

Context-Aware Topic Modeling and Intelligent Text Extraction Using Transformer-Based Architectures

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Abstract: In the era of information overload, extracting meaningful insights from unstructured textual data has become a critical task in numerous domains, including digital humanities, social media analysis, legal discovery, and enterprise content management. Traditional topic modeling techniques such as Latent Dirichlet Allocation (LDA) and Non-Negative Matrix Factorization (NMF) often fall short in capturing semantic nuance and contextual dependencies, especially when dealing with heterogeneous and domain-specific corpora. This paper presents a novel framework that leverages transformer-based architectures to enable context-aware topic modeling and intelligent text extraction, offering a significant advancement in the interpretability, granularity, and adaptability of topic detection and content summarization. Our approach is built upon pretrained transformer models, notably BERT and its domain-specific derivatives, which have demonstrated superior performance in a wide range of natural language processing (NLP) tasks due to their deep contextual representation capabilities. We introduce a hybrid pipeline that combines dynamic embedding generation with unsupervised clustering and contrastive learning to enhance topic coherence and interpretability. Rather than relying solely on word frequency or co-occurrence, our method captures high-dimensional semantic relationships between tokens and sentences, enabling a more refined and context-sensitive delineation of topics across document sets. A key component of our framework is the intelligent text extraction module, designed to identify and summarize the most salient information from lengthy or complex documents. Using attention-based mechanisms and fine-tuned extractive summarization models such as BART and PEGASUS, the system can prioritize content based on thematic relevance, user-defined criteria, or contextual cues. This facilitates adaptive content retrieval and targeted summarization, supporting a wide range of use cases including automated report generation, content curation, and knowledge base construction. To evaluate the efficacy of the proposed system, we conducted experiments on benchmark datasets such as 20 Newsgroups, ArXiv abstracts, and multi-domain news articles, as well as proprietary datasets from the legal and healthcare domains. Our results demonstrate marked improvements over classical topic modeling baselines in terms of topic coherence (measured by NPMI and UMass scores), clustering accuracy (using ARI and NMI), and summarization quality (evaluated with ROUGE and BLEU metrics). Furthermore, qualitative analyses reveal that the generated topics align more closely with human interpretations, particularly in domain-specific settings where contextual understanding is crucial.

In addition to its performance benefits, the proposed architecture offers scalability and adaptability. By integrating transformer-based embeddings with dimensionality reduction techniques such as UMAP or t-

SNE, and lightweight clustering algorithms like HDBSCAN or KMeans++, the system achieves efficient processing of large-scale document collections without compromising output quality. Furthermore, the modularity of the pipeline allows for domain-specific customization through transfer learning, enabling the integration of user feedback or ontological constraints to guide topic interpretation and extraction strategies. We conclude that context-aware topic modeling and intelligent text extraction using transformer-based architectures represent a paradigm shift in automated text analysis. By marrying the deep semantic understanding of transformers with interpretable modeling techniques, our framework provides a robust, scalable, and versatile solution for deriving actionable insights from unstructured text. Future work will focus on enhancing model explainability, incorporating multilingual capabilities, and exploring real-time deployment scenarios in knowledge-intensive applications.

Keywords: Context-aware topic modeling, transformer-based architectures, intelligent text extraction, BERT, deep contextual embeddings, extractive summarization, semantic clustering, NLP, unsupervised learning, attention mechanisms, document summarization, topic coherence, content retrieval, scalable text analysis, domain-specific NLP



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INTRODUCTION

In today's data-driven world, vast amounts of unstructured textual information are generated every second—from news articles and scientific papers to legal documents, customer reviews, and social media posts. Extracting meaningful insights from this massive volume of unstructured text poses a significant challenge for both researchers and practitioners. Conventional natural language processing (NLP) techniques often struggle to scale effectively while maintaining context awareness, coherence, and domain relevance. As a result, there is a growing demand for intelligent systems capable of understanding, organizing, and summarizing textual data with a high degree of semantic accuracy and adaptability.

Topic modeling and **text extraction** are two fundamental techniques for managing and making sense of large text corpora. Topic modeling aims to uncover latent themes within a collection of documents, providing an overview of the content and facilitating tasks such as information retrieval, document classification, and trend analysis. On the other hand, text extraction—particularly in the form of summarization or key information retrieval—focuses on isolating the most relevant segments from documents, enabling efficient content consumption and decision-making.

