CSE584 Midterm Project Report: Sentence Generation Classifier

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Abstract

Advancements in AI and NLP demand improved techniques for text completion and classification, particularly in complex linguistic contexts. This study evaluates seven state-of-the-art large language models using novel two encoder architecture with SBERT and LUAR. The prepared dataset of truncated sentences from public sources enabled extensive evaluation. The LUAR model excelled with over 15% higher accuracy, attributed to its distinct random sampling method enhancing generalizability. Findings highlight the crucial impact of model size and architecture complexity, with larger and multi-layered configurations offering superior performance. This work advances methodology by introducing an encoder setup that strengthens classification and suggests model design optimizations, highlighting potential future research avenues with diverse datasets and broader model exploration.

1 Introduction

With the rapid advancements in artificial intelligence and natural language processing, significant strides have been made in the domains of textual data completion and classification. These enhanced capabilities of generating coherent and contextually appropriate text continuations open up vast potential across various applications, from refining user interactions to propelling automated content creation. Despite these advancements, challenges persist, particularly in developing models that can accurately interpret and replicate complex linguistic styles, thereby necessitating continued exploration into model architectures and training methodologies.

This research embarks on an exploration of various advanced Large Language Models (LLMs) to assess their efficacy in completing incomplete sentences extracted from a diverse array of datasets. The investigation leverages seven state-of-the-art LLMs: GPT-4o, Gemini1.5-Pro, Llama3.1-70B, Llama3.1-8B, Qwen2.5-32B, Qwen2.5-72B, and Claude3.5-Sonnet, each tasked with generating sentence continuations (OpenAI et al., 2024; Dubey et al., 2024; Team et al., 2024; Team, 2024; Anthropic, 2024). Central to this investigation is novel encoder architectures that seeks to leverage distinct embedding spaces for enhanced classification, alongside experiments employing SBERT and LUAR as encoders (Reimers and Gurevych, 2019; Rivera-Soto et al., 2021), further enriching the analysis.

The dataset preparation involved extracting complete sentences from six publicly available datasets, followed by strategic truncation and deduplication processes, ultimately resulting in a robust set of 28,538 incomplete sentences. This structured dataset serves as the foundation for rigorous training, testing, and validation, distributed across various models to ensure balanced evaluations.

The comprehensive experimentation provides pivotal insights into how architectural choices—such as encoder configurations and classification layer complexity—impact performance. Through the meticulous evaluation of these elements, the study not only advances the current understanding of model capabilities but also sets the stage for future innovations in LLMs research and development.

2 Related Work

The increasing use of LLMs has driven the need for effective tools to detect machine-generated text and evaluate performance in sentence completion tasks (Mitchell et al.; Bao et al., 2024; Soto et al., 2024; Guo and Yu, 2023; Abburi et al., 2023; Wang et al., 2023; Akram; Su et al., 2023; Liu et al., 2024; Mireshghallah et al., 2024; Gagiano and Tian). DetectGPT (Mitchell et al.) introduces a novel zero-shot framework for detecting AI-generated content

by analyzing probability curvature, demonstrating that models can differentiate machine-generated text without prior exposure to the content. FAST-DetectGPT (Bao et al., 2024) builds upon this concept by introducing a more efficient detection mechanism that operates in zero-shot scenarios using conditional probability curvature. SeqXGPT (Wang et al., 2023) is an AI-generated text detector focusing on sentences instead of documents. They make use of log probabilities from several models as features. (Gagiano and Tian, 2023) proposes a prompting strategy using predictions and confidence scores of a fine-tuned model. Hence, they aim to make the model think more. In addition, they use a label smoothing strategy to fine-tune a model. (Soto et al., 2024) proposes few-shot learning using style representations, called LUAR (Rivera-Soto et al., 2021) to detect machine generated task. (Guo and Yu, 2023) proposes a model denoising strategy based on the assumption that human-written text should reside outside the distribution of machine-generated text. They first denoise input text with artificially added noise using an LLM. Then, they semantically compare that denoised text with the original text to detect if the text is generated by a machine. Another interesting finding is that smaller and partially trained models are better machine generated text detectors (Mireshghallah et al., 2024). Their approach is based on a curvature test using the likelihood surface of a surrogate detection model.

