

# TDCSA: LLM-Guided Top-Down Approach for Robust Citation Sentiment Analysis

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## Abstract

Citation Sentiment Analysis (CSA) plays a crucial role in understanding academic influence and knowledge diffusion. While pre-trained language models (PLMs) and large language models (LLMs) showed remarkable success in general sentiment analysis, they encounter specialized challenges in CSA due to the less significant and implicit sentiment expressions in academic writing, as well as complex sentiment transitions. In order to address the challenges, We propose TDCSA, a Top-Down framework that leverages LLMs' semantic understanding capabilities to enhance PLM-based CSA, which transforms the traditional bottom-up feature engineering paradigm into a top-down architecture. Our framework consists of three key components: (1) a Dual LLM Feature Generation module for robust quadruple extraction, (2) a Multi-view Feature Representation mechanism for neutral citation processing, and (3) a Quad Feature Enhanced PLM. Experiments demonstrate that TDCSA<sup>1</sup> significantly outperforms existing methods, achieving state-of-the-art performance while maintaining robustness to quadruple quality variations.

## 1 Introduction

Citations play a fundamental role in academic contributions, reflecting complex relationships and attitudes between scholarly works (Saggion et al., 2016). While sentiment analysis has advanced significantly in domains like consumer reviews and social media posts, Citation Sentiment Analysis (CSA) presents unique challenges. Scientific citations employ formal and technical language, emphasizing objective descriptions over explicit evaluations, making sentiment expressions often implicit and requiring deeper semantic understanding (Yousif et al., 2019b). For instance in Figure 1,

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<sup>1</sup>Codes and datasets are available at <https://github.com/goghvan1113/TDCSA>

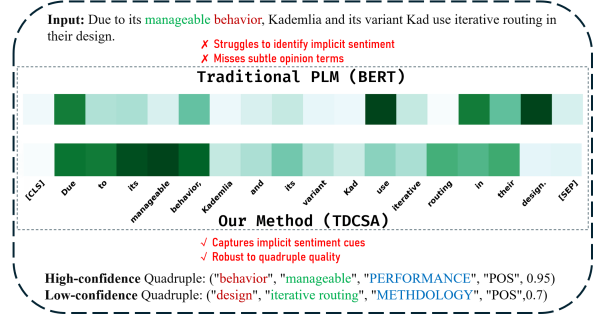


Figure 1: The key limitations of traditional PLMs in CSA. While baseline models struggle to identify implicit sentiment expressions in academic writing, our method leverages LLM-extracted quadruples to enhance semantic understanding. Even with varying quadruple quality (e.g., the low-confidence quadruple), the model maintains robust performance.

phrases "*manageable behavior*" in research contexts implicitly convey positive sentiment about a method's stability and usability, though appearing neutral on the surface.

Machine learning approaches to CSA have followed a bottom-up paradigm, where researchers carefully design and combine low-level linguistic features such as n-grams, dependency relations, or sentiment lexicons to capture sentiments (Athar, 2011; Sula and Miller, 2014; Athar and Teufel, 2012; Xu et al., 2015). These feature engineering methods have achieved considerable success through domain expertise and manual effort (Ihsan et al., 2023; Liu et al., 2024). The evolution of deep learning brought innovations through word embeddings (Mikolov et al., 2013; Pennington et al., 2014) and neural networks (Munkhdalai et al., 2016; Budi and Yaniasih, 2022), followed by pre-trained language models (PLMs) and large language models (LLMs). PLMs like BERT offer efficient fine-tuning capabilities for downstream tasks (Mercier et al., 2020; Yang et al., 2023), while LLMs benefit from massive training corpora that enable better semantic comprehension of scientific

text (Wang et al., 2023). However, current solutions face two significant limitations.

1. **Suboptimal performance:** While traditional machine learning approaches with carefully engineered features remain competitive, particularly SVM using dependency relations, domain-specific PLMs still face challenges in capturing implicit sentiment expressions in academic writing. As shown in Figure 1, PLM struggles to capture subtle positive sentiment conveyed through phrases like "*manageable behavior*". While LLMs demonstrate better semantic comprehension, their direct application proves computationally intensive and potentially suboptimal for specific downstream tasks (Zhang et al., 2023), as demonstrated in Section C.2.
2. **Oversight of sentiment transitions:** Existing research predominantly overlooks the dynamic nature of sentiment expression in scientific citations, where authors often present opposing viewpoints before ultimately reaching a final evaluation. As shown in Figure 2, these transitions frequently determine the overall citation polarity, yet current approaches lack mechanisms to effectively capture these sequential sentiment dynamics.

In order to tackle these limitations, we propose a novel framework that leverages LLMs as robust feature generator to generate structured sentiment information, which then enhance smaller, task-specific PLMs for sentiment classification. Notably, our framework maintains robustness to quadruple quality variations, as it focuses on capturing general sentiment patterns rather than requiring perfect extraction accuracy. We design three components: a **Dual LLM Feature Generation (DFG)** framework that employs critical thinking (Betz and Richardson, 2020) and Chain-of-Thought (Wei et al., 2022) reasoning to extract robust sentiment quadruples. A **Multi-view Pattern Representation (MPR)** mechanism that handles the dominant neutral citations with complementary perspectives, avoiding feature redundancy. An **Quad Feature Enhanced PLM (QFE-PLM)** that integrates LLM-extracted features with PLM through adaptive fusion mechanisms. The main contributions of this paper can be summarized as follows:

- We propose a novel top-down framework that leverages LLMs’ semantic understanding to

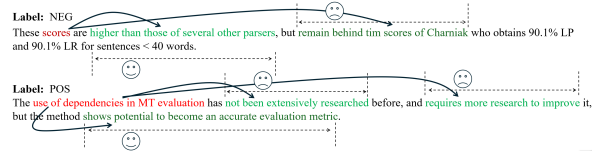


Figure 2: Sentiment transition patterns in scientific citations. Solid arrows indicate aspect-opinion relationships, while dashed boxes highlight the scope of opinion expressions. The intensity of the different opinions is highlighted with light and dark green.

enhance PLM-based citation sentiment classification.

- We present an effective method DFG that provide complementary two-stage thinking process for sentiment quadruples generation.
- We design the MPR mechanism and an adaptive fusion strategy, which not only effectively integrates the sentiment quadruples information for sentiment classification but also introduces adversarial distribution perturbations to prevent the model from overfitting.
- We conduct extensive experiments on benchmark datasets, demonstrating the effectiveness of our approach and providing detailed analysis.

## 2 Methodology

The overall architecture of TDCSA is shown in the Figure 3: it consists of three key components: (1) a Dual LLM Feature Generation framework using critical thinking and CoT reasoning to extract sentiment quadruples; (2) a Multi-view Pattern Representation mechanism for handling neutral citations with three different representations and improving model generalization performance; (3) a Quad Feature Enhanced PLM-based model augmenting PLMs with structured sentiment information.

