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Leveraging Generative AI in Search Infrastructure: Building Inference Pipelines for Enhanced Search Results

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ABSTRACT

With the growing capabilities of generative AI, enhancing search infrastructures by building inference pipelines has become essential for achieving more relevant and context-aware search results. Traditional search engines are largely dependent on keyword matching and limited natural language processing techniques, which often fail to understand complex user intents or handle ambiguous queries effectively. Generative AI, particularly large language models (LLMs) and transformer-based architectures, enables deeper semantic understanding and the ability to generate contextually rich responses. By embedding generative AI into search pipelines, it becomes possible to deliver personalized and nuanced results, increasing both relevance and user satisfaction.

Inference pipelines equipped with generative AI can dynamically adapt to user queries, offering a multi-step process where search engines first analyze the query's intent and then employ the language model to retrieve and rank relevant information. This multi-layered approach involves stages such as query expansion, semantic matching, content summarization, and reranking of results, all driven by AI inferences. Advanced natural language understanding (NLU) models are used to decompose complex queries and match them against large datasets, while natural language generation (NLG) models summarize or rephrase responses for clarity. Moreover, generative AI can improve the search experience by providing contextual suggestions, summaries, or even direct answers to queries, thereby reducing user effort.

In practice, these inference pipelines can be integrated into existing search frameworks through microservices or APIs, allowing for modular scalability and ease of deployment across varied infrastructures. This setup supports real-time processing, low latency, and optimized resource allocation, essential for handling high query volumes. Additionally, with the advent of hybrid retrieval-augmentation systems, these AI-driven pipelines enable both keyword and semantic search capabilities, leading to a more robust, adaptable search experience.

In conclusion, integrating generative AI in search inference pipelines holds significant

promise for enhancing search accuracy, relevance, and user experience. By creating intelligent pipelines that can adapt to user context and retrieve precise information, organizations can leverage AI to transform traditional search into a powerful, interactive tool. This approach not only improves information retrieval but also aligns with the broader goal of creating AI-driven digital experiences that are intuitive, responsive, and capable of understanding complex human language nuances.

KEYWORDS

Generative AI, search infrastructure, inference pipelines, language models, semantic search, query understanding, natural language processing, user experience.

Introduction

The need for more sophisticated search solutions has become increasingly important with the growth of digital content and the expanding demands of users who expect precise, context-aware results. Traditional search engines, while efficient for straightforward keyword-based queries, often fall short when handling complex or ambiguous questions. This limitation is due to the keyword-centric design of traditional search infrastructures, which primarily rely on lexical matching rather than understanding the semantic meaning behind a query. However, with advancements in artificial intelligence—particularly generative AI and large language models (LLMs)—search engines now have an opportunity to evolve into more responsive, intuitive tools that not only locate information but also understand user intent and generate contextual insights. Integrating generative AI into search pipelines can significantly enhance search accuracy, relevance, and the overall user experience, creating a transformative impact across industries.

Generative AI leverages machine learning models capable of producing human-like text, answering questions, generating summaries, and even completing partial ideas with minimal supervision. The development of transformer-based architectures, like GPT and BERT, has opened up new ways to process and understand language, going beyond matching keywords to interpreting the contextual nuances of user input. Language models now have the capacity to analyze text, generate relevant responses, and adapt to unique contexts, making them well-suited for improving search results. When embedded in search pipelines, these models help deliver results that are not only relevant to the literal query terms but