Another research area is about authorship verification (AV), which decides if a pair of text is written by the same author. Our task is different from AV in the sense that we predict the author. Therefore, our task is more specific because in addition to differentiating the authors, we predict the specific author. The similarity is that writing styles play an important role. (Huang et al., 2024a) reviews the challenges and methodologies of authorship attribution with LLMs. They highlight the importance of generalization across domains and improved explainability in authorship detection methods. The capability of LLMs on authorship attribution and verification has also been analyzed (Huang et al., 2024b). They propose a linguistically informed prompting for zero-shot setting and show that there is no need to fine-tune a model for this task. Similar to (Huang et al., 2024b), (Hung et al., 2023) also proposes different prompting strategies for AV. They add several criteria to the prompt that are relevant to the styles of a text such as tone, mood, idioms, or punctuation. (Rivera-Soto et al., 2021) develops a new model to learn authorship representations using contrastive loss. Their training process tries to make the texts' representations from the same author similar. They use SBERT (Reimers and Gurevych, 2019) as an encoder. (Wegmann et al., 2022) argues that to learn style representations, using an authorship verification task may not be appropriate because, in this way, models might learn content too. Therefore, they propose a content control mechanism using contrastive learning. Their experiments show that learning style representations this way is more effective.

3 Datasets

3.1 Incomplete sentences

For our experiments, we first extracted complete sentences with at least 8 words from six publicly available datasets. After extracting the complete sentences from each dataset, we truncated them by keeping the first half based on the word count. In other words, if a sentence S contains n words, we kept only the first $\lceil \frac{n}{2} \rceil$ words. For example, the sentence with 16 words, *"A man is being pulled on a water ski as he floats in the water casually."*, was truncated to *"A man is being pulled on a water"*, keeping the first 8 words.

After truncation, we identified identical sentences in the dataset and removed these duplicates. With all the processing, we ended up with 28,538 incomplete sentences across the six datasets. Below is a brief description of each dataset we utilized.

3.1.1 HellaSwag

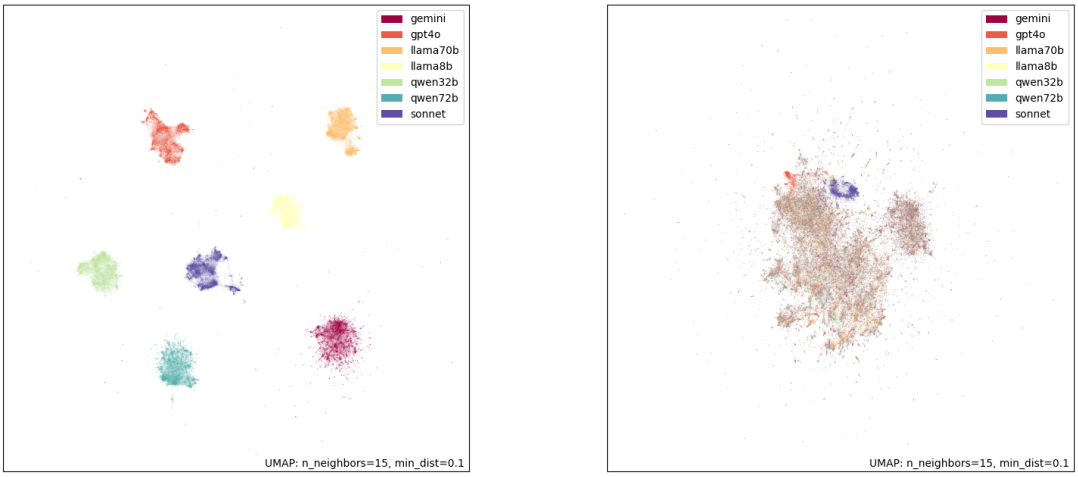
The HellaSwag dataset[1] (Zellers et al., 2019) is designed to test ability of models to predict the most plausible continuation of a given sentence. `ctx_a` column contains complete sentences for each example. We extracted 6,357 sentences from this column.

3.1.2 SNLI Corpus

The Stanford Natural Language Inference(SNLI) Corpus dataset[2] (Bowman et al., 2015) is designed to train and evaluate models on natural language understanding tasks, which was released by the Stanford Natural Language Processing Group.

[1] https://www.kaggle.com/datasets/thedevastator/hellaswag-a-new-commonsense-nli-dataset

[2] https://www.kaggle.com/datasets/stanfordu/stanford-natural-language-inference-corpus/data



(a) Embedded using LUAR

(b) Embedded using SBERT

Figure 1: Two-dimensional visualisations of embeddings of X_js

`sentence1` column contains complete sentences for each example. We extracted 6,928 sentences from this column.