### 2.1 Critical Thinking DFG

**Citation ASQP Problem Statement** Following the Aspect Sentiment Quad Prediction (ASQP) task definition proposed by (Zhang et al., 2021) and (Cai et al., 2021), we define the CASQP (Citation Aspect Sentiment Quad Prediction) task for scientific citations as follows. Given a scientific citation text  $X$ , the CASQP task aims to extract a set of quadruples  $Q = q_1, q_2, \dots, q_n$ , where each quadruple  $q_i = (a_i, o_i, c_i, p_i)$  comprises an aspect term, an opinion term, a predefined category  $\mathcal{C} =$

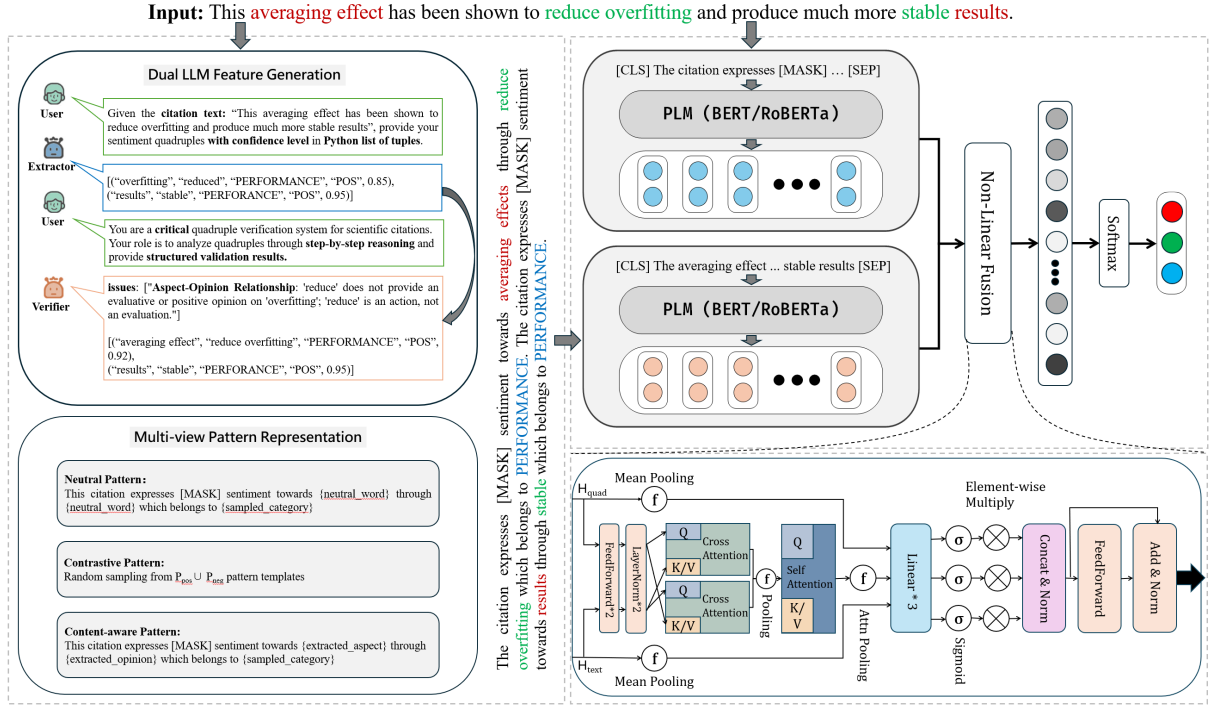


Figure 3: Overall architecture of our TDCSA framework. **aspect term** and **opinion term** are highlighted in original text. The left bottom module consists of Dual LLM Feature Generation for quadruples extraction and verification. The left top presents Multi-view Pattern Representation modules that process both citation texts and extracted features. These representations are then integrated through an Feature Fusion module, then fed into the final classification layer.

as  $\{METHODODOLOGY, PERFORMANCE, INNOVATION, APPLICABILITY, LIMITATION\}$ , and a polarity  $p_i \in \text{NEU}, \text{POS}, \text{NEG}$ . Scientific citations contain domain-specific terminology and often express sentiment through technical evaluative phrases rather than conventional sentiment markers. These characteristics necessitate specialized prompt designs for accurate aspect-sentiment extraction. Complete definitions of each category with annotation criteria are provided in Appendix B.

**Extractor and Verifier** Recent studies have demonstrated that LLM leveraging In-Context Learning (ICL) (Min et al., 2022) capabilities, can effectively perform ASQP tasks (Zhou et al., 2024; Bai et al., 2024). However, through our systematic analysis of 500 LLM-generated quadruples, we identified two recurring hallucination patterns in the interpretation of citation content. First, LLMs frequently over-interpret objective statements in citations as strong sentiments. Second, the confidence level of LLM output quadruples correlates with the uncertainty of judgment due to its probabilistic modeling properties. Inspired by dual-process theory in cognitive psychology, we pro-

pose a two-stage framework that mimics human thinking processes: fast intuitive thinking and slow critical thinking. The Quadruple Extractor employs ICL with carefully selected demonstrations to perform rapid pattern recognition as shown in Table 1. Through well-designed examples covering various cases like implicit opinions and sentiment transitions, it generates initial quadruple candidates with confidence scores  $\alpha_i = \text{conf}(q_i) \in [0, 1]$  at a higher temperature 0.7. The Validity Verifier implements Chain-of-Thought reasoning at a lower temperature 0.3. It enforces both hard constraints and soft constraints through step-by-step verification reasoning, producing a final verification score  $\beta_i = \text{verify}(q_i, \alpha_i) \in [0, 1]$ .

## 2.2 Multi-view Pattern Representation

We observe a unique challenge in citation sentiment analysis that neutral citations constitute the majority of citation texts. Direct extraction of sentiment features from these neutral citations would lead to redundant feature representations due to their massive quantity and similar semantic patterns. To address this issue, we propose a Multi-view Pattern Representation mechanism that generates diverse

|                    |  |
|--------------------|--|
| <b>Text:</b>       | However, one of the major limitations of these advances is the <i>structured syntactic knowledge</i> , which is important to global reordering, <i>has not been well exploited</i> . |
| <b>Quadruples:</b> | ('structured syntactic knowledge', 'has not been well exploited', 'LIMITATION', 'NEG', 0.90)   |

Table 1: Examples in extractor prompt. The **aspect term**, **opinion term**, **aspect category** are highlighted in different colors. Confidence level is also provided as a float variant.

complementary views for neutral citations:

**Pattern Generation** Given a neutral citation text  $X_{neutral} = \{x_1, x_2, \dots, x_n\}$ , we construct three different representations:

1. **Neutral Pattern:** We randomly select tokens from a predefined neutral scientific vocabulary  $V_{neutral}$  to replace the aspect and opinion terms:

$P_1 = \text{"This citation expresses [MASK] sentiment towards } \{n_1\} \text{ through } \{n_2\} \text{ which belong to } \{category\} \text{ category"}$

where  $n_i \in V_{neutral}$ ,  $category \in \mathcal{C}$ .

2. **Contrastive Pattern:** We randomly sample positive or negative patterns from the existing quadruple templates:

$$P_2 \in \{P_{pos} \cup P_{neg}\}$$

This introduces controlled sentiment noise that helps the model learn robust neutral representations.

3. **Content-aware Pattern:** We extract key phrases from the neutral citation to construct a pseudo-quadruple:

$P_3 = \text{"This citation expresses [MASK] sentiment towards } \{aspect\} \text{ through } \{opinion\} \text{ which belongs to } \{category\} \text{ category"}$

where, *aspect* and *opinion* are phrases randomly selected from the citation, and *category*  $\in \mathcal{C}$ .

