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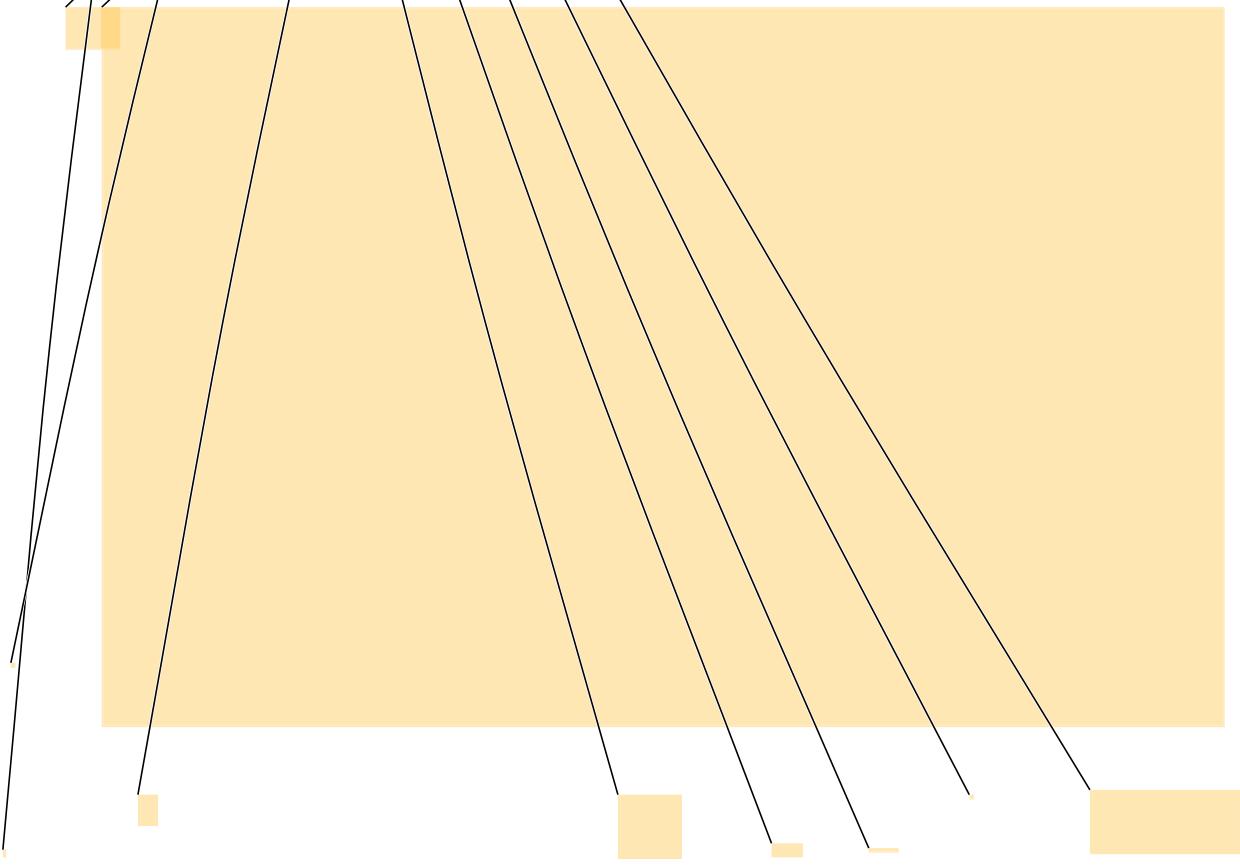
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# LIMEEdgeRefine: Enhancing Text Clustering with LLM-Based Boundary Point Refinement

Zijin Feng<sup>\*</sup>, Liuyang Lin<sup>\*</sup>, Lingzhi Wang<sup>†</sup>, Hong Cheng, Kam-Fai Wong  
 Department of Systems Engineering and Engineering Management  
 The Chinese University of Hong Kong  
 {zjfeng, lylin, lzwang, hcheng, kfkwong}@se.cuhk.edu.hk

## Abstract

Text clustering is a fundamental task in natural language processing with numerous applications. However, traditional clustering methods often struggle with domain-specific fine-tuning and the presence of outliers. To address these challenges, we introduce LIMEEdgeRefine, an iterative clustering method enhanced by large language models (LLMs), focusing on edge points refinement. LIMEEdgeRefine enhances current clustering methods by creating super-points to mitigate outliers and iteratively refining clusters using LLMs for improved semantic coherence. Our method demonstrates superior performance across multiple datasets outperforming state-of-the-art techniques, and offering robustness, adaptability, and cost-efficiency for diverse text clustering applications.