3.1.3 COCO caption

The COCO caption dataset[3] is used for the Microsoft COCO dataset to provide image captions in natural language. `caption` column contains complete sentences for each example. Total number of sentences we can access was 762 and we extracted 559 unique sentences from this column.

3.1.4 MultiNLI

The Multi-Genre Natural Language Inference (MultiNLI) Corpus dataset[4] (Williams et al., 2018) is designed to evaluate models on sentence-level natural language understanding across multiple genres. The dataset was released by the New York University (NYU) Natural Language Processing Group. `sentence1` and `sentence2` columns contain complete sentences for each example. We extracted 4,950 sentences from them.

3.1.5 Brown Corpus

The Brown Corpus dataset [5] is one of the first major collections of text for linguistic research, covering a wide variety of genres in American English. `tokenized_text` column contains complete sentences for each example. We extracted 4,943 sentences from this column.

3.1.6 Bible Corpus

The Bible Corpus dataset[6] contains the full text of the Bible in the American Standard Version. `t` column contains complete sentences for each verse. We extracted 4,801 sentences from this column.

Datasets	# of sentences	# of sentences without duplicates
HellaSwag	7119	6357
SNLI Corpus	7119	6928
COCO caption	762	559
MultiNLI	5000	4950
Brown Corpus	5000	4943
Bible Corpus	5000	4801
Total	30000	28538

Table 1: The number of sentences from each dataset before and after removing duplicates.

3.2 Complete sentences from Large Language Models

To complete the given incomplete sentences, we used 7 models: GPT-4o, Gemini1.5-Pro, Llama3.1-70B, Llama3.1-8B, Qwen2.5-32b, Qwen2.5-72B, and Claude3.5-Sonnet (OpenAI et al., 2024; Dubey

[3] https://github.com/tylin/coco-caption (Chen et al., 2015)

[4] https://cims.nyu.edu/~sbowman/multinli/

[5] https://www.kaggle.com/datasets/nltkdata/brown-corpus/data (Francis and Kucera, 1964)

[6] https://www.kaggle.com/datasets/oswinrh/bible?select=t_asv.csv

et al., 2024; Team et al., 2024; Team, 2024; Anthropic, 2024). For Gemini and Claude, we generated the following sentences using the prompt *"Complete the given sentence. Do not give any explanation."*, while for the others, we used the prompt *"Complete the given sentence"*. We then stored all the generated sentences from each model in separate files and combined them into a single file.[7] While all the models except Gemini generated following sentences for every given incomplete sentence, Gemini did not generate following sentences for seven of the incomplete sentences due to sensitivity reasons, and we excluded these seven sentences from the Gemini dataset. We preprocessed datasets and as shown on the Tab. 1, we have about 28K unique sentences and each dataset sources has similar distributions except COCO caption as mentioned in section 3.1.3.

4 Classification Model

We propose a simple but effective neural architecture. Our dual encoder (Bromley et al., 1993) learns different embedding spaces for the X_is and X_js. We concatenate the embeddings of X_is and X_js and feed them into a simple neural classifier consisting of one or two fully connected layers. As encoders, we experiment with SBERT (Reimers and Gurevych, 2019), which was designed to learn representations for semantic similarity, and LUAR (Rivera-Soto et al., 2021), which was intended to model authorship styles. We use cross-entropy loss, Adam optimizer (Kingma and Ba, 2014), batch size of 8, and learning rate of 0.0001. Because of time constraints, we could not do a lot of hyperparameter optimizations. Our hypothesis was that LUAR should perform way better based on the findings in (Rivera-Soto et al., 2021) and Fig 1. LUAR is more capable of distinguishing different styles of texts.

The experiment was initiated with methods aimed at enhancing the diversity and robustness of the data within the evaluation framework. The augmented datasets were labeled from 0 to 6, each number indicating the specific LLM responsible for generating a given sentence. This consolidated dataset served as the primary input. of rigorous training and evaluation, 70% of the data was allocated for training, 10% for testing, and the remaining 20% for validation. This stratified approach ensured balanced distribution across all dataset splits, which is essential for a comprehensive assessment of model performance.