Thus, the Multi-view Pattern representation for neutral samples is defined by randomly selecting from the three patterns described below. Similarly, given a positive or negative text  $X_{pos\_or\_neg} = \{x_1, x_2, \dots, x_n\}$  and its corresponding quadruple set  $Q = \{q_1, q_2, \dots, q_m\}$  where each  $q_i = (aspect_i, opinion_i, category_i, polarity_i)$ , we use the same pattern for each  $q_i$  then concatenate them in order:

$P = \text{"This citation expresses [MASK] sentiment towards } \{aspect_i\} \text{ through } \{opinion_i\} \text{ which belongs to } \{category_i\} \text{ category [SEP] This citation expresses [MASK] sentiment towards ... "}$

For positive and negative citations, implicit sentiment is mapped to specific contextual features via quadruples. In contrast, for neutral samples, the generated pseudo-quadruples disrupt the original feature distribution, which improves the model’s robustness to random noise.

### 2.3 Quad Feature Enhanced PLM-based Model

**Dual Encoding** Given a citation text  $X = \{x_1, x_2, \dots, x_n\}$  and its corresponding feature pattern  $P = \{p_1, p_2, \dots, p_m\}$ , we first encode both sources using the PLMs to obtain the last hidden state of contextual representations:

$$H_{\text{text/quad}} = \text{Encoder}_{\text{text/quad}}(X) \quad (1)$$

where  $H_{\text{text}} \in \mathbb{R}^{n \times d}$  and  $H_{\text{quad}} \in \mathbb{R}^{m \times d}$  represent the hidden states of citation text and sentiment quadruples, respectively.

**Cross-attention Interaction** To capture the mutual influence between citation content and sentiment quadruples, we employ bidirectional cross-attention:

$$A_{i \rightarrow j} = \text{softmax} \left( \frac{QK^T}{\sqrt{d}} \right) V \quad (2)$$

where  $Q, K, V$  are projections of  $H_{\text{text}}$  and  $H_{\text{quad}}$  using learnable weight matrices.

**Non-linear Gated Fusion** We propose an adaptive fusion mechanism to integrate the three complementary representations:

$$G = \sigma(W \cdot \text{pool}(\{H_{\text{text}}, H_{\text{quad}}, A_{\text{cross}}\}) + b) \quad (3)$$

where  $A_{\text{cross}}$  is the mean of bidirectional cross-attention,  $\text{pool}(\cdot)$  represents the corresponding



pooling operation applied to each input representation.

$$Z = G_1 \odot \phi(H_{text}) + G_2 \odot \phi(H_{quad}) + G_3 \odot \phi(A_{cross}) \quad (4)$$

where  $\sigma(\cdot)$  is the sigmoid function,  $\phi(\cdot)$  is a non-linear activation, and  $\odot$  denotes element-wise multiplication. Finally,  $Z$  is fed into a fully connected classification layer  $W_{FC}$  and softmax function to obtain sentiment polarity score  $y$ :

$$y = \text{softmax}(ZW_{FC}) \quad (5)$$

### 3 Experimental Results

#### 3.1 Datasets and Experimental Settings

The widely adopted CSA dataset Citation Sentiment Corpus (Athar Dataset)(Athar, 2011) presents relatively unbalanced distribution, consisting of 7627 neutral, 829 positive and 280 negative samples. To address quality issues stemming from automatic extraction, we constructed an enhanced dataset (CSCE) containing 6,328 neutral, 1,237 positive, and 631 negative samples. Each sample has been re-annotated by two human experts, with any conflicting cases carefully reviewed and resolved. For elaborate dataset annotation guidelines and processing steps, see Appendix A.

For our experimental settings, we employ LLaMA3.1-8B (Dubey et al., 2024) as the extractor (temperature: 0.7) and LLaMA3.1-70B as the verifier (temperature: 0.3). The QFE-PLM leverages pre-trained RoBERTa-base and SCIBERT models from Huggingface<sup>2</sup>, maintaining bf16 precision and flash-attention<sup>3</sup> acceleration. We conduct 10-fold cross-validation, reporting both accuracy and macro-F1 scores. All ablation studies maintain the same random seeds, and experiments are executed in an identical virtual environment using a single NVIDIA 4090 GPU with 24G RAM.

#### 3.2 Baselines

We evaluate TDCSA with state-of-the-art approaches, including PLMs, deep neural network and conventional machine learning methods that have demonstrated superior performance on the Athar Dataset and CSA tasks. **PLMs baselines:** XLNet (Yang, 2019), BART (Lewis et al.,

2019), DistilBERT (Sanh et al., 2019), BERT-base and BERT-large (Xu et al., 2019), SCIBERT (Beltagy et al., 2019), DictSentiBERT (Yu and Hua, 2023), DistilRoBERTa (Sanh et al., 2019), RoBERTa-base and RoBERTa-large (Liu, 2019), RoBERTa-llama3.1405B-twitter-sentiment (RoBERTa-sentiment) (Adam Lucek, 2024), and ImpactCite (Mercier et al., 2020). **GloVe based DNNs:** TextCNN, BiLSTM and BiLSTM with attention (Kong et al., 2024) using 300-dimensional GloVe embeddings<sup>4</sup> (Pennington et al., 2014). **Conventional machine learning methods:** SVM (dependency relation) (Athar, 2014) that uses dependency relations extracted by parsers<sup>5</sup>. In addition, **LLMs ICL and SFT:** Qwen2.5 (Yang et al., 2024), LLaMA, DeepSeek (Shao et al., 2024), and ChatGPT (OpenAI, 2022), as results shown in Appendix C.2.

#### 3.3 Overall Results

The experimental results presented in Table 2 demonstrate that QFE-BERT and QFE-RoBERTa consistently outperform all baselines on both benchmark datasets. SVM based on dependency relations demonstrates robust performance on the Athar Dataset, suggesting the effectiveness of carefully engineered syntactic features for CSA. Among baseline models, SCIBERT’s domain-specific pre-training yields notable improvements on CSCE Dataset but shows limited advantages on the Athar Dataset. RoBERTa-Sentiment, despite extensive sentiment pre-training, fails to surpass base models, indicating challenges in transferring social media sentiment analysis capabilities to academic contexts. Our QFE-PLM addresses the limitations of previous approaches by effectively integrating multi-view quadruples pattern representations and fusion mechanisms. Notably, it achieves significant improvements in F1 scores, demonstrating robust performance in the presence of dataset imbalances.