## 1 Introduction

Text clustering is a critical task in various NLP applications, such as topic modeling and information retrieval. Effective clustering enables better data management and more insightful analysis. However, text clustering presents several challenges, particularly in handling edge points—data points that are difficult to assign to clusters due to their ambiguous or extreme characteristics.

The advent of large language models (LLMs) offers new solutions to these challenges. LLMs possess powerful text understanding capabilities that can significantly improve clustering accuracy. For instance, IDAS [2] integrates abstractive summarizations from LLMs directly into clustering processes, and ClusterLLM [2] utilizes LLM-predicted sentence relations to guide clustering.

However, previous LLM-enhanced clustering methods often require extensive LLM API queries, lack domain generalization, or are not sufficiently effective. In this work, we focus on leveraging the text understanding and in-context learning/capabilities of LLMs to handle the edge points that traditional methods struggle with.

Our proposed LIMEEdgeRefine text clustering method consists of a two-stage clustering edge points refinement processing. Initially, we employ K-means to initialize clusters. In the first stage, we identify edge points using a hard threshold and then form super-points to perform efficient hierarchical secondary clustering. This approach enhances cluster quality by effectively mitigating the effects of outliers. The formation of super-points allows for a more granular examination of cluster boundaries, which is particularly beneficial for accurately delineating ambiguous data points. In the second stage, we leverage the advanced text understanding capabilities of LLMs to refine the cluster edges. This involves a soft edge points removal and re-assignment mechanism, where LLMs reassess and reassign edge points based on their semantic context. This step capitalizes on LLMs' ability to comprehend nuanced text relationships, thereby ensuring more accurate and reliable clustering results.

We evaluate our method through extensive experiments on eight diverse datasets. The results demonstrate that our method consistently outperforms baseline approaches in terms of clustering accuracy. Additionally, our complexity analysis confirms that our method is more efficient than state-of-the-art techniques, making it a practical choice for large-scale applications. In summary, our contributions are as follows:

- We introduce a novel two-stage clustering method that effectively refines edge points using LLMs, enhancing clustering accuracy.
- Our method reduces the need for domain-specific fine-tuning and minimizes computational expenses, offering a more efficient solution.
- Comprehensive experimental results demonstrate the superiority of our method in terms of both accuracy performance and efficiency.

## 2 Related Work

Clustering, a cornerstone of unsupervised learning, has seen diverse applications across various data modalities, including text, images, and graphs [2, 2, 2, 2, 2]. Traditional approaches such as K-means [7] and agglomerative clustering [2] initially dominated, operating on vector representations to partition data based on similarity measures like Euclidean distance or cosine similarity [2, 2].

Recent years have witnessed a paradigm shift towards deep clustering, leveraging deep neural networks to enhance clustering [zhou2022comprehensive]. Zhou et al. propose deep clustering into multi-stage [2, 2], iterative [2, 2, 2], generative [2], and simultaneous methods [2, 2]. More recent research has also explored LLM-enhanced clustering. wang2023goal expands clustering applications to interpretability and explanation generation tasks. In unsupervised clustering, IDAS [2] integrates abstractive summarizations from LLMs directly into clustering processes, highlighting the trend towards leveraging advanced NLP models for clustering tasks. A state-of-the-art method, ClusterLLM [2], utilizes LLM-predicted sentence relations to guide clustering. However, ClusterLLM requires extensive LLM queries and domain-specific fine-tuning, limiting efficiency and generalizability. Semi-supervised approaches, such as viswanathan2024large, require a subset of ground truth labels or expert feedback, whereas our work focuses on unsupervised clustering.

