three classification tasks, we have a series of task-specific layers consisting of dense and dropout layers.

$$O_1 = dense(Z_*); O_2 = tanh(O_1);$$
$$O_3 = dropout(O_2); O_4 = dense(O_3);$$
$$P_* = softmax(O_4)$$

where, O_1 to O_4 are intermediate output values from corresponding layers, and P_* means probability values for either sentiment, claim, or language classes. In the initial dense layer, we used 64 neurons, and in the latter dense layer, we used a different number of neurons which is equal to the number of labels corresponding to the tasks.

Training: For the multi-task loss function, we used the CrossEntropy loss for each of the tasks and monitored the loss for the test split of the dataset.

$$L_{total} = \sum_{i=1}^{K} L_i$$

where L_i is the loss for different tasks and K is the number of tasks.

To train our proposed model, we took 50 epochs for BiLSTM and 5 epochs for BERT. However, we used the "early stopping"[7] method to eliminate overfitting in our model. For the optimizer, we selected the Adam optimizer with a learning rate of 0.0005 and 2e-5 for BiLSTM and BERT and the batch size was taken as 32 to train the model.

[7] https://keras.io/api/callbacks/early_stopping/

	Task	1-TL	K[#]-TL	K-TL[$]	Best Score[*]	1-TL$_{BERT}$	K-TL$_{BERT}$
Similar Task	Sentiment (se)	0.687	0.767	0.749	0.767 (all task)	0.736	0.826
	Sarcasm (sa)	0.957	0.909	0.907	0.957 (sa)	0.972	0.937
	Emotion (em)	0.682	0.742	0.699	0.848 (sa+em)	0.751	0.818
	Irony (ir)	0.649	0.819	0.793	0.875 (sa+ir)	0.690	0.858
	Hate (ht)	0.718	0.793	0.727	0.83 (sa+em+ht)	0.771	0.838
	Offensive (of)	0.722	0.874	0.858	0.884 (sa+ht+of)	0.780	0.903
Dissimilar Task	Sentiment (se)	0.668	0.539	0.595	0.682 (se+cl)	0.922	0.841
	Claim (cl)	0.706	0.623	0.629	0.706 (cl)	0.963	0.851
	Language (la)	0.953	0.690	0.038	0.953 (la)	0.987	0.981

Table 2: F1-Score comparison of 1-TL vs K-TL vs best MTL combination ([#]: K = 6 for similar tasks and K = 3 for dissimilar tasks; [$]: Results of MTLs without max pooling layer; [*]: All the Best Scores used GlobalMaxPooling layers)

5 Experiment and Result

5.1 Experimental Setup

We used 'TensorFlow' and 'Keras' to implement our proposed models and used the 'Collaboratory' environment to execute the code and calculate the F1-Score to evaluate the performance. Moreover, we have evaluated and compared the performances of 6-TL (all similar classification task) and 3-TL (all dissimilar classification task) with and without the GlobalMaxPoolig layer.

Similar Task Comparison: Here, we will compare and contrast how these similar tasks have performed in our MTL framework. We perform all the combinations of MTLs such as 2-TL (combination of 2 tasks), 3-TL (combination of 3 tasks), 4-TL (combination of 4 tasks), 5-TL, and 6-TL and provided the results in 2.

For similar tasks as shown in Table 2, the BERT-based models outperform the best combination of BiLSTM-based MTL combination. For sentiment, hate speech and offensive language classification, the best performance was achieved by BERT models whereas for sarcasm, emotion and irony classification the BiLSTM-based models outperformed.

Dissimilar Task Comparison: For dissimilar tasks, it can be observed from Table 2 that the performance in BERT models has significantly increased in both MTL and STL. However, the performance in MTL cannot beat the performance in STL models. Additionaly, if we observe the performances of dissimilar tasks in which the GlobalMaxPooling layer is not used, in that case, the F1-Score in sentiment and claim classification are slightly increased, but the F1-Score for the language classification task is dramatically decreased to 0.038.

6 Observation

In this study, our main motive was to study the performance of our model for different similar and dissimilar tasks and draw some insights from that. After all the experiments, there were a few noticeable points we delved deep into —

Firstly, we have observed that the performances of similar tasks as a whole are far better than dissimilar tasks in our MTL setting. One of the reasons can be the size of the dataset used for similar and dissimilar tasks or similar tasks help one another to perform better than dissimilar tasks do.

Secondly, as already discussed in Section 4, for similar tasks we have used the Short-Head approach, and for dissimilar tasks we have used the Long-Head approach. The reason behind this is the simple fact that similar tasks have many attributes in common among them. So, their common or shared layers are more in number rather than the individual task-specific layers. Whereas, the dissimilar tasks have very few things in common among them and each task needs extra standalone attention. For this reason, for dissimilar tasks, we have used more layers in the individual task-specific layers.

7 Conclusion

In this paper, we proposed a multi-task learning approach using deep learning that can classify sentences into similar classes like sentiment, sarcasm, emotion, irony, hate, and offensive. We also proposed a multi-task architecture that is used to handle dissimilar tasks like claim detection, sentiment analysis, language identification, etc. We have observed that similar tasks performed well in the MTL framework as compared to dissimilar tasks.

8 Limitations

Our proposed MTL works also have some limitations. Firstly, we didn't explore any transformer-based architectures such as BERT (Devlin et al., 2018), and we'll explore them in future works. Secondly, as already discussed in Section 3 to prepare our dataset, we used some open-source models to produce the missing labels needed for our experiments. Hence, there might be some false labelling as those models are not 100% accurate. It must have a negative effect on the overall performance in the individual tasks. This is one of the limitations of our work.

Thirdly, for similar tasks, it can be seen from Table 1 that the number of texts in sentiment and sarcasm datasets is much larger than the emotion, irony, hate and offensive dataset's number of texts. So, there may be a performance bias in our overall classification. This is another limitation of our work.

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