To evaluate the influence of different architectural setups, the performances of single-encoder and dual-encoder configurations were compared. This assessment provided insights on how the architectural type impacts the models' effectiveness. Moreover, differential impacts of **classification layer** complexity were investigated by conducting experiments with one-layer and two-layer setups. The one-layer setup utilized a linear classification layer, whereas the two-layer scenario incorporated an additional linear layer with a ReLU activation function. This exploration highlighted the role of network depth and non-linearity in classification accuracy.

Environment setups for each model were meticulously configured due to their unique requirements. The LUAR model necessitated a specialized setup, prompting differentiated environmental configurations for each model. For instance, the SBERT configuration employed the latest module versions from the transformers library to ensure compatibility and optimal performance. Detailed module version specifications used for the LUAR experiment are available in the GitHub repository[8], providing transparency and supporting reproducibility for future research.

Lastly, the **ablation study** concentrated on evaluating the contribution of individual components within the classification model. Models were trained using only X_j, while other configuration parameters remained constant, except for the classification layers. By systematically omitting specific inputs, the study discerned the impact of each component on overall model performance, thereby emphasizing the significance of each feature within the augmented setup. This analysis was integral in understanding model nuances and guiding future improvements.

5 Results

5.1 Main Experiment

For each encoder, we experimented with six architectural setups, including the ablation case. First, we applied both single- and dual-encoder configurations to the datasets. Additionally, we created two setups by varying the number of classification

[7] https://github.com/berkatil/cse584-midterm-project/blob/main/dataset/combined_data.csv

[8] https://github.com/berkatil/cse584-midterm-project/blob/main/environment.yml

layers, 1 and 2, for each encoding method. Each experiment results were represented with confusion matrix and stored in our github repository[9]. Fig 2 is one of the confusion matrix.

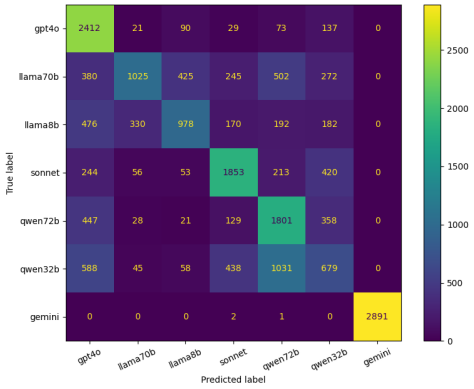


Figure 2: LUAR result with 3 epoch, dual encoder, and 2 classification layers

Since our task is a classification problem, we evaluate their performances using the following metrics: Precision, Recall, F1 Score, Accuracy. The results in these metrics are presented in Table 2.

As expected, LUAR significantly outperformed, achieving around 0.6 across all metrics. In contrast, the performances of SBERT varied roughly between 0.3 to 0.4, depending on the setups, even in the ablation case. We will further elaborate on the results in the next section.

5.2 Ablation Study

For the ablation study, we applied both SBERT and LUAR encoder as a single encoder configuration. We provided the generated sentences X_js only without the given incomplete sentences for this study and results are shown in Table 3.

6 Discussion

The results of the experiment underscore the superior performance of the LUAR model, which outperformed its counterparts by achieving more than 15% higher accuracy, alongside other evaluative scores as depicted in Table 2. This outcome not only aligns with the initial hypothesis but also validates the efficacy of the LUAR model's design, particularly its employment of random sampling during training. This additional step has been referenced in literature to enhance model generalizability (Rivera-Soto et al., 2021; Boenninghoff et al., 2020).

Analyzing the impact of epoch quantity, it was observed that increasing the number of epochs consistently enhanced model performance. Furthermore, the architecture of classification layers was found to significantly affect model outcomes. A single-layer classifier tends to oversimplify logical deductions, potentially leading to underfitting, whereas models utilizing two classification layers exhibited markedly improved performance metrics.

Model	# of unique tokens	average # of words
GPT4o	33174	19.03
Llama70b	39115	12.50
Llama8b	34721	16.68
Sonnet	28450	12.37
Qwen72b	22913	6.52
Qwen32b	27646	8.43
Gemini	20684	4.10

Table 4: Model response statistics

When evaluating different classifiers, it emerged that sentence classification efficiency is higher for models such as GPT4o, Sonnet, and Gemini. Conversely, both classifiers encountered difficulties in classifying sentences generated by the qwen32b model.