## 3 Our Framework

### 3.1 Problem Formulation

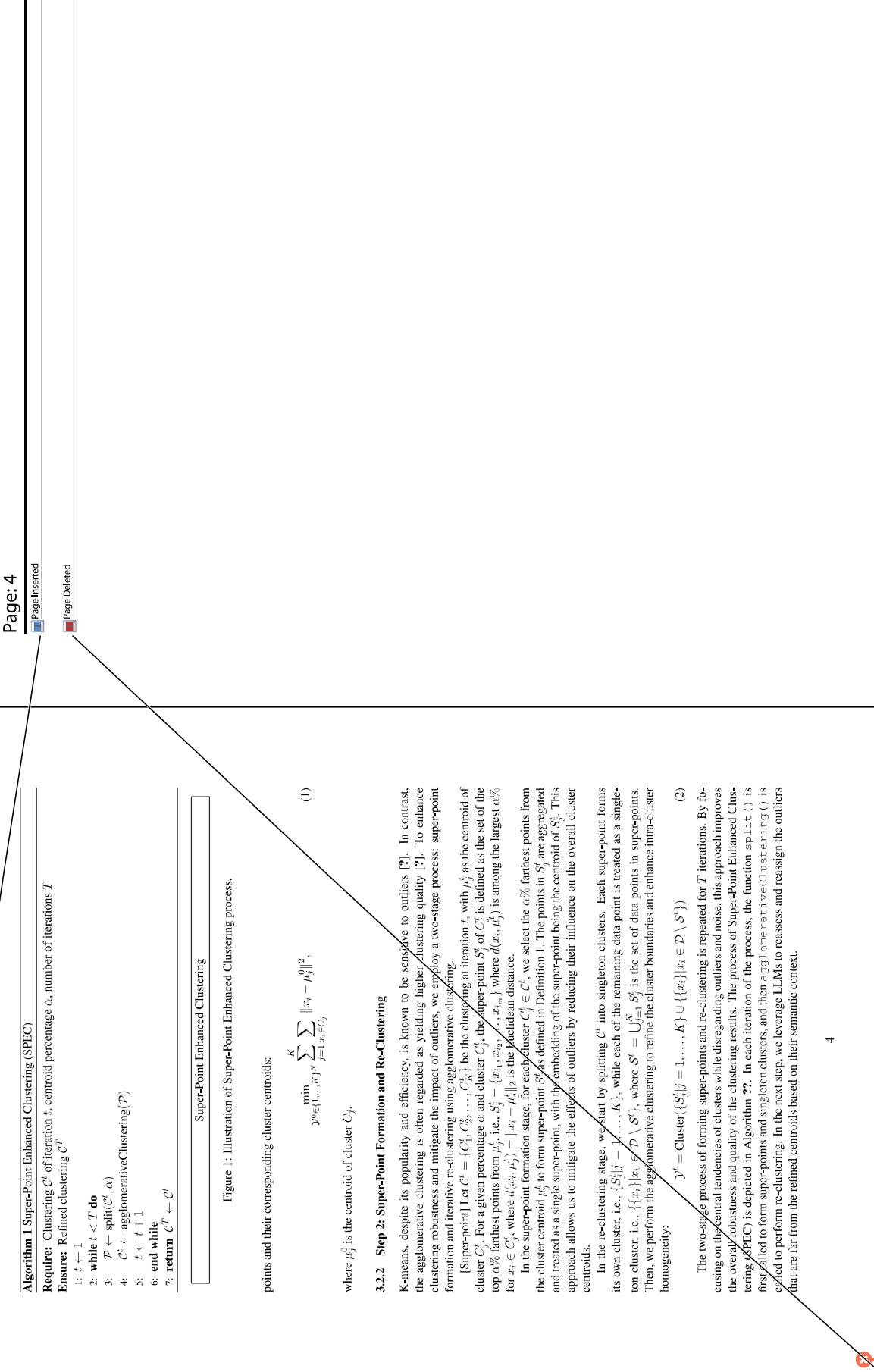
Text clustering takes an unlabeled corpus  $\mathcal{D} = \{x_i\}_{i=1}^N$  as input, and outputs a clustering assignment  $\mathcal{Y} = \{y_i\}_{i=1}^N$  that maps the input texts to cluster indices. Here,  $x_i$  represents individual text instances in the corpus, and  $y_i$  represents the cluster index assigned to the text  $x_i$ . Given a pre-defined number of clusters  $K$ , denote by  $\mathcal{C} = \{C_1, C_2, \dots, C_K\}$  a clustering of corpus  $\mathcal{D}$ .