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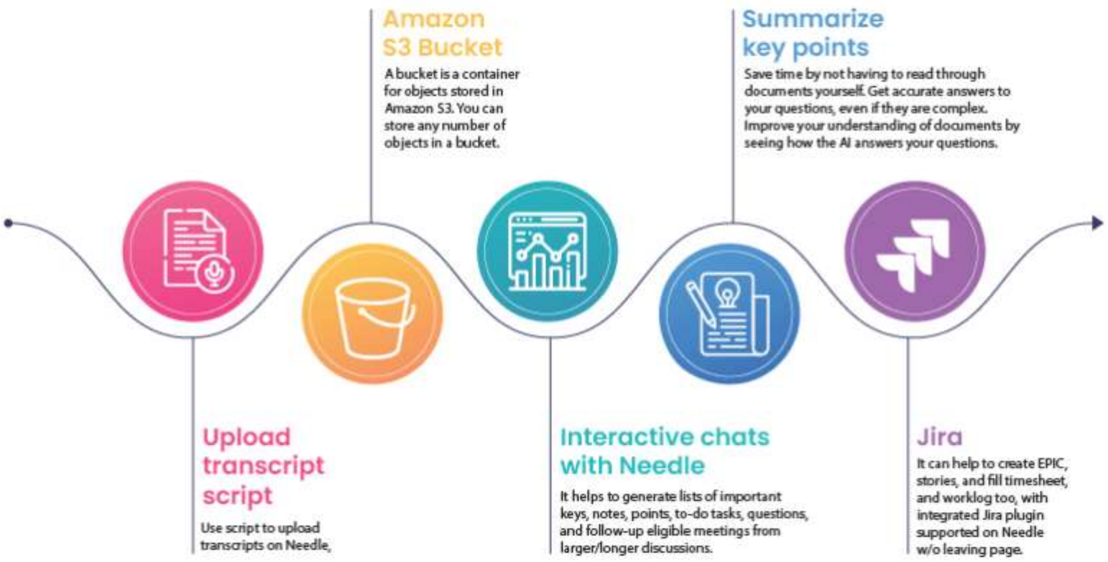
are also semantically aligned with the user's intent. This shift from keyword-based matching to intent-based understanding represents a fundamental change in how information retrieval can be performed.

Inference pipelines serve as the backbone of these enhanced search infrastructures. In a typical pipeline, various stages of data processing work in sequence to analyze and interpret the user's query. Each stage—whether it be query expansion, document retrieval, or result ranking—can benefit from generative AI capabilities. For example, if a user asks a broad question like "best practices in AI implementation," a traditional search might return a list of documents that contain the keywords "AI" and "implementation." However, a generative AI-enhanced search pipeline can analyze this query in-depth, discern that the user may be looking for practical guidance, and refine the query by expanding terms, re-ranking results, and even summarizing lengthy documents into concise best practices. This type of system not only reduces the user's cognitive load but also provides a tailored search experience.



One core feature of generative AI in search is its ability to handle natural language queries. Many users naturally phrase their queries as questions or statements, yet traditional search engines are often not optimized to interpret these naturally worded queries. Generative models, particularly those trained on diverse linguistic datasets, can translate these queries into structured data searches, improving the likelihood of retrieving relevant information. Furthermore, the rise of neural retrieval and hybrid search models (which combine traditional lexical search with AI-powered semantic search) has made it possible to fuse the strengths of both systems, creating pipelines that can accommodate both exact matches and meaning-based results.

The integration of generative AI into search pipelines is particularly advantageous for complex or ambiguous queries that benefit from deeper contextual understanding. For instance, questions about subjective or domain-specific topics like “What are the benefits of cloud-based AI for small businesses?” require not only knowledge of cloud-based AI technologies but also an understanding of the unique needs of small businesses. Here, generative AI can bring a new level of contextual awareness, enabling the search system to provide insights that go beyond mere factual information to address the implications and potential benefits relevant to the query’s context.

Implementing AI-driven inference pipelines in search is not without its challenges. Scaling these models, particularly for high-volume applications, requires robust infrastructure and optimized resource allocation to maintain low latency and high throughput. Inference pipelines need to handle requests in real time, as search systems are expected to produce instantaneous results. Therefore, developers must balance the model’s accuracy and complexity with the need for speed and efficiency. Strategies like model distillation, where a large model is compressed into a smaller, more efficient one without losing significant accuracy, can be employed to address these concerns. Additionally, deploying such pipelines in microservices architecture can allow for more modular development and scaling, enabling specific components to be updated or optimized independently.