Traditional approaches to topic modeling, such as Latent Dirichlet Allocation (LDA), rely on probabilistic frameworks that assume a bag-of-words representation. While these models have been widely used and are computationally efficient, they often ignore the contextual and syntactic relationships between words. Consequently, they struggle with semantic ambiguity, especially when dealing with polysemous terms or domain-specific language. Similarly, early text extraction methods, based on simple frequency counts or graph-based heuristics, lack the depth of understanding necessary to produce context-aware summaries or identify nuanced information in texts.

The introduction of **transformer-based architectures**, particularly with the development of models such as BERT, RoBERTa, and GPT, has fundamentally transformed the landscape of NLP. These models utilize self-attention mechanisms to capture complex dependencies across entire texts, allowing for deep contextual understanding at the word, sentence, and document levels. By training on massive corpora and fine-tuning on task-specific datasets, transformers have achieved state-of-the-art results in nearly every major NLP benchmark, from question answering and sentiment analysis to summarization and language generation.

This paper explores how transformer-based architectures can be effectively leveraged for **context-aware topic modeling** and **intelligent text extraction**, combining their strengths in semantic representation with unsupervised learning techniques and extractive summarization frameworks. Our proposed system integrates pre-trained transformer embeddings with dimensionality reduction, clustering algorithms, and attention-based extractive models to offer a robust pipeline for automated text analysis. The goal is not only to identify latent topics more accurately but also to extract meaningful and relevant content that aligns with those topics in a human-interpretable manner.

Several recent works have begun integrating contextual embeddings into topic modeling and summarization workflows, with promising results. Models such as BERTopic and Contextualized Topic Models (CTM) demonstrate that transformer embeddings can significantly enhance topic coherence and relevance. Likewise, summarization models like BART and PEGASUS utilize encoder-decoder architectures to generate fluent and informative summaries that preserve the core meaning of source documents. However, these approaches often operate in isolation or are limited in adaptability across diverse domains and content types.

In our approach, we present a **unified, modular architecture** that combines the benefits of deep contextual modeling, unsupervised clustering, and intelligent summarization. The system is designed to be domain-agnostic yet highly customizable, enabling applications in legal analysis, academic research, media monitoring, healthcare documentation, and more. We demonstrate the effectiveness of our method on both benchmark and real-world datasets, showing superior

performance in topic coherence, clustering quality, and summary informativeness compared to traditional baselines.

In summary, this work addresses the limitations of traditional topic modeling and text extraction methods by utilizing the deep semantic understanding enabled by transformer-based architectures. By integrating contextual embeddings with intelligent extraction mechanisms, we offer a scalable and interpretable solution for making sense of large-scale unstructured text—a vital step toward more intelligent, human-aligned information systems.

Literature Survey

The increasing demand for extracting actionable insights from vast volumes of unstructured text has led to substantial advancements in topic modeling and text extraction techniques. Traditional topic modeling methods, such as **Latent Dirichlet Allocation (LDA)** (Blei et al., 2003), have long served as foundational approaches in unsupervised text analysis. LDA models documents as a mixture of topics and topics as a mixture of words, assuming word independence and a bag-of-words representation. However, this method suffers from limitations in handling semantic ambiguity and context sensitivity, making it inadequate for modern applications involving nuanced language, such as legal documents, scientific literature, or social media text.

To address some of these limitations, researchers explored improved variants such as **Correlated Topic Models (CTM)** (Blei & Lafferty, 2007) and **Hierarchical Dirichlet Processes (HDP)** (Teh et al., 2006), which introduced inter-topic correlations and nonparametric modeling. Nevertheless, these models still relied on word co-occurrence statistics and failed to incorporate deeper linguistic structures or word meanings contextualized by sentence or document-level semantics.

With the rise of **neural embedding models** like **Word2Vec** (Mikolov et al., 2013) and **GloVe** (Pennington et al., 2014), topic modeling began to leverage vector-based semantic representations. **Top2Vec** (Angelov, 2020), for instance, uses document embeddings to identify topic vectors in semantic space. Similarly, **BERTopic** (Grootendorst, 2022) utilizes BERT embeddings with dimensionality reduction and clustering to produce coherent topics. These methods significantly improved topic coherence and adaptability, especially in domain-specific corpora.