### 3.2 Our Method

K-means clustering determines cluster centroids based on the mean, which is highly sensitive to extreme values. As a result, outliers—data points significantly different from the majority—can drastically affect centroid positions. Our method follows a four-step process to enhance clustering accuracy by mitigating the effects of outliers and leveraging large language models for improved cluster assignments.

#### 3.2.1 Step 1: Cluster Initialization

We initialize clusters using the K-means algorithm, which partitions data points into  $K$  clusters, each represented by a centroid. Denote by  $\mathcal{Y}^0 = \{y_i^0\}_{i=1}^N$  the initial clustering assignment, where  $y_i^0$  represents the cluster index assigned to the  $i$ -th data point  $x_i$ . For simplicity, we use  $x_i$  to refer to both the individual text instances and its corresponding embedding representation, with the same applies for other notations. The objective function for K-means is to minimize the sum of squared distances between data



```

Algorithm 2 LLM-Assisted Cluster Refinement (LAGR)
Require: Corpus  $\mathcal{D}$ , prompt percentage  $\beta$ , number of LACR iterations  $L$ , centroid percentage  $\alpha$ , number of SPEC iterations  $J$ 
Ensure: Clusters  $C$ 
1:  $C^0 \leftarrow \text{KMeans}(\mathcal{D})$ 
2:  $C^1 \leftarrow \text{SecondaryClustering}(C^0, \alpha, T)$ 
3:  $l \leftarrow 1$ 
4: while  $l < L$  do
5:    $V' \leftarrow \emptyset$ .  $V \leftarrow \text{farthestNodes}(C^l, \beta)$ 
6:   for each  $x_i \in V$  do
7:     if  $\text{LLMAssessor}(C^l, x_i)$  then
8:        $V' \leftarrow V' \cup \{x_i\}$ 
9:     end if
10:    end for
11:    $C^{l+1} \leftarrow \text{re-assign}(C^l, V')$ 
12:    $l \leftarrow l + 1$ 
13: end while
14: return  $C \leftarrow C^l$ 

```

LLM-Assisted Cluster Refinement

Figure 2: Illustration of LLM-Assisted Cluster Refinement process.

### 3.2.3 Step 3: Cluster Refinement with Large Language Models

For each reorganized cluster  $C_j^l \in \mathcal{C}^l$ , we further refine the clustering by leveraging the contextual understanding of large language models (LLMs). Specifically, we identify the latest  $\beta\%$  of points from the cluster centroid  $\mu_j^l$ , denoted as  $V_j^l$ . The set of all such points across all clusters is  $V = \{V_1^l, \dots, V_K^l\}$ . These points are then assessed by LLMs to determine whether they should remain in their current clusters or be reassigned.

Given a clustering  $C$ , for each point  $x_i \in V$ , we query the LLM, denoted as  $\text{LLMAssessor}(C, x_i)$ , to determine if  $x_i$  should be removed from its current cluster. If  $\text{LLMAssessor}(C, x_i)$  suggests removal, we reassign  $x_i$  to the nearest cluster based on its distance to the centroids:

$$y_i^l = \begin{cases} \arg \min_{j \neq K} \|x_i - \mu_j^{l-1}\|, & \text{if removal} \\ y_i^{l-1}, & \text{otherwise} \end{cases} \quad (3)$$

Note that the clustering assignment  $V$  and clustering  $C$  represent different aspects of clustering and can be deducted from each other. The process will be repeated for  $L$  iterations to ensure thorough refinement. The motivation for this step is to utilize the advanced contextual analysis capabilities of LLMs to identify and correct misclassified points, thereby improving the overall clustering accuracy. The algorithm of LLM-Assisted Cluster Refinement (LAGR) is illustrated in Algorithm 2.