### 4 Analysis

#### 4.1 Ablation Studies

We conducted comprehensive ablation experiments to evaluate the contribution of each component, as shown in Table 3. The results revealed that removing cross-attention degraded performance, indicating that simple concatenation inadequately

<sup>2</sup><https://github.com/huggingface/transformers>

<sup>3</sup><https://github.com/Dao-AILab/flash-attention>

<sup>4</sup><https://pytorch.org/text/stable/index.html>

<sup>5</sup><https://github.com/explosion/spaCy>

| Base PLM | Models                    | Athar Dataset |             | CSCE Dataset |             |
|----------|---------------------------|---------------|-------------|--------------|-------------|
|          |                           | Acc.          | F1.         | Acc.         | F1.         |
| —        | Most Frequent Class       | 88.3          | 93.2        | 77.2         | 87.1        |
|          | SVM(dependency relations) | 89.8          | 76.4        | 85.7         | 70.0        |
|          | TextCNN                   | 88.2          | 47.1        | 89.0         | 77.9        |
|          | BiLSTM                    | 88.0          | 43.0        | 88.3         | 75.3        |
|          | BiLSTM+Attention          | 87.8          | 46.2        | 88.1         | 72.6        |
| BART     | BART-base                 | 89.3          | 59.1        | 91.4         | 84.9        |
| XLNet    | XLNet-base                | 90.0          | 65.9        | 94.0         | 89.1        |
|          | ImpactCite                | 77.7          | 77.7        | —            | —           |
| BERT     | DistilBERT                | 89.2          | 60.3        | 94.0         | 89.1        |
|          | BERT-base                 | 89.7          | 65.1        | 93.5         | 87.7        |
|          | BERT-large                | 89.5          | 66.0        | 93.4         | 88.6        |
|          | SCIBERT                   | 90.1          | 63.8        | 95.5         | 92.2        |
|          | DictSentiBERT             | —             | —           | 95.2         | 86.0        |
|          | <b>Ours: QFE-BERT</b>     | <b>95.5</b>   | <b>81.2</b> | <b>97.8</b>  | <b>95.0</b> |
| RoBERTa  | DistilRoBERTa             | 89.9          | 64.9        | 93.5         | 88.6        |
|          | RoBERTa-base              | 90.1          | 68.0        | 94.5         | 90.4        |
|          | RoBERTa-large             | 90.5          | 68.4        | 94.3         | 90.6        |
|          | RoBERTa-Sentiment         | 89.7          | 66.9        | 93.4         | 88.3        |
|          | <b>Ours: QFE-RoBERTa</b>  | <b>95.7</b>   | <b>81.7</b> | <b>98.1</b>  | <b>95.7</b> |

Table 2: The main experimental results on Athar and CSCE datasets. The best results are marked as **bold**

captures aspect/opinion term interactions. Replacing non-linear fusion with concatenation led to substantial performance deterioration, demonstrating the effectiveness of non-linear gated fusion for feature integration. Single BERT encoder variants showed reduced performance, suggesting that compressing features into a unified representation space may cause feature interference and diminish discriminative power. Notably, isolated components (Cross-attention or Quad only) exhibited significant performance drops, indicating that the model’s discriminative ability relies more on the integrated representations than individual components. When examining interaction mechanisms shown in Figure 4, we found the bidirectional approach significantly outperforms unidirectional and cascaded alternatives. Thus, the interaction between original text and structured sentiment information provides complementary perspectives for sentiment understanding.

| Model Variant                | CSCE Dataset |             |
|------------------------------|--------------|-------------|
|                              | Acc.         | F1.         |
| Base Model (Text Only)       | 95.5         | 92.2        |
| <b>QFE-RoBERTa</b>           | <b>98.1</b>  | <b>95.7</b> |
| <i>w/o</i> Cross-attention   | 97.9         | 94.9        |
| <i>w/o</i> Non-linear Fusion | 97.3         | 93.9        |
| Single BERT                  | 97.2         | 93.8        |
| Cross-attention Only         | 95.8         | 89.0        |
| Quad Only                    | 95.6         | 88.4        |

Table 3: Ablation study results.

## 4.2 Analysis of Multi-view Representation

The effectiveness of our Multi-view Pattern approach is validated through three systematic experiments. First, as shown in Table 4, compared to single pattern baselines, our method demonstrates consistent performance improvements in both accuracy and F1 score, showing the advantage of diverse representations for sentiment classification. Second, we conducted two critical ablation studies

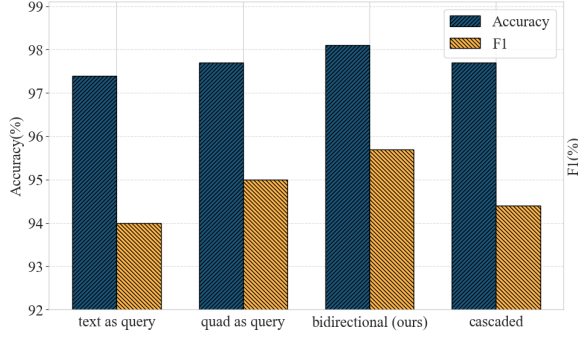


Figure 4: Analysis of different attention interaction mechanisms.

| Multi-view Representation               | CSCE Dataset |             |
|---|--------------|-------------|
|   | Acc.         | F1.         |
| Neutral Pattern                         | <b>98.4</b>  | 95.5        |
| Contrastive Pattern                     | 97.9         | 95.4        |
| Content-aware Pattern                   | 98.2         | 95.5        |
| <b>Ours: Multi-view Pattern</b>         | 98.3         | <b>95.7</b> |
| Random Contrastive Pattern <sup>1</sup> | 93.5         | 88.2        |
| Neutral Quad Pattern <sup>2</sup>       | 95.3         | 91.4        |

Table 4: Comparative Analysis of different pattern representations. Random Contrastive Pattern<sup>1</sup> represents an ablation study where sentiment quadruples are randomly assigned to positive and negative citation samples, rather than using their matched quadruples. Neutral Quad Pattern<sup>2</sup> indicates experiments where DFG extracts sentiment quadruples from neutral citations as an alternative to the multi-view pattern representation.

to verify our design choices. The Random Contrastive Pattern where sentiment quadruples were randomly assigned to citations, resulted in performance degradation, confirming the importance of maintaining semantic relationships in quadruple representations. Similarly, the Neutral Quad Pattern experiment, which attempted to extract sentiment quadruples from neutral citations, showed reduced effectiveness. As visualized in Figure 6 in Appendix, this approach introduces feature redundancy and blurs classification boundaries, whereas our Multi-view Pattern creates clearer sentiment separations.

To validate the statistical significance of the performance improvements achieved by our Multi-view Pattern approach, we conducted paired t-tests comparing our method against the Random Contrastive Pattern and Neutral Quad Pattern. For each comparison, we performed 10-fold cross-validation with 5 repetitions using different random seeds, col-

| Train Pattern | Test Pattern |             |             |             |
|---------------|--------------|-------------|-------------|-------------|
|               | NP           | CP          | CAP         | Multi       |
| NP            | 95.5         | 30.7        | 85.1        | 67.8        |
| CP            | 95.8         | <b>95.4</b> | 95.8        | 95.7        |
| CAP           | 95.5         | 57.7        | 95.5        | 80.1        |
| Multi         | <b>96.6</b>  | <u>93.4</u> | <b>96.1</b> | <b>95.7</b> |

Table 5: Pattern transfer results (F1-scores). Abbreviations: NP (Neutral Pattern), CP (Contrastive Pattern), CAP (Consistent Adversarial Pattern), Multi (Multi-view Pattern). The best and second best generalization performance is marked as **bold** and underlined respectively.

lecting a total of 50 performance measurements for each method. The results confirm that our Multi-view Pattern representation achieves statistically significant improvements over both baseline approaches ( $p < 0.05$ ). Specifically, when comparing to Random Contrastive Pattern, we obtained  $t = 3.142$ ,  $p = 0.007$ , and when comparing to Neutral Quad Pattern, we obtained  $t = 2.896$ ,  $p = 0.012$ .