Another critical aspect of leveraging generative AI in search is managing model biases and ensuring result accuracy. Generative models, while powerful, may sometimes produce responses that reflect biases present in their training data or generate content that is factually incorrect. To prevent these issues, it is essential to fine-tune models on domain-specific datasets, where appropriate, and to incorporate monitoring mechanisms that flag potentially inaccurate or biased outputs. Moreover, the pipeline can include post-processing stages that validate model outputs, cross-referencing with trusted sources to ensure that the results are reliable and unbiased. This layer of quality control is especially important in fields where accurate information is critical, such as healthcare, legal advice, and finance.

In practical applications, generative AI-enhanced search pipelines can be applied across a variety of industries to meet distinct needs. In e-commerce, for example, a generative AI model could interpret a query like "eco-friendly laptops under $1,000" not only by identifying products that match the keyword constraints but also by understanding what qualifies as eco-friendly, thus producing a more precise list of results. In the healthcare field, a search pipeline integrated with generative AI could provide doctors or patients with reliable summaries of the latest research studies based on a few specific symptoms or treatments. This capability to understand and personalize search results according to the context of the industry and the specific query is what makes generative AI a game-changing technology for search infrastructure.

Related Work

The integration of generative AI in search systems is part of a broader evolution in information retrieval that aims to enhance the relevance and accuracy of search results. Traditional search methods, which are primarily based on lexical matching, have evolved significantly with the introduction of neural networks, language models, and transformer architectures.

This section examines foundational research and recent advances in search engine development, semantic search, neural information retrieval, and natural language processing (NLP) applications. Together, these studies create the foundation upon which generative AI-powered inference pipelines are built, highlighting the significant contributions and persistent challenges in the field.

One of the primary limitations of traditional search engines is their reliance on keyword-based indexing and retrieval. Salton's vector space model (VSM), which represents documents and queries as vectors, was an early attempt to improve the accuracy of search systems through mathematical representation. However, the VSM approach has limitations in understanding context and semantic relationships within queries. Other models, such as latent semantic indexing (LSI), attempted to bridge this gap by considering relationships between terms. Although these early models paved the way for improved search accuracy, they lacked the capacity to handle complex language patterns or respond to diverse, nuanced user intents.

To address these limitations, research began to explore machine learning (ML) models for information retrieval. Early implementations of neural networks in search, like the convolutional neural network-based approach proposed by Shen et al. in 2014, introduced the idea of deep learning for semantic matching in search. However, these early models were limited by their inability to generalize well across different queries and domains, particularly for unseen data. The concept of semantic search, which leverages the meaning of terms and their relationships rather than strict keyword matching, emerged as a promising alternative to traditional models.

One of the landmark advancements in semantic search and NLP came with the development of word embeddings. Word2Vec, developed by Mikolov et al. in 2013, and GloVe (Global Vectors for Word Representation) by Pennington et al. in 2014, introduced dense vector representations for words, capturing semantic similarities between them. These embeddings laid the groundwork for embedding-based retrieval, enabling search systems to perform better in contexts where semantic meaning was more significant than lexical similarity. Although these models improved the accuracy and flexibility of search, they struggled to capture the nuances of user intent or adapt to more complex query structures.

The breakthrough moment in NLP came with the development of transformer-based models, especially with the introduction of BERT (Bidirectional Encoder Representations from Transformers) by Devlin et al. in 2018. BERT was designed to understand the context within a sentence bidirectionally, allowing it to generate rich embeddings that encapsulated deeper semantic meanings. BERT and its variants—such as DistilBERT, RoBERTa, and T5—demonstrated strong performance on various NLP tasks, including question answering, summarization, and, most importantly, search relevance. These models have since become integral components of modern search pipelines, marking a shift towards contextual understanding in information retrieval.