**Prompting Details.** For each data point  $x_i \in V$ , our method generates a prompt consisting of three main components. Firstly, an instruction inst is crafted to guide the selection process, tailored to the task's context, such as "Select one classification of the banking customer utterances that better corresponds with the query in terms of intent". Secondly, the prompt includes the actual text of the data point  $x_i$  itself, forming the core of the query. Finally, our method incorporates a set of eight demonstrations comprising classification and cluster description pairs. We set the number of demonstrations to be eight based on the findings of rad2023dias, min2022rethinking, yu2022z. To simplify the notation, we denote  $C_k$  as both the  $k$ -th nearest cluster to  $x_i$  and its description, with the distance measured by the Euclidean distance between the embedding of  $x_i$  and the centroid of each cluster. The classification

Table 1: Dataset statistics.

Task Name	#clusters	#data	Domain
CLINC(I)	150	22,500	Intent
MTOP(I)	117	62,434	Intent
Massive(I)	60	50,063	Intent
GoEno	27	58,000	Emotion
CLINC(D)	10	15,000	Domain
MTOP(D)	4	14,221	Domain
Massive(S)	11	50,063	Scenario

and cluster description pairs are formally defined as  $\{(k, C_k) | k = 1, 2, \dots, 8\}$ . These pairs serve as exemplars to assist in aligning the data point with the appropriate classification.

**Remark.** Our method focuses on addressing edge data points (outliers) that exhibit extreme characteristics, which are significantly different from the majority of the data. The rationale behind LIMEEdgeRefine is to address the limitations of previous clustering methods in handling these edge points and improving cluster cohesion. In Step 1 (§2.2), K-means provides an initial set of edge points and moving cluster centroids, resulting in lower clustering quality. Step 2 (§2.2) introduces super-points to reduce the influence of outliers by focusing on the most representative points in each cluster, enhancing the cluster's internal homogeneity. Step 3 (§2.2) leverages the contextual understanding of LLMs to further refine the clusters by removing misclassified points, thereby improving the overall clustering accuracy.

In addition to K-means, clustering algorithms that adopt distance metrics and rely on a mean value-based approach also suffer from the impact of outliers. Therefore, our method is portable to these algorithms as well.

## 4 Experimental Setup

**Datasets and Baselines.** In our experimental evaluation we assess LIMEEdgeRefine across diverse datasets, including CLINC(I), MTOP(I), Massive(I), CLINC-Domain, MTOP-Domain, and Massive-Scenario. These datasets cover intent classification, topic modeling, emotional clustering, and domain-specific scenarios. We compare LIMEEdgeRefine against established unsupervised baselines including IDAS [2] and ClusterLLM [2]. The detailed statistics of these datasets is listed in Table 2.

**Hyper-Parameters and Experimental Settings.** We set parameter  $K$  of K-means to be the number of ground truth clusters. We adopt modularity [2], a popular metric of the clustering quality without requiring knowledge of the ground truth clustering, as objective function. We automatically determine the values of hyperparameters by conducting a rigorous grid search and select the values that yield the relatively highest modularity score. Besides, our clustering approach utilizes Instructor embeddings [2], and for our experiments, we employ the ChatGPT (gpt-3.5-turbo-0301), Llama2 (llama-2-7b-chat), and Mistral (mistral-B-Instruct-O.3) as our LLMs.

## 5 Experimental Results

### 5.1 Comparison of Effectiveness

We compare the accuracy (ACC) and normalized mutual information (NMI) scores of our method with baselines, and report the results in Table 2. Table 2 demonstrates the effectiveness of LIMEEdgeRefine method across multiple datasets. LIMEEdgeRefine consistently achieves superior accuracy (ACC) and normalized mutual information (NMI). The method's ability to handle edge points is evident from the significant performance improvements. Specifically, LIMEedgeRefine achieves an average ACC improvement of 17.2%, 10.9%, 17.3%, 11.6%, 12.6%, and 17.7% over Instructor, SCCL-I, Self-supervised

Table 2: Results (in %) on multiple datasets. Underlines (highlights) indicate top (second) scores per column.