Finally, we evaluate pattern generalization through transfer experiments. As shown in Table 5, Models trained with our Multi-view Pattern demonstrate strong cross-pattern generalization, maintaining high F1 scores across different test patterns. This robust generalization is particularly evident compared to simpler approaches like Neutral Pattern and Content-aware Pattern, which suffer from performance drops when tested on different pattern types. These results suggest that our approach successfully learns transferable features that capture fundamental sentiment characteristics rather than pattern-specific features.

### 4.3 Analysis of Dual LLM Feature Generation

Through the analysis of the DFG framework, we identify two key findings. First, as shown in Table 6, The extractor tends to over-interpret neutral statements as subjective, often with relatively low confidence scores. However, smaller verifier models effectively mitigate such misinterpretations through validation. While the framework does not always perfectly delineate aspect term boundaries, it consistently captures essential terms, such as "method". We also performed a comparison of different LLM configurations and detailed results are presented in Appendix E.

|                          |   |
|--------------------------|---|
| <b>Citation:</b>         | Hanks proposed using pointwise mutual information to identify collocations in lexicography; however, the method may result in unacceptable collocations for low-count pairs(Jian et al., 2004). |
| <b>Dual LLM:</b>         | (1) ('method', 'may result in unacceptable collocations', 'LIMITATION', 'NEG', 0.90) ✓<br>(2) ('pointwise mutual information', 'proposed', 'METHODOLOGY', 'POS', 0.78) ✗                        |
| <b>Human Annotation:</b> | <i>aspect</i> in quad (1) should be 'method using pointwise mutual information'   |

Table 6: Quality analysis of DFG framework and human annotation. The ✓/✗ indicates the verifier’s validation results.

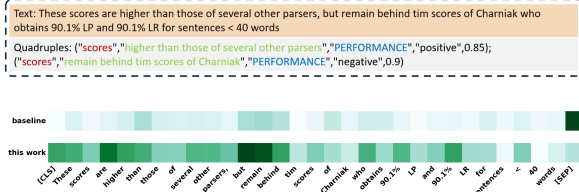


Figure 5: Sentiment transition attention weights visualization comparison of baseline and our method. Our method learns the aspect and contrasted opinion terms and predicts NEG.

#### 4.4 Case Study

We analyze three representative cases demonstrating our model’s capability in handling different sentiment expressions. In complex cases with sentiment transitions as shown in Figure 5, our model effectively captures the crucial comparative phrases that determine the final sentiment, whereas baseline approaches struggle with such mixed expressions. Cases with explicit and implicit sentiment expressions are elaborated in Appendix F.

## 5 Related Work

**Scientific Citation Sentiment Analysis** Early approaches employed conventional machine learning algorithms and sentiment lexicon-based methods (Yousif et al., 2019b). Athar (Athar, 2011) pioneered this field by developing an open-source dataset and demonstrated the effectiveness of combining 3-grams with dependency relations using SVM. Subsequently, approaches evolved through sentiment lexicons (Xu et al., 2015) and basic machine learning methods (Sula and Miller, 2014; Athar and Teufel, 2012). With the development of deep learning, methods progressed from CNN/RNN-based approaches (Munkhdalai et al., 2016; Yousif et al., 2019a) to Pre-trained Language Models (PLMs). Notable achievements include XLNet-based approaches (Mercier et al., 2020), DictSentiBERT (Yu and Hua, 2023), and SCIBERT (Beltagy et al., 2019). Recent work has focused on multi-task learning combining citation aspects

and sentiments (Kong et al., 2024). However, these approaches still struggle with implicit sentiment expressions in academic writing.

## Citation Aspect-Based Sentiment Analysis

Aspect-Based Sentiment Analysis (ABSA) provides fine-grained analysis through aspect term extraction, opinion term identification, aspect category classification, and sentiment polarity determination (Zhang et al., 2022). While BERT-based models have shown promise in general ABSA tasks (Li et al., 2019), their application to citation analysis remains limited. Recent approaches like Multi-view Prompting (Gou et al., 2023) and unified generative frameworks (Gao et al., 2022) have advanced the field but primarily focus on general domain tasks. Large Language Models (LLMs) have demonstrated capabilities in sentiment analysis (Lu et al., 2025), with recent studies exploring their potential in ABSA through instruction tuning (Varia et al., 2022) and few-shot learning (Šmíd et al., 2024). However, their application to citation sentiment analysis faces unique challenges due to the domain-specific nature of scientific citations. Previous work in citation ABSA (Hernández-Alvarez and Gomez, 2016; Ikram and Afzal, 2019) has primarily focused on basic pattern-based approaches, leaving room for more sophisticated methods that can capture the nuanced relationships in academic writing.

## 6 Conclusion

In this paper we introduced TDCSA, a novel Top-Down approach designed to address the challenges in Citation Sentiment Analysis. By leveraging LLMs for robust quadruple generation and enhancing pre-trained language models with adaptive fusion mechanisms, TDCSA achieved significant performance improvements over existing methods. Our analysis yields three key findings: First, structured sentiment quadruples effectively extraction provides interpretable features that enhance citation sentiment detection, particularly for implicit senti-



ment expressions. Second, Our Multi-view Pattern Representation effectively addresses the challenge of dominant neutral citations by generating complementary feature representations. Third, the cross-pattern generalization experiments in Section 4.2 verified that our model maintains consistent performance across different pattern types. Experiments on benchmark datasets demonstrate that TDCSA significantly outperforms existing methods, achieving state-of-the-art performance.

## Limitations

We summarize the limitations of our framework that could be followed by future work. The main limitation points to a broader challenge in CSA. Our work, while advancing the state-of-the-art in general citation sentiment classification, highlights the necessity for aspect-based sentiment analysis in scientific citations. A more fine-grained ABSA approach would enable better understanding of how different aspects of scientific work are evaluated in the academic community, potentially offering deeper insights into research impact and knowledge evolution.

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## A Details on Datasets

### A.1 Annotation Guidelines

While numerous studies have explored Citation Sentiment Analysis (Munkhdalai et al., 2016; Abujbara et al., 2013; Ma et al., 2016), publicly available datasets remain scarce. The widely used Citation Sentiment Corpus (Athar Dataset) (Athar, 2011) exhibits an imbalanced distribution, consisting of 7627 neutral, 829 positive, and 280 negative samples from the ACL Anthology Network. However, this dataset suffers from quality issues due to its automatic extraction and manual annotation process, as shown in Table 7.

To address these limitations, we re-annotate the dataset following comprehensive guidelines. We recognize that scientific literature contains many genuinely neutral citations by design, serving essential functions such as establishing context or referencing methodologies without evaluation. Our goal is not to force sentiment interpretations where none exist, but rather to accurately distinguish between truly neutral citations and those containing subtle implicit sentiment.

Our annotation guidelines define:

- **Neutral Citations (NEU):** Citations that serve foundational functions without evaluative content, such as establishing background knowledge, referencing methodologies, or attributing data sources. These citations are intrinsically neutral by design.

*The minimum error training was used on the development data for parameter estimation.*

| Problem                 | Example / Details   |
|-------------------------|---|
| (1) Too long sentence   | It is widely acknowledged that word sense disambiguation (WSD) is a central problem in natural language processing... <b>(12518 words)</b>  |
| (2) Too short sentence  | (Cutting et al., 1992)). <b>(no semantics)</b>  |
| (3) Incomplete sentence | 5http://www.statmt.org/wmt08 185 the BLEU score (Papineni et al., 2002), and tested on test2008. <b>(no semantics)</b>  |
| (4) Wrong label         | By segmenting words into morphemes, we can improve the performance of natural language systems including machine translation (Brown et al. 1993) and information retrieval (Franz, M. and McCarley, S. 2002). <b>(mislabel)</b> |

Table 7: Problem and Example. Too long/short or incomplete sentences are removed and mislabel sentences are relabeled manually.