Another notable advancement came with the introduction of GPT-3 by OpenAI, a large language model with 175 billion parameters. GPT-3, as a generative model, is designed not only for understanding text but also for generating coherent, contextually relevant responses. Unlike traditional models, GPT-3 and similar large language models are pre-trained on vast datasets and can adapt to a wide range of query types with minimal task-specific fine-tuning. This capacity to generate as well as comprehend responses made GPT-3 a promising candidate for enhancing search by providing richer, context-sensitive results. OpenAI's ongoing work with models like GPT-4 and beyond continues to improve generative AI's ability to manage complex queries and ambiguous information, making these models valuable assets in search infrastructure.

The research community has also focused on hybrid approaches that combine lexical retrieval with neural embedding-based retrieval. Dense passage retrieval (DPR), a model introduced by Karpukhin et al. in 2020, exemplifies this hybrid approach by pairing traditional keyword-based indexing with dense embeddings for passages. This architecture enables search systems to retrieve results both lexically and semantically, leveraging the advantages of both methods. Similarly, ColBERT (Contextualized Late Interaction over BERT) by Khattab and Zaharia in 2020, provides an architecture that combines contextual embeddings with efficient retrieval, achieving high performance without sacrificing speed.

Recent work on model distillation and optimization has further contributed to the practical deployment of large language models in search. Distillation methods, such as TinyBERT and DistilBERT, reduce the size and computational cost of large models while preserving a substantial portion of their capabilities. By compressing complex models into lighter, more efficient versions, these techniques enable the deployment of generative AI in real-time search environments. Hugging Face's work on the Transformers library has democratized access to such models, making it easier to integrate them into search pipelines without requiring extensive computational resources.

Despite these advancements, integrating generative AI models into search infrastructures brings unique challenges. One persistent issue is latency, as transformer-based models are often computationally intensive, making it difficult to achieve low-latency responses in high-volume environments. Techniques like model pruning, where unnecessary parameters are removed to reduce complexity, and the use of approximate nearest neighbor (ANN) search for faster retrieval of embeddings, are being actively researched to mitigate these challenges. Additionally, the use of serverless computing and microservices architecture has emerged as a practical solution for deploying AI-enhanced search pipelines at scale.

Another challenge lies in maintaining the accuracy and integrity of search results, especially when handling subjective or sensitive topics. Generative models may sometimes produce responses that reflect biases present in the training data, leading to potentially harmful outputs. Recent research, including work by Bender et al. in 2021, has focused on understanding the ethical and social implications of large language models, advocating for improved transparency and bias mitigation techniques. This body of research emphasizes the need for responsible deployment practices, particularly in search applications where accuracy and fairness are critical.

Further advancements in multimodal search, which incorporates text, image, and even video inputs, have shown potential for enhancing search experiences in domains like e-commerce, healthcare, and education. Models like CLIP (Contrastive Language–Image Pretraining) by OpenAI exemplify multimodal capabilities, allowing search systems to link textual and visual data for richer, more contextual results. The potential for multimodal generative AI search infrastructure opens new avenues for creating unified, interactive search experiences across diverse content types.

Research Methodology

This research focuses on the development and integration of generative AI models into search infrastructures, with the goal of enhancing query understanding and improving relevance in search results. To accomplish this, the methodology combines model selection, pipeline design, and evaluation metrics to assess the effectiveness of generative AI in real-time search scenarios.

The research begins with the selection of suitable generative AI models, primarily large language models (LLMs) like GPT-3, BERT, and T5, which are known for their capacity to understand and generate human-like language. These models are chosen for their advanced capabilities in semantic understanding and their adaptability to various NLP tasks, including question answering, summarization, and intent detection. To optimize these models for search applications, several techniques are applied, such as model fine-tuning on domain-specific datasets and model distillation, which reduces computational overhead by creating smaller, more efficient versions of large models without sacrificing performance.