Method	CLINC(I)				MTOP(I)				GoEmo				CLINC(D)				MTOP(D)				Massive(S)			
	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI		
Instrument	70.29	80.82	82.77	83.50	81.36	92.60	92.94	93.28	13.15	34.28	70.63	73.52	54.08	54.10	74.78	74.78	54.08	54.10	54.08	54.10	54.08	54.10		
SCCL-4	93.88	95.88	94.00	92.75	34.06	35.94	72.50	73.52	55.07	59.89	72.88	76.96	22.05	24.78	54.18	54.18	54.18	54.18	54.18	54.18	54.18	54.18		
Self-supervised	35.04	37.39	75.83	72.31	60.09	65.01	77.64	75.74	23.89	25.57	68.02	68.67	54.81	54.81	54.81	54.81	54.81	54.81	54.81	54.81	54.81	54.81	54.81	
ClusterLM-4	58.67	61.08	60.84	54.98	63.62	64.96	89.08	88.49	89.36	89.36	67.31	68.69	61.34	53.97	60.85	60.85	60.85	60.85	60.85	60.85	60.85	60.85		
ClusterLM	92.12	93.53	92.13	87.30	87.30	87.30	84.77	89.23	85.70	68.69	63.91	60.21	64.91	54.53	54.18	57.26	57.26	57.26	57.26	57.26	57.26	57.26	57.26	
IDAS	52.50	55.62	57.07	56.32	90.57	85.31	85.85	82.74	60.21	64.91	60.21	64.91	60.21	64.91	60.21	64.91	60.21	64.91	60.21	64.91	60.21	64.91	60.21	
w/o LACR	85.08	93.7	51.64	73.79	62.21	75.11	25.91	21.19	55.62	57.07	90.57	85.31	60.21	64.87	66.05	66.05	66.05	66.05	66.05	66.05	66.05	66.05	66.05	
w/o LACR & SPEC	77.93	92.31	33.91	71.59	57.17	74.54	34.01	29.31	57.26	56.32	76.85	82.74	59.11	64.87	66.05	66.05	66.05	66.05	66.05	66.05	66.05	66.05	66.05	
LIMERefine	86.77	92.95	46.00	72.22	63.12	76.66	34.76	29.74	59.40	61.27	22.89	88.12	63.05	68.67	68.67	68.67	68.67	68.67	68.67	68.67	68.67	68.67	68.67	

Table 3: Ablation study on clustering quality with various LLMs.

Method	CLINC(I)				MTOP(I)				Massive(I)					
	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI		
NMI														
LIMERefine-GPT3.5	86.77	94.86	46.00	72.92	63.42	76.66	34.76	29.74	59.40	61.27	22.89	88.12	63.05	68.67
LIMERefine-Llama2	86.60	94.72	46.04	72.93	62.90	76.31	34.50	29.55	59.44	61.27	22.89	88.12	63.05	68.67
LIMERefine-Mistral	86.69	94.81	45.88	72.91	62.18	76.47	34.47	29.56	59.44	61.27	22.89	88.12	63.05	68.67
Method	CLINC(D)				MTOP(D)				Massive(S)					
	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI	ACC	NMI		
LIMERefine-GPT3.5	59.40	61.27	92.84	38.19	63.05	68.67	34.76	29.74	59.40	61.27	22.89	88.12	63.05	68.67
LIMERefine-Llama2	59.26	60.93	92.54	37.78	63.12	68.76	34.76	29.55	59.26	60.93	22.89	88.12	63.05	68.76
LIMERefine-Mistral	59.48	61.74	92.64	37.84	62.61	68.35	34.47	29.56	59.48	61.74	22.89	88.12	63.05	68.35

I, ClusterLM-I, ClusterLM, and IDAS, respectively, averaging across all tested datasets. In terms of NMI, LIMERefine outperforms the baseline by an average of 8.4%, 3.8%, 5.4%, 4.7%, 4.8%, and 4.3%, respectively. The ablation study underscores the critical role of LLM-based Adaptive Cluster Refinement (LACR) and Semantic Point Edge Clustering (SPEC) modules, with performance notably dropping when these are removed. We conduct an ablation study to quantify the impact of various LLMs on effectiveness of our method, and report the results in Table ???. Table ?? shows that our LIMERefine on open-sourced LLMs Llama2 and Mistral also demonstrates promising results. This indicates that our method does not purely rely on the powerful LLM understanding capabilities of closed-sourced LLM GPT3.5, highlighting its effectiveness across different LLMs.