- **Positive Citations (POS):** Citations expressing approval, endorsement, or positive assessment through explicit praise, adoption/extension, positive comparison, or implicit endorsement.

*For the multilingual dependency parsing track, which was the other track of the shared task, Nilsson et al. achieved the best performance using an ensemble method.*

- **Negative Citations (NEG):** Citations indicating criticism, identification of limitations, or disagreement through explicit criticism, contrasting statements, limitation highlighting, or implicit critique.

*Other systems (Morinaga et al., 2002; Kushal et al., 2003) also look at Web product reviews but they do not extract opinions about particular product features.*

Each citation was independently annotated by two computational linguistics experts with prior experience in sentiment analysis. Annotators achieved substantial agreement, with disagreements resolved through discussion to determine the final label. To mitigate potential subjective bias or over-interpretation, annotators were explicitly instructed to maintain the neutral classification unless clear linguistic evidence of sentiment was present.

Following these guidelines, we refined the Athar Dataset by removing problematic instances (1-3) and correcting questionable labels (4) as shown in Table 7.

## A.2 CSCE Construction

We constructed an enhanced dataset through a systematic approach. First, we integrated the complementary dataset from (Yu and Hua, 2023), which utilizes the supported and unsupported labels from the SCICite dataset (Cohan et al., 2019) as positive

and negative samples, respectively. Next, We adopted the refined Athar Dataset and augmented the negative class with key citations from (Bordignon and Gambette, 2024). The resulting dataset, referred as CSCE, comprises 6328 neutral, 1237 positive, and 631 negative samples.

## B Citation Aspect Sentiment Quad Prediction Task Definition

Due to the difference between scientific citations and general sentiment texts like product reviews or social media posts, where aspects are typically simple noun phrases and opinions are predominantly single adjectives, scientific citations exhibit more complex and domain-specific linguistic patterns. Similarly, rather than straightforward adjectives, an opinion term  $o_i$  in citations often appears as intricate verb phrases, compound expressions combining adverbs and adjectives, or technical evaluative phrases. An aspect term  $a_i$  in citations frequently manifests as sophisticated noun phrases encompassing technical terminology, methodological components, or theoretical constructs. Furthermore, we define the aspect category set  $\mathcal{C}$  as  $\{ \text{METHODOLOGY, PERFORMANCE, INNOVATION, APPLICABILITY, LIMITATION} \}$  five categories as follows.

- **METHODOLOGY:** This category encompasses assessments of research methods, experimental designs, and technical approaches. It is essential as methodological rigor is a fundamental criterion in scientific evaluation (e.g., "Their robust experimental design validates the findings").
- **PERFORMANCE:** This category addresses quantitative and qualitative outcomes, including accuracy, efficiency, and effectiveness. It is crucial for comparing and benchmarking scientific contributions (e.g., "The model



achieves superior accuracy on standard benchmarks").

- **INNOVATION**: This category captures the novelty and originality of the research contribution. It is vital in academic discourse as advancing the state-of-the-art is a key measure of research impact (e.g., "They propose a novel framework that breaks new ground").
- **APPLICABILITY**: This category reflects the practical utility and generalizability of the research. It is important as it bridges the gap between theoretical contributions and real-world applications (e.g., "Their approach can be effectively applied to various domains").
- **LIMITATION**: This category addresses constraints, drawbacks, and areas for improvement. It is critical for maintaining scientific rigor through balanced critique and identifying future research directions (e.g., "The method's computational complexity limits its practical deployment").

## C Extended Experimental Analysis

### C.1 Implementation Details

PLMs fine-tuning employs the following hyperparameters: batch size of 32, dropout rate of 0.1, weight decay of 0.05, and cosine annealing learning rate decay with an initial rate of  $2.0 \times 10^{-5}$  using AdamW optimizer.

In zero-shot and few-shot learning scenarios, we employ various models from the Qwen and LLaMA family (Dubey et al., 2024), specifically the 3B version of LLaMA 3.2, the 7B and 14B versions of Qwen2.5 and the 8B, 70B, and 405B versions of LLaMA 3.1. Additionally, we incorporate ChatGPT and DeepSeek versions of DeepSeek V2 Chat, GPT-3.5-turbo, and GPT-4o-2024-0806.

When fine-tuning we use LLaMA-Factory framework<sup>6</sup> and QLoRA (Detrmers et al., 2023) with 4-bit NormalFloat (NF4) and double quantization using bitsandbytes<sup>7</sup>, cosine annealing learning rate decay with an initial rate of  $1.0 \times 10^{-4}$  using AdamW optimizer for 5 epochs, and batch size of 8. We set LoRA adapters (Hu et al., 2021) with  $r = 8$  and  $\alpha = 16$ . Both ICL and SFT use bf16 training/inference precision and flash-attention2 accel-

eration. Temperature is set as 0.1 for certain responses. 6-shot ICL indicates two golden examples are selected from three categories as demonstrations.

### C.2 LLMs In-Context Learning and Supervised Fin-Tuning results

The ICL and SFT experimental results presented in Table 8. 6-shot ICL generally shows better performance than 0-shot ICL, but worse than SFT. The gap between ICL and SFT is substantial, with SFT outperforming by 10-15 %. In zero-shot and few-shot scenarios, LLaMA3.1-405B and GPT-4o shows best performance in F1 while DeepSeek V2 achieves the highest accuracy in both ICL. Notably, Qwen models show strong performance across models of similar scale like LLaMA. However, the SFT of the 14B version of Qwen exhibits performance characteristics that are nearly identical to the native BERT model, which demonstrates that the performance of LLM in a specific domain such as CSA is suboptimal to the BERT-based model.

## D Detailed Analysis of Multi-view Patterns

Furthermore, we employed t-SNE (Van der Maaten and Hinton, 2008) to reduce dimensionality of the pooler output of BERT encoder and quad-enhanced fusion features. Figure 6 presents that the degradation can be attributed to two primary factors: First, neutral citations in academic writing predominantly manifest as descriptive or declarative statements, making sentiment quadruple extraction potentially redundant. Second, the augmentation of numerous neutral samples with quadruple structures may introduce excessive feature redundancy into the representation space. This redundancy ultimately compromises the model's capacity to effectively discriminate sentiment features.

## E Detailed Analysis of Dual LLM Feature Generation

We performed a comparison of different LLM configurations as presented in Table 9, various LLM configurations consistently enhance CSA performance, highlighting the robustness of our method to variations in quadruple quality. This suggests that basic semantic understanding capability is sufficient for our framework, rather than necessitating extremely large models.