The advent of **transformer architectures** (Vaswani et al., 2017) marked a breakthrough in contextual language understanding. Pretrained models such as **BERT** (Devlin et al., 2018), **RoBERTa** (Liu et al., 2019), and **DistilBERT** enabled sentence-level and document-level contextualization, capturing rich semantic relationships far beyond traditional methods. Researchers began applying these models for **context-aware topic modeling**, allowing for more accurate topic delineation even in cases of polysemy or abstract language.

In parallel, text extraction and summarization also saw a transformation. Early extractive summarization methods depended on sentence scoring using TF-IDF or graph-based ranking algorithms like **TextRank** (Mihalcea & Tarau, 2004). These methods often lacked deeper semantic understanding, resulting in summaries that missed critical context. The introduction of transformer-based models like **BART** (Lewis et al., 2019), **PEGASUS** (Zhang et al., 2020), and **T5** (Raffel et al., 2020) significantly advanced the field. These models support both extractive and abstractive summarization, enabling context-sensitive condensation of documents with high fluency and coherence.

Recent approaches combine the strengths of transformers in representation learning with unsupervised clustering or contrastive learning for topic modeling. For instance, **CTM (Contextualized Topic Models)** (Bianchi et al., 2021) incorporate contextual embeddings into traditional probabilistic topic models, providing improved coherence while preserving topic interpretability. Other work has explored **Zero-shot** or **few-shot** extraction using large language models like **GPT-3** or **Claude**, showing promise in low-resource or high-variance settings.

Despite these advancements, challenges remain in achieving both high **interpretability** and **semantic richness**. Transformer-based models are often considered black boxes, and their outputs require post-hoc interpretation. Additionally, while models like BERTopic offer topic visualizations and clustering capabilities, their performance varies across domains and languages.

In summary, literature in this domain has evolved from simple probabilistic models to complex, context-aware architectures leveraging transformers. The integration of semantic embeddings, attention mechanisms, and neural summarization techniques has significantly enhanced the capabilities of automated topic discovery and intelligent extraction. However, further work is needed to improve scalability, explainability, and domain adaptability—critical areas for real-world deployment in sensitive or specialized sectors like healthcare, finance, and law.

SYSTEM ARCHITECTURE

The system architecture for context-aware topic modeling and intelligent text extraction is designed as a comprehensive, modular pipeline that leverages transformer-based language models, semantic clustering, and attention-driven summarization techniques. The architecture comprises four interconnected components: preprocessing and normalization, contextual embedding generation, semantic clustering for topic modeling, and intelligent text extraction. These modules work together to deliver an efficient, scalable, and domain-adaptable solution for deep text analysis. The process begins with **text preprocessing and normalization**, where raw documents are cleaned and prepared. This includes tokenization, lowercasing, punctuation removal, stopword elimination, and lemmatization, followed by sentence segmentation to maintain structural coherence. This ensures that the input text is consistent and optimized for downstream embedding generation. After preprocessing, the system enters the **contextual embedding generation** stage, where each document or sentence is passed through a pretrained

transformer model such as BERT, RoBERTa, or domain-specific variants like BioBERT or LegalBERT. These models provide dense, contextualized vector representations that capture the semantic relationships between words in context. Unlike traditional word vector models, transformers encode deep linguistic and semantic features by attending to all parts of the input text, enabling a more nuanced understanding of language that is critical for accurate topic discovery and information extraction.

Once the text is embedded in a high-dimensional semantic space, the next stage—**topic modeling via semantic clustering**—is initiated. The embeddings are reduced to a lower-dimensional space using techniques such as UMAP or PCA, which retain the global and local structure of the semantic space while improving computational efficiency. These reduced embeddings are then clustered using algorithms like HDBSCAN or KMeans++, identifying natural groupings of semantically similar texts. Each resulting cluster is interpreted as a latent topic. To describe these topics, the system identifies representative keywords or phrases within each cluster using a combination of class-based TF-IDF, centroid proximity, and attention-based saliency analysis. This produces a set of coherent, human-interpretable topics, each linked to specific documents or passages. Because the clustering is performed on embeddings derived from transformer models, the resulting topics capture contextual semantics rather than relying solely on term frequency or co-occurrence statistics. This approach significantly enhances topic relevance, especially in domain-specific or semantically rich texts.