## 5.2 Comparison of Efficiency

The efficiency of our LIMERefine method is highlighted by its significantly reduced query complexity compared to other models like ClusterLM [2] and IDAS [7]. ClusterLM requires a fixed number of  $1/18$  prompts for each dataset and additional fine-tuning efforts, while IDAS scales with the dataset size, requiring  $O(N + C)$  prompts where  $N$  is the number of documents and  $C$  is the number of clusters. In contrast, LIMERefine operates with  $O(N \times \beta \times L)$  prompts, where  $\beta$  is a small fraction of  $N$ .

and  $L$  is the number of iterations. The detailed complexity analysis can be found in Appendix. For our experiments, with  $\beta = 0.1$  and  $L = 3$ , LIMEEdgeRefine demonstrates superior efficiency, reducing the number of prompts needed and thereby improving computational performance without compromising clustering quality.

### 5.3 Discussion of Hyper-Parameters

We determine the hyper-parameters (i.e.,  $\beta$  and  $L$ ) used in the LACR module based on the results of Bank77 [2] dataset. The sensitivity analysis shows that the clustering quality of our method is not sensitive to the value of  $\beta$ . Specifically, when  $\beta$  varies from 0.1 to 0.9 with a step size of 0.1, the standard deviation of accuracy scores is 0.32 only, indicating stability. For better efficiency, a small  $\beta$  value is sufficient to achieve satisfied performance. The discussion of more hyper-parameters can be found in Appendix.

## 6 Conclusion

In this work, we introduced LIMEEdgeRefine, a novel text clustering method enhanced by LLMs. Our method effectively addresses the challenges posed by outlier data points and domain-specific fine-tuning requirements observed in traditional clustering approaches. The experimental results demonstrate not only the effectiveness but also the efficiency of LIMEEdgeRefine.

### Limitations

While LIMEEdgeRefine demonstrates significant improvements in text clustering, several limitations should be noted. Firstly, the method's performance relies on the quality and capacity of the underlying LLMs, which can vary depending on the dataset and domain specificity. Secondly, LIMEEdgeRefine requires hyper-parameter tuning, such as the threshold for identifying edge points and the number of iterations, which may not always generalize well across different datasets.

### Acknowledgments

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## Appendix

### A Experimental Setup Details

Datasets The statistics of the used datasets are shown in Table ??.

**Baselines** Apart from SOTA method ClusterLM and IDAS, we compare other baselines listed in zhang2023clusterlm. **Hyper-Parameter Selection** In Section 5.3, we discussed the selection of  $\beta$  for LIMEEdgeRefine. Additionally, we performed a sensitivity test on the Bank77 dataset to determine the optimal number of iterations  $L$  for LLM-Assisted Cluster Refinement (LACR), ultimately setting  $L = 3$  due to stable performance observed after three iterations. For the hyper-parameters  $\alpha$  and  $T$  used in Super-Point Enhanced Clustering (SPEC), we conducted a dataset-specific sensitivity analysis to optimize performance across different datasets. Specifically, we determine the values of hyperparameters by conducting a rigorous grid search and select the values that yields the relatively highest modularity score. This approach allows us to tailor the hyper-parameters to the unique characteristics of each dataset, leading to more accurate and meaningful clustering results. Details of the hyper-parameter selection process are summarized in Tables ?? and ??.

Table 4: Sensitivity test on  $\alpha$ ,  $\alpha$  varies from 0.1 to 0.6 measured by accuracy (ACC) and modularity (MOD).

Method	CLINC(I)	MITOP(I)	Massive(I)	GoEino	CLINC(D)	MITOP(D)	Massive(S)
	MOD	ACC	MOD	ACC	MOD	ACC	MOD
$\alpha = 0.1$	82.47.1	62.5.27.9	47.6.89.8	62.7.90.0	72.7.77.6	43.5.69.9	82.67.7.2
$\alpha = 0.2$	85.1.35.6	62.6.25.9	55.6.90.1	61.0.91.4	72.0.76.9	50.2.78.9	83.9.78.5
$\alpha = 0.3$	83.4.48.1	63.0.24.9	54.4.90.2	60.7.90.7	72.5.77.0	46.5.75.8	83.0.78.0
$\alpha = 0.4$	81.0.49.0	61.1.27.4	50.7.89.1	60.9.89.7	72.2.71.1	40.7.72.6	82.0.76.8
$\alpha = 0.5$	80.1.51.7	62.1.31.3	44.1.88.2	58.2.89.2	73.7.71.8	42.4.67.0	81.4.74.9
$\alpha = 0.6$	80.1.51.6	61.2.30.3	40.4.85.4	57.5.89.4	73.1.76.1	42.4.69.9	79.9.76.6

Table 5: Accuracy scores for different values of  $L$  from 1 to 13 across various datasets.