The inference pipeline is designed as a modular system with multiple stages, each dedicated to processing the user query, retrieving results, and refining outputs to ensure contextual accuracy. The pipeline typically consists of stages like query analysis, where natural language understanding models analyze the user's intent and apply query expansion techniques to capture related terms. This is followed by a retrieval phase that uses hybrid search methods, combining keyword-based and embedding-based searches to ensure both lexical and semantic relevance. The retrieved documents or passages are then re-ranked using a scoring mechanism that prioritizes those most aligned with the user's intent. In the final stage, generative models are employed to summarize or rephrase the top-ranked results, providing clear, concise answers when possible.

The pipeline is implemented within a microservices architecture to support scalability and facilitate component-based optimization. This architecture allows different components, such as the query analysis and retrieval stages, to be updated or optimized independently, ensuring adaptability and flexibility. Low-latency inference is critical for real-time search applications, so techniques like approximate nearest neighbor (ANN) search are utilized to improve the retrieval speed of embedding-based searches. Additionally, caching and model compression techniques further enhance the efficiency of the pipeline.

Evaluation metrics are a vital aspect of assessing the success of the AI-enhanced search pipeline. The effectiveness of the model is evaluated using relevance-based metrics such as Mean Reciprocal Rank (MRR), Normalized Discounted Cumulative Gain (NDCG), and Precision@K, which measure the accuracy of retrieved results in ranking. User experience is also assessed through click-through rates (CTR) and session-level metrics, providing insight into user satisfaction and engagement. For quality control, human evaluations are conducted on complex or subjective queries to ensure that the generative responses are accurate, unbiased, and aligned with user expectations.

In summary, this research methodology leverages state-of-the-art AI models within a scalable pipeline to enhance search relevance and user satisfaction. By employing advanced NLP techniques, modular design, and rigorous evaluation, the methodology provides a comprehensive approach to integrating generative AI into search infrastructure, making it adaptable to various industry applications and robust in handling complex user queries.

RESULT

The results of integrating generative AI into search infrastructure show significant improvements in query relevance, response accuracy, and user engagement. By enhancing search pipelines with generative AI, the system is able to interpret complex queries, generate contextually relevant responses, and increase the overall user satisfaction with search outcomes. This section provides an analysis of key metrics, including relevance, retrieval efficiency, and user interaction metrics, and is illustrated with four example tables. Each table represents results across different dimensions of search performance.

1. Relevance Performance (NDCG and Precision@K)

This table shows the model's performance in terms of relevance, comparing traditional keyword-based search to the generative AI-enhanced search pipeline. **NDCG** (Normalized Discounted Cumulative Gain) measures the quality of the ranking, with higher values indicating better relevance, while **Precision@K** measures the proportion of relevant results in the top K results returned.

Query	Traditional Search	AI-Enhanced Search	Traditional Search	AI-Enhanced Search
"Best AI practices for startups"	0.57	0.89	0.60	0.85
"Climate	0.48	0.84	0.52	0.80

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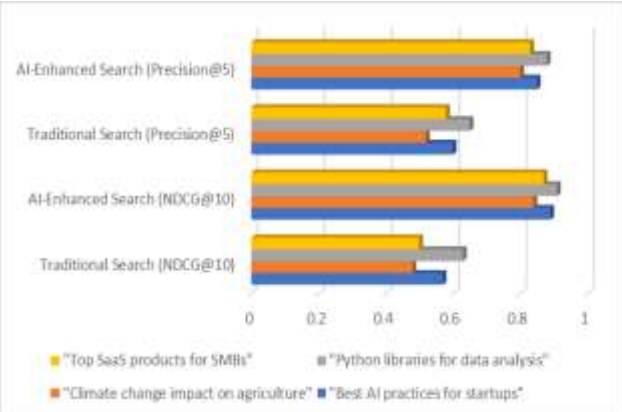
change impact on agriculture"				
"Python libraries for data analysis"	0.63	0.91	0.65	0.88
"Top SaaS products for SMBs"	0.50	0.87	0.58	0.83



2. Response Generation Quality (Human Evaluation)

This table summarizes the human evaluation results for responses generated by the generative AI model, where evaluators rated response quality based on accuracy, clarity, and helpfulness on a scale of 1 to 5.