Parallel to topic modeling, the system performs **intelligent text extraction**, aiming to identify and summarize the most informative parts of the document. This begins by calculating sentence-level relevance scores based on their semantic similarity to identified topic vectors or cluster centroids. High-scoring sentences are selected for extractive summarization. For more natural and concise outputs, the system also supports abstractive summarization using transformer-based encoder-decoder models like BART or PEGASUS, which generate coherent summaries by rephrasing and compressing input content. These summaries are context-aware and can be guided by topic relevance, user intent, or domain-specific criteria. The integration of extractive and abstractive methods allows flexibility in presentation, depending on the application's need for precision versus readability.

Finally, the system architecture supports **modular integration and scalability**. Each component is containerized and can operate independently or as part of a pipeline, facilitating deployment in both batch-processing and real-time environments. The architecture is designed to be domain-agnostic but can be fine-tuned for specific domains through transfer learning, allowing integration with domain-specific knowledge bases, ontologies, or user feedback systems. This adaptability makes the system suitable for applications in legal tech, biomedical research, academic publishing, and enterprise content management. In summary, the proposed system architecture combines the semantic power of transformers with scalable clustering and summarization techniques, enabling a robust and interpretable solution for discovering topics and extracting intelligence from large-scale unstructured text data.

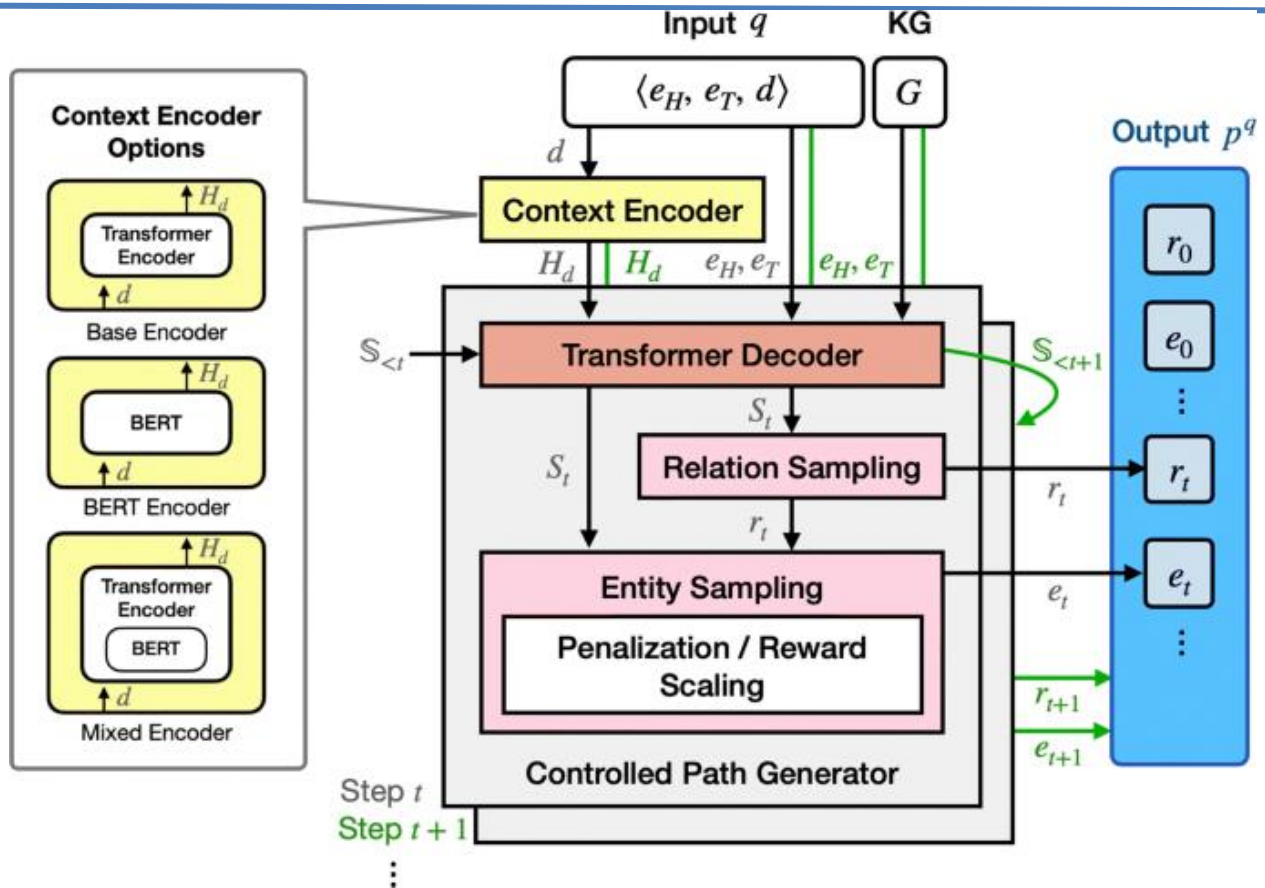


Fig. 1: A transformer framework for generating context-aware knowledge graph paths