Method	CLINC(I)	MITOP(I)	Massive(I)	GoEino	CLINC(D)	MITOP(D)	Massive(S)
	ACC	MOD	ACC	MOD	ACC	MOD	ACC
$L = 1$	84.8.51.6	60.4.26.8	50.7.90.6	60.7.91.0	76.7.41.1	75.1.83.7	78.2.84.6
$L = 2$	51.6.61.1	27.5.50.9	90.6.60.5	70.8.75.1	77.0.40.7	74.9.83.7	77.7.84.56
$L = 3$	51.6.60.4	26.1.47.3	90.5.60.7	91.1.76.1	77.0.40.5	75.1.83.7	78.2.84.9
$L = 4$	51.6.60.4	26.3.47.2	90.7.60.8	90.9.73.7	76.7.41.8	71.8.83.8	78.2.84.6
$L = 5$	51.6.61.1	27.7.48.9	90.6.59.8	91.1.71.1	76.1.45.4	69.9.79.9	76.6.85.2
$L = 6$	45.3.60.1	25.0.49.7	84.7.59.7	91.1.72.3	76.4.42.9	69.1.81.7	77.8.85.2
$L = 7$	49.9.61.0	25.0.52.0	86.5.60.1	85.2.51.1	60.9.24.2	52.4.90.6	60.9.91.2
$L = 8$	51.6.61.2	23.5.52.1	90.6.60.9	91.1.73.7	76.2.39.9	72.9.73.8	78.5.85.2
$L = 9$	45.3.60.1	25.0.49.7	84.7.59.7	91.1.71.1	76.1.45.4	69.9.79.9	76.6.84.6
$L = 10$	51.6.61.1	27.0.49.0	90.1.60.0	90.8.73.7	77.0.40.0	74.2.83.4	76.8.84.7
$L = 11$	51.6.61.1	27.0.49.0	90.1.60.0	90.8.73.7	77.0.40.0	74.2.83.4	76.8.84.9
$L = 12$	51.6.60.4	26.8.50.7	90.6.60.7	91.0.76.7	41.1.75.1	83.3.78.2	84.6.51.6
$L = 13$	61.1.27.5	50.9.90.6	60.5.90.8	75.1.77.0	40.7.74.9	83.3.77.7	84.56.51.6

## B Complexity Comparison

**Complexity of ClusterLLM.** Given a set of unlabeled corpus  $\mathcal{D}$  in the fine-tuning stage, ClusterLLM constructs 1024 triplet questions and prompts the LLMs with each triplet. In the clustering granularity determination stage, ClusterLLM constructs 594 data pairs by sampling from two clusters that are merged at each step of agglomerative clustering, then prompts the LLMs with each query. In total, ClusterLLM takes 1618 prompts, regardless of the dataset.

**Complexity of IDAS.** Given a set of unlabeled corpus  $\mathcal{D} = \{x_i\}_{i=1}^N$ , in the label generation step, IDAS first prompts the LLMs to generate a description of each of the  $|C|$  clusters. Then, for each corpus in  $\mathcal{D}$ , IDAS constructs and prompts the LLMs. In total, IDAS takes  $O(N + |C|)$  prompts.

**Complexity of LMErgeRefine.** Given a set of unlabeled corpus  $\mathcal{D} = \{x_i\}_{i=1}^N$  and a parameter  $\beta$ , at each iteration, our LACR algorithm constructs  $N \times \beta$  queries and prompts the LLMs with each query, taking  $O(N \times \beta)$  prompts. Over  $L$  iterations, our LACR takes  $O(N \times \beta \times L)$  prompts in total. In our experiments, we set  $\beta = 0.1$  and  $L = 3$ .

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