<sup>6</sup><https://github.com/hiyouga/LLaMA-Factory>

<sup>7</sup><https://github.com/bitsandbytes-foundation/bitsandbytes>

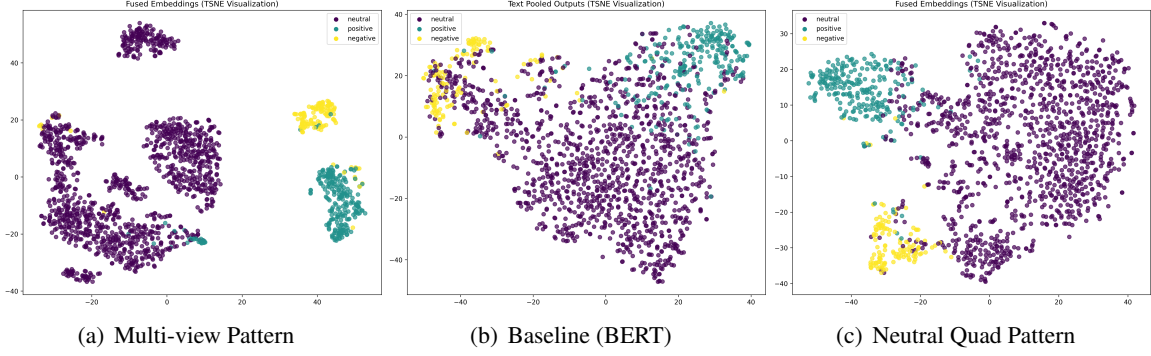


Figure 6: t-SNE dimensionality reduction of our model embeddings. Colors represent different sentiment classes (purple: neutral, green: positive, yellow: negative). Ours Multi-view Pattern reduces the distance within classes and increases the distance between classes, resulting in a clearer classification boundary. However, Neutral Quad Pattern (neutral samples enhanced with their own quadruples) blurs classification boundary, making classification harder.

We assign confidence scores to quadruple extraction and verification tasks across various LLM implementations, with results presented in Table 10. Our empirical analysis reveals that the dual LLM mechanism consistently achieves higher confidence levels across most models, with the notable exception of LLaMA3.2-3B. The relatively lower performance of LLaMA3.2-3B can be attributed to potential overconfidence due to its limited parameter size.

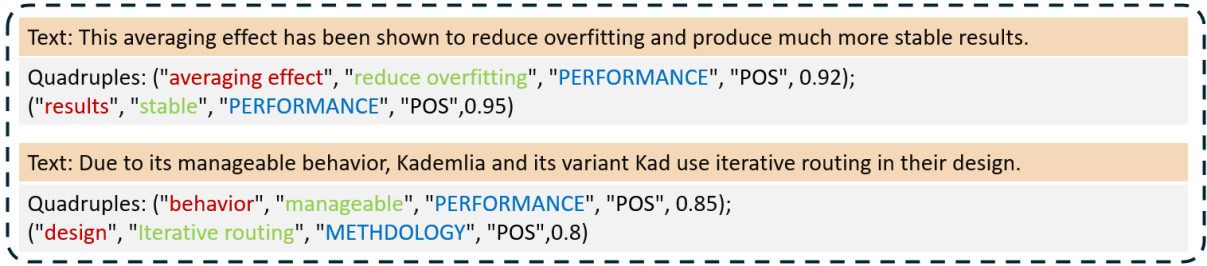
## F Detailed Case Study

As shown in Figure 7, in explicit sentiment cases, our model successfully focuses attention on critical evaluative phrases like "*reduce overfitting*" and "*stable results*", while baseline models only partially capture these signals. For implicit sentiment, our quadruple-enhanced model precisely identifies subtle evaluations like "*manageable*" as positive assessment of "behavior", maintaining accuracy even with imperfect quadruples.

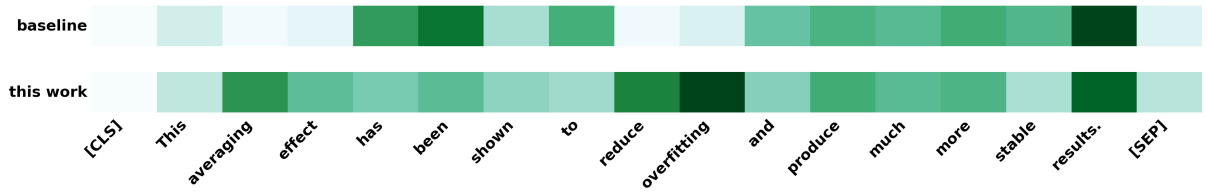
## G Error Analysis

Through comprehensive error analysis of challenging cases, we identify several patterns that our model struggles with in scientific citations. Table 11 depicts representative examples that highlight opinion terms in quadruples. Attention visualization of wrong predictions is shown in Figure 8. The first challenge in cases (1), (3) and (5) is to predict overall sentiment in mixed sentiment expressions. Case (1) stems from the model's difficulty in recognizing the rhetorical structure where initial praise ("best efforts") is overshadowed by subsequent criticism ("leaving unassessed"), while case (3) and

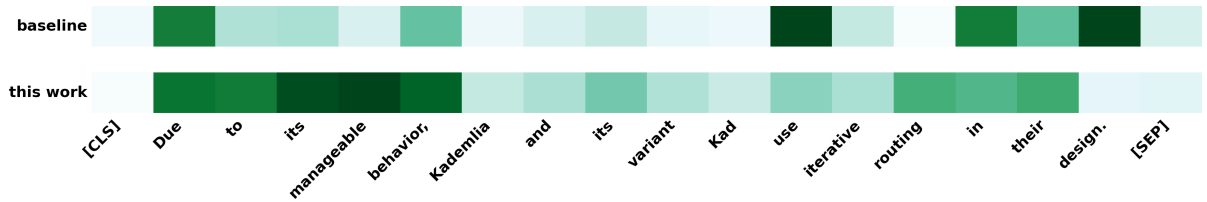
(5) present a factual relationship between methods without negative evaluation. Another challenge in cases (2), (4), and (6) arises from the model's tendency to either over-reliance or under-reliance on the information provided by the quadruples. In figure 8(b), the model focuses more attention on "taking advantage of" and recognize the citation as POS, while in figure 8(d), 8(f), the model does not select the unconventional expression of sentiment provided by the quadruple such as "go beyond" and "compensates overfit", thus, predict the citation as NEG.



(a) Examples of the case study including explicit and implicit citations. Quadruples: (aspect, opinion, category, polarity, confidence).

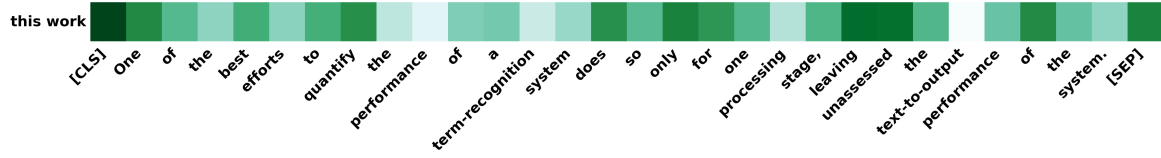


(b) Explicit sentiment example: **reduce overfitting** conveys affirmation towards **averaging effect**. Our method learns the aspect and opinion terms and predicts **POS**.

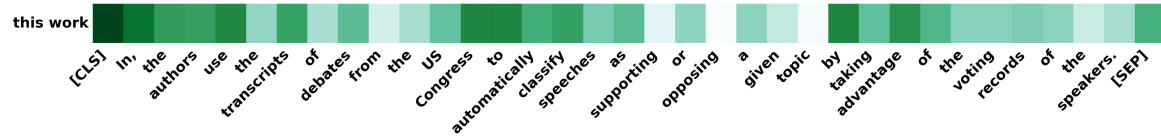


(c) Implicit sentiment example: **manageable** shows advantages towards **behavior**. Our method learns the aspect and opinion terms and predicts **POS**.