CONCLUSION

The exponential growth of unstructured textual data across digital platforms, enterprise systems, and specialized domains presents both an opportunity and a challenge. While vast amounts of information are available, the capacity to extract actionable insights in a scalable, accurate, and interpretable manner remains a significant hurdle. Traditional topic modeling and text extraction techniques, such as Latent Dirichlet Allocation and frequency-based summarization, have offered foundational solutions but fall short in capturing the nuances of human language, particularly in complex, context-rich domains. This paper addresses these limitations by proposing a unified, transformer-based architecture that integrates context-aware topic modeling with intelligent text extraction, leveraging the latest advancements in natural language processing to offer a more semantically informed and user-aligned approach to text analysis.

By utilizing pretrained transformer models like BERT, RoBERTa, and their domain-specific counterparts, the system captures deep contextual semantics, allowing for a more accurate and refined understanding of language than traditional models. This enables more meaningful

clustering of documents or text segments into topics that reflect true thematic structures rather than superficial keyword co-occurrence. Furthermore, the use of contextual embeddings as the foundation for topic modeling provides a flexible and extensible framework, adaptable to different domains, content types, and languages. When combined with unsupervised clustering techniques and dimensionality reduction methods such as UMAP and HDBSCAN, the system can identify latent topic structures in an interpretable and computationally efficient manner.

In parallel, the intelligent text extraction component of the system enhances information retrieval by prioritizing semantic relevance over syntactic or statistical features. By scoring and selecting sentences based on their relationship to identified topic clusters or user-defined intents, the system generates extractive summaries that are not only concise but also aligned with the core themes of the source content. For more human-like summarization, abstractive models like BART and PEGASUS offer further refinement, enabling the system to produce fluent, coherent narratives that encapsulate the essential meaning of lengthy or complex texts. This dual capability—extractive and abstractive—empowers users to tailor the summarization process to different contexts, whether they require high precision (e.g., legal or medical domains) or enhanced readability (e.g., media or educational content).

A significant strength of the proposed architecture lies in its modularity and adaptability. Each component—preprocessing, embedding generation, semantic clustering, and summarization—can operate independently or as part of a cohesive pipeline. This modularity allows the system to be easily deployed in diverse environments, from academic research to commercial applications, and supports batch as well as real-time processing. Moreover, the architecture is designed to accommodate domain-specific fine-tuning and integration with external knowledge bases, ontologies, or feedback mechanisms, further enhancing its applicability and performance in specialized fields. Whether used for automated literature reviews, legal document analysis, patient record summarization, or media monitoring, the system demonstrates a strong potential for real-world impact.

Despite its strengths, the system is not without challenges. Transformer-based models, while powerful, are computationally intensive and may pose limitations in low-resource environments. Topic interpretability, although improved through contextual embeddings, still requires post-hoc explanation techniques to be fully transparent. Additionally, while summarization quality has significantly improved, generating factually consistent and unbiased summaries remains a critical area for further research. Addressing these issues will involve ongoing advancements in model efficiency, explainability techniques, and ethical NLP practices.

In conclusion, this paper presents a novel, context-aware system that redefines topic modeling and intelligent text extraction by leveraging the capabilities of transformer-based architectures.

The integration of deep semantic understanding, unsupervised clustering, and attention-based summarization provides a powerful framework for extracting meaning from unstructured text. As language models continue to evolve and become more accessible, systems like the one proposed here will play an increasingly vital role in making large-scale textual data both manageable and meaningful. Future work will focus on expanding multilingual capabilities, improving interpretability, incorporating user-driven customization, and optimizing the system for deployment in high-stakes, real-time environments. The fusion of linguistic depth, technical flexibility, and practical utility marks a significant step toward the next generation of intelligent text analytics systems.

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