The effect of model size was evident in comparative analyses within the study, particularly among the Llama and Qwen models. While Llama demonstrated consistent performance regardless of size, variations in Qwen model sizes significantly influenced the LUAR classifier's performance. It is usually easier to find larger models, suggesting a correlation between model size and classification efficacy.

An additional experiment was conducted to explore the correlation between dataset characteristics and model accuracy, focusing on factors such as the number of unique tokens and average word length (see Table 4). This analysis highlighted that generated sentences by LLMs such as GPT4o, Sonnet, and Gemini were more effective, while outputs from the Qwen32b model posed classification challenges. Although certain correlations between accuracy, unique tokens, and word count were identified, they were not statistically significant, likely attributable to the limited sample size. Nonetheless, the study indicates that model size potentially

[9] https://github.com/berkatil/cse584-midterm-project

Encoder	Setup	Precision	Recall	F1 Score	Accuracy
SBERT	Dual, 1 Layer	0.370121	0.375202	0.356964	0.377922
	Dual, 2 Layers	**0.436489**	**0.430565**	**0.423831**	**0.432599**
	Single, 1 Layer	0.302669	0.311536	0.294239	0.313294
	Single, 2 Layers	0.367233	0.375006	0.362895	0.376522
LUAR	Dual, 1 Layer	**0.628634**	0.607513	0.584749	0.609173
	Dual, 2 Layers	0.616155	0.606646	0.593206	**0.611661**
	Single, 1 Layer	0.610068	**0.607937**	**0.596391**	0.610884
	Single, 2 Layers	0.606333	0.593647	0.581397	0.599741

Table 2: Performance of each setup with different metrics

Encoder	Setup	Precision	Recall	F1 Score	Accuracy
SBERT	1 Layer	0.366762	0.388330	0.363484	0.392433
	2 Layers	**0.436988**	**0.448674**	**0.434210**	**0.451568**
LUAR	1 Layer	**0.621281**	0.613296	0.590984	0.615807
	2 Layers	0.612787	**0.620237**	**0.594096**	**0.620368**

Table 3: Performance of the ablation case with different metrics

plays a crucial role in influencing classification efficiency across diverse large language models. This finding underscores the importance of considering model size in the development and deployment of classification systems.

Upon analyzing the ablation study results, a comparison between the best outcomes from Table 2 and Table 3 reveals that the ablation study consistently produced higher scores across all metrics. This suggests that the X_is included in the main experiment have a minimal impact on performance and may act as noise in the dataset. One possible explanation is that providing identical X_is simply completes the input sentences without contributing any meaningful information for the classification task.

7 Conclusion

In conclusion, this study comprehensively evaluated the performance of various large language models (LLMs) and neural architectures in tasks related to sentence completion and classification. The LUAR model demonstrated marked superiority, corroborating the initial hypothesis and effectively distinguishing between textual styles. It was observed that enhancing the number of epochs and classification layers significantly bolstered model performance, thus mitigating tendencies of underfitting observed in simpler classifiers.

Significant insights emerged regarding model size, particularly in the Llama and Qwen families. Our classifier exhibited stable performance regardless of size for Llama models, contrasting with the Qwen models, where larger configurations appreciably enhanced classification accuracy. This finding underscores the necessity of factoring in model size for optimal model deployment. Additionally, while models like GPT4o, Sonnet, and Gemini effectively managed complex sentence structures, they faced challenges with some outputs, reflecting the critical influence of underlying architecture on model competency.

Furthermore, an analysis of dataset characteristics, such as unique token count and word length, revealed some degree of correlation with accuracy. However, these correlations were less significant compared to the dominant impact of model size and structure. Therefore, future research could explore larger datasets to better understand these dynamics and consider additional architectural innovations to further advance model efficacy.

8 Limitation and Future Works

Limitation: Although the dataset was selected with the intention of maintaining fairness, the limited sample size from the COCO caption dataset (559 X_js) necessitated supplementation from another dataset, which could introduce slight biases in the findings. Moreover, in the context of the LUAR model experiments, an earlier version

of the transformer module (4.38.1) had to be utilized instead of the latest version employed for the SBERT experiments, potentially affecting the results.

Future Work: Future research could explore the integration of additional classifiers beyond the two initially selected, to provide a more comprehensive analysis. Furthermore, an in-depth examination of performance variations across different datasets would represent a promising direction for subsequent experimental efforts.

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