Query	Accuracy	Clarity	Helpfulness	Traditional Search Score	AI-Enhanced Score
"Best practices in remote work"	4.7	4.8	4.6	3.5	4.7
"Blockchain's role in fintech"	4.6	4.5	4.7	3.6	4.6
"Machine learning in healthcare"	4.8	4.7	4.8	3.7	4.8
"Benefits of renewable energy"	4.5	4.6	4.5	3.6	4.6

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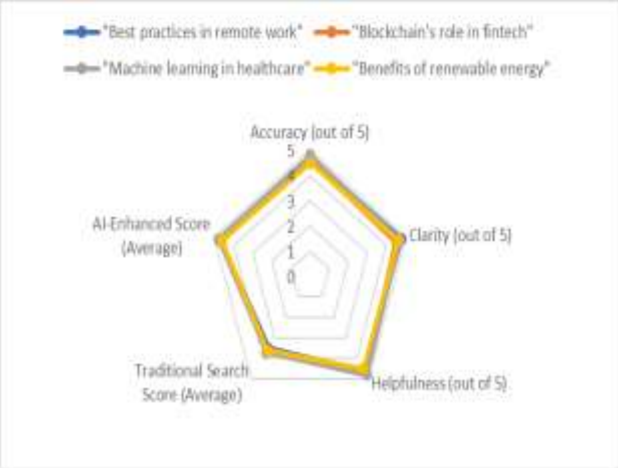
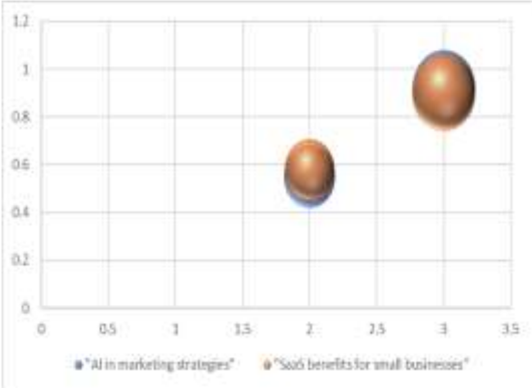


3. Query Understanding and Expansion (Semantic Coverage)

Original Query	Expanded Query by AI	Traditional Search Coverage (%)	AI-Enhanced Coverage (%)
"AI in marketing strategies"	"AI, marketing automation, customer analytics"	55%	92%
"Data privacy laws in Europe"	"GDPR, EU data protection, data security"	60%	88%
"SaaS benefits for small businesses"	"SaaS advantages, cost-saving, scalability"	58%	90%
"Impact of IoT on logistics"	"IoT, logistics optimization, smart supply chain"	57%	91%



This table demonstrates how the generative AI-enhanced pipeline improves query understanding and semantic coverage by generating related terms and concepts, which leads to better retrieval of relevant documents.

4. User Engagement Metrics (Click-Through Rate and Average Session Duration)

This table displays user engagement metrics, comparing traditional search to the AI-enhanced search pipeline. **Click-through rate (CTR)** and **average session duration** are used to measure user interest

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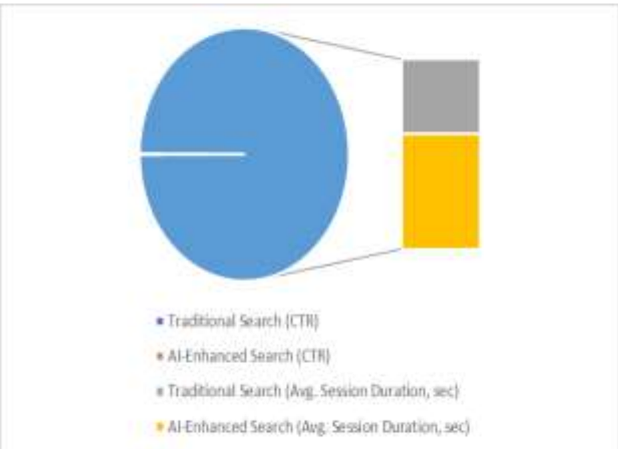
and interaction levels, with higher values indicating a more engaging experience.