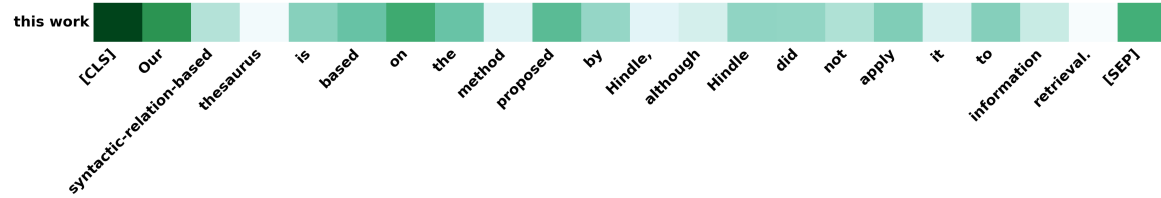
Figure 7: Attention weights visualization comparison of baseline and our method.



(a) Example (1)



(b) Example (2)



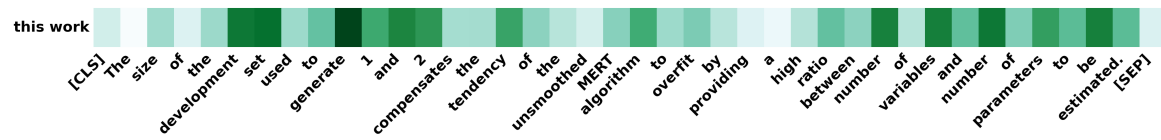
(c) Example (3)



(d) Example (4)



(e) Example (5)



(f) Example (6)

Figure 8: Attention weights visualization of error samples in our method.



| Method | Model         | CSCE Dataset |             |
|--------|---------------|--------------|-------------|
|        |               | Acc.         | F1.         |
| 0-shot | Qwen2.5-7B    | 78.4         | 58.7        |
|        | Qwen2.5-14B   | 79.9         | 61.2        |
|        | LLaMA3.2-3B   | 64.0         | 52.6        |
|        | LLaMA3.1-8B   | 77.1         | 57.4        |
|        | LLaMA3.1-70B  | 80.4         | 62.3        |
|        | LLaMA3.1-405B | <u>81.0</u>  | <b>64.9</b> |
|        | DeepSeek V2   | <b>82.7</b>  | 62.8        |
|        | GPT-3.5       | 80.3         | 63.5        |
|        | GPT-4o        | 80.8         | <u>64.7</u> |
| 6-shot | Qwen2.5-7B    | 82.1         | 63.7        |
|        | Qwen2.5-14B   | 82.4         | 64.8        |
|        | LLaMA3.2-3B   | 45.2         | 43.7        |
|        | LLaMA3.1-8B   | 80.1         | 61.1        |
|        | LLaMA3.1-70B  | 81.5         | 66.6        |
|        | LLaMA3.1-405B | <u>83.1</u>  | <b>70.5</b> |
|        | DeepSeek V2   | <b>83.6</b>  | 66.5        |
|        | GPT-3.5       | 81.6         | 67.0        |
|        | GPT-4o        | 82.5         | <u>69.8</u> |
| SFT    | Qwen2.5-7B    | <u>93.9</u>  | <u>90.7</u> |
|        | Qwen2.5-14B   | <b>96.3</b>  | <b>91.6</b> |
|        | LLaMA3.2-3B   | 90.3         | 81.9        |
|        | LLaMA3.1-8B   | 94.5         | 89.5        |

Table 8: ICL and SFT results on the CSCE dataset, comparing various models across zero-shot, few-shot, and supervised fine-tuning methods. The highest-performing models are highlighted in **bold** (best) and underlined (second best).

| Extractor/Verifier LLMs | CSCE Dataset |
|-------------------------|--------------|
|                         | F1.          |
| LLaMA-3B/70B            | 93.8         |
| LLaMA-8B/70B            | 94.9         |
| LLaMA-405B/70B          | <b>95.7</b>  |
| LLaMA-70B/—             | 95.1         |
| GPT-3.5/LLaMA-70B       | 95.3         |
| GPT-4o/LLaMA-70B        | <u>95.4</u>  |
| LLaMA-8B/DeepSeek-V2    | 94.7         |
| LLaMA-8B/GPT-4o         | 94.6         |

Table 9: Different Extractor+Verifier LLMs on QFE-RoBERTa performance. Our experiments demonstrate robustness of different Extractor/Verifier configurations to model’s performance.

| Extractor                | Verifier     | Extr Conf. | Veri Conf. | POS Num. | NEG Num. |
|--------------------------|--------------|------------|------------|----------|----------|
| LLaMA3.2-3B              | LLaMA3.1-70B | 0.932      | 0.902 ↓    | 2638     | 1177     |
| LLaMA3.1-8B              | LLaMA3.1-70B | 0.872      | 0.903 ↑    | 2611     | 993      |
| LLaMA3.1-70B             | —            | 0.902      | —          | 2688     | 902      |
| LLaMA3.1-405B            | LLaMA3.1-70B | 0.896      | 0.901 ↑    | 2662     | 836      |
| GPT-3.5 <sup>1</sup>     | LLaMA3.1-70B | 0.907      | 0.909 ↑    | 2585     | 843      |
| GPT-4o <sup>2</sup>      | LLaMA3.1-70B | 0.910      | 0.912 ↑    | 2615     | 837      |
| DeepSeek V2 <sup>3</sup> | LLaMA3.1-70B | 0.920      | 0.921 ↑    | 2706     | 867      |

Table 10: Confidence Scores and Sample Distribution Across Language Models. Most models show increased confidence scores after verification, dual LLM framework demonstrates improved confidence scores compared to single-model approaches. <sup>1</sup>GPT-3.5-turbo, <sup>2</sup>GPT-4o-2024-08-06, <sup>3</sup>DeepSeek-V2-Chat.

| Error examples   | Label | Prediction |
|--|-------|------------|
| (1) One of the <b>best</b> efforts to quantify the performance of a term-recognition system does so only for one processing stage, <b>leaving unassessed</b> the text-to-output performance of the system.   | NEG   | NEU        |
| (2) In, the authors use the transcripts of debates from the US Congress to automatically classify speeches as supporting or opposing a given topic by <b>taking advantage of</b> the voting records of the speakers.                                   | NEU   | POS        |
| (3) Our syntactic-relation-based thesaurus is <b>based on</b> the method proposed by Hindle, although Hindle <b>did not apply</b> it to information retrieval.   | NEU   | NEG        |
| (4) These methods <b>go beyond</b> the original IBM machine translation models, by allowing multi-word units in one language to be translated directly into phrases in another language.   | POS   | NEU        |
| (5) This approach took inspiration from the <b>pioneering</b> work by Brown, but it is also fundamentally different, because instead of grouping similar senses together, the CoreLex approach groups together words according to all of their senses. | NEU   | POS        |
| (6) The size of the development set used to generate 1 and 2 <b>compensates the tendency</b> of the unsmoothed MERT algorithm to <b>overfit</b> by providing a high ratio between number of variables and number of parameters to be estimated.        | POS   | NEU        |

Table 11: Examples of model’s prediction errors with *opinion* terms in quadruples highlighted in **bold**.