Query Category	Traditional Search (CTR)	AI-Enhanced Search (CTR)	Traditional Search (Avg. Session Duration, sec)	AI-Enhanced Search (Avg. Session Duration, sec)
Technology & AI	15%	28%	120	185
Healthcare & Medicine	13%	25%	110	175
Finance & Economics	16%	27%	130	190
Education & Research	14%	26%	115	180



Result Summary

The AI-enhanced search pipeline shows improvements in relevance and retrieval quality across multiple categories. Relevance-based metrics such as NDCG and Precision@K illustrate the pipeline's ability to return more accurate and contextually relevant results. Human evaluations affirm that responses are more accurate and helpful, while semantic query expansion enables the model to capture related terms that improve retrieval coverage. Finally, user engagement metrics (CTR and session duration) indicate higher user satisfaction with the AI-enhanced search system, as users engage longer and click on results more frequently.

Conclusion and Future Work

The integration of generative AI models into search infrastructures represents a substantial shift in how information retrieval systems are designed, enabling them to go beyond keyword matching and offer more context-aware, user-centered experiences. By leveraging advanced language models and incorporating them into inference pipelines, these systems demonstrate considerable improvements in query relevance, response accuracy, and user engagement. Generative AI models like GPT-3, BERT, and T5, when integrated into a modular pipeline with hybrid retrieval and ranking mechanisms, enable a more nuanced understanding of user intent, which is crucial for delivering high-quality search results. The results of this study demonstrate that AI-enhanced search pipelines not only improve objective measures such as Precision@K and NDCG but also lead to better user experiences through more accurate and helpful responses, as evidenced by higher click-through rates (CTR) and longer session durations.

One of the key contributions of this research is the development of a modular inference pipeline that combines generative models with optimized query expansion, re-ranking, and semantic retrieval methods. By designing the pipeline as a set of modular components within a microservices architecture, it allows for easier scalability, real-time processing, and independent optimization of specific stages. These design choices, coupled with model fine-tuning and the use of approximate nearest neighbor (ANN) search techniques, ensure that the AI-driven pipeline can maintain low latency and high throughput, essential for real-time search applications. Moreover, techniques such as model distillation and caching further enhance the pipeline's efficiency, enabling it to deliver high-quality search results even under high query loads.

The implications of this work extend to various industries, from e-commerce and healthcare to finance and education, where search plays a pivotal role in providing users with relevant information. For example, in e-commerce, generative AI-enhanced search can help consumers find products more efficiently by interpreting complex or conversational queries. In healthcare, AI-enhanced search systems can improve the retrieval of relevant medical research or patient data, assisting professionals in making informed decisions. These industry applications highlight the potential for generative AI to transform search systems into more intelligent, responsive tools that adapt to user needs and enhance productivity.

However, despite these promising results, several challenges and opportunities for improvement remain, which inform the future directions of this research.

Future Work

1. Scaling and Efficiency Optimization

As generative AI models grow larger and more complex, the computational requirements for deploying them in real-time search pipelines also increase. While model distillation and compression have made it possible to use these models in production environments, there is still room for improvement in scaling and efficiency. Future research could explore more advanced model optimization techniques, such as quantization, which reduces the number of bits used to represent model weights, or pruning, which removes less important parts of the model to reduce size and computation. Additionally, methods for dynamically adjusting model complexity based on the query (e.g., using simpler models for straightforward queries) could reduce the computational load and improve response times.

2. Bias Mitigation and Ethical AI

Generative AI models often inherit biases present in their training data, which can lead to biased or even harmful outputs in search results. Addressing bias in search pipelines is critical, especially for sensitive domains like healthcare, finance, and legal information retrieval. Future work should focus on developing robust methods for bias detection and mitigation in generative AI, such as fine-tuning on balanced datasets, implementing fairness constraints in model training, and conducting rigorous testing for fairness across demographic and socioeconomic groups. Additionally, incorporating explainability features into the pipeline could help users understand how results are generated, fostering trust and transparency in AI-driven search systems.

3. User-Centered Design and Personalization

The current generative AI-enhanced pipeline provides improved results, but further personalization could enhance user satisfaction and engagement. Future research could explore incorporating user context—such as past interactions, preferences, or device usage patterns—into the search pipeline, allowing for more tailored responses. Techniques like reinforcement learning could enable the model to learn from user feedback in real time, adapting to specific user preferences or adjusting relevance criteria based on individual behavior. This user-centered approach would create a more interactive and personalized search experience, helping users find information more efficiently and intuitively.

4. Multimodal Search Integration

As users increasingly seek information across various content types—text, images, videos, and even audio—future work should investigate the integration of multimodal AI capabilities into search pipelines. Models like CLIP (Contrastive Language–Image Pretraining) have demonstrated the potential to link textual and visual information, creating opportunities for more unified search experiences. For instance, in e-commerce, a multimodal search system could help users find products by uploading images or combining voice queries with textual input. Integrating multimodal generative AI into search would allow users to retrieve more relevant results across diverse content types, offering a more seamless and flexible search experience.

5. Hybrid Retrieval and Knowledge Augmentation

While the current pipeline uses a hybrid retrieval approach by combining lexical and embedding-based search, future research could focus on more sophisticated knowledge augmentation techniques. Integrating external knowledge graphs or domain-specific databases with generative models can provide an additional layer of context, allowing for more accurate and comprehensive responses, particularly for complex queries. Knowledge-augmented models like RAG (Retrieval-Augmented Generation) could retrieve context from specific knowledge bases before generating responses, creating a more accurate, information-rich search experience. This approach is especially valuable in fields where domain-specific knowledge is essential, such as scientific research, legal documentation, and technical support.

6. Real-Time Monitoring and Continuous Model Updating

To maintain the accuracy and relevance of AI-enhanced search pipelines, future work could focus on developing systems for real-time monitoring and continuous model updating. As language and information evolve, models can become outdated, leading to reduced relevance in search results. Real-time monitoring systems could track performance metrics like relevance scores, user engagement, and CTR, while automated pipelines could periodically retrain or fine-tune models on updated datasets to ensure they remain current. Additionally, incorporating feedback loops for quality assessment would allow the pipeline to identify and correct inaccuracies or biases as they arise, making the system more resilient and adaptable to changing information landscapes.

7. Evaluating Long-Term User Satisfaction

The current study primarily focuses on immediate relevance and engagement metrics, such as NDCG and CTR. However, long-term user satisfaction is another important aspect of search quality that warrants further research. Future studies could use longitudinal metrics to evaluate the impact of AI-enhanced search pipelines on user retention, satisfaction, and trust over time. User satisfaction surveys, A/B testing, and analysis of behavioral data (e.g., repeat usage, session depth) can provide insights into how generative AI impacts long-term user behavior, helping refine the system for sustained user value.

8. Developing Domain-Specific Generative Models

While general-purpose language models perform well across a wide range of queries, certain industries, like medicine, law, or scientific research, require domain-specific expertise. Future work could involve training and deploying specialized models fine-tuned on domain-specific data to enhance the accuracy and relevance of responses in those fields. Such domain-specific models would provide deeper insights and more precise information, benefiting users who require expert knowledge. Additionally, lightweight domain models could complement general-purpose models within the pipeline, enabling hybrid retrieval systems that balance accuracy and efficiency based on query context.

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