

Large Language Models and Information Retrieval

Kalyani Pakhale

Indian Institute of Technology, India

ABSTRACT

This research article explores the synergistic integration of Optical Character Recognition (OCR) technology and Large Language Models (LLMs) to advance Information Retrieval (IR) processes. In a data-centric society, efficient IR is imperative, and the combination of OCR and LLMs presents a powerful solution. OCR transforms diverse document types into machine-readable formats, while LLMs excel in language understanding and generation. The article delves into the technical intricacies of these technologies, their seamless integration, and their potential to revolutionize information retrieval. By investigating their collaborative capabilities, this research contributes to the evolving landscape of natural language processing and information retrieval systems.

Keywords Natural Language Processing · Large Language Model · OCR · Information Retrieval

1 Introduction

Language, as a fundamental form of human expression, presents an intricate system governed by complex grammatical rules. Since the proposal of the Turing Test in the 1950s, the endeavor to imbue machines with language intelligence has been a persistent pursuit. However, decoding and comprehending language remains a profound challenge in the field of artificial intelligence (AI).

The pathway to addressing this challenge has seen the evolution of language modeling as a primary approach, encompassing a journey from statistical language models to the transformative realm of neural language models. In recent years, pre-trained language models (PLMs) have emerged as a groundbreaking advancement. These models, based on pre-training Transformer architectures on vast corpora, have showcased remarkable capabilities in a wide array of natural language processing (NLP) tasks.

One crucial realization in this journey has been the substantial impact of model scaling on performance and capabilities. As researchers scaled up the parameters of these models, they witnessed not only improved model capacity but also the emergence of special abilities such as in-context learning. This transformation led to the coinage of the term "large language models" (LLMs) to distinguish these models with significant parameter scales, often numbering in the tens or hundreds of billions.

The research community, comprising both academia and industry, has witnessed a surge of advancements in LLMs. Notably, the introduction of ChatGPT, a formidable AI chatbot powered by LLMs, has garnered widespread attention. This technological evolution is now poised to revolutionize the development and utilization of AI algorithms.

In this survey, we embark on a journey to review the recent advances in LLMs, delving into their background, key discoveries, and mainstream techniques. We meticulously focus on four pivotal aspects:

pre-training, adaptation tuning, utilization, and capacity evaluation. Additionally, we consolidate available resources essential for developing LLMs and deliberate on the lingering challenges that guide future directions.

This survey endeavors to offer an up-to-date and comprehensive review of the literature on LLMs, serving as a valuable resource for both researchers and engineers navigating this exciting landscape of language models. Through this exploration, we aspire to shed light on the transformative potential of LLMs and their enduring impact on the AI community and beyond.

2 Overview of Large Language Models

Language is a fundamental tool for human communication and self-expression and in the realm of artificial intelligence, effective communication is equally essential for machines interacting with humans and other systems. Large Language Models often abbreviated as LLMs, have emerged as state-of-the-art AI systems designed to process and generate text, striving to communicate coherently

The rise of LLMs addresses the growing need for machines to adeptly handle complex language-related tasks such as translation, summarization, information retrieval, and engaging in natural conversational interactions.[1]

Recent breakthroughs in language models are primarily attributed to advancements in deep learning techniques and neural architectures like transformers, accompanied by increased computational capabilities and the availability of extensive training data sourced from the internet. These advancements have sparked a revolutionary transformation, enabling the development of LLMs that can approximate human-level performance on specific evaluation benchmarks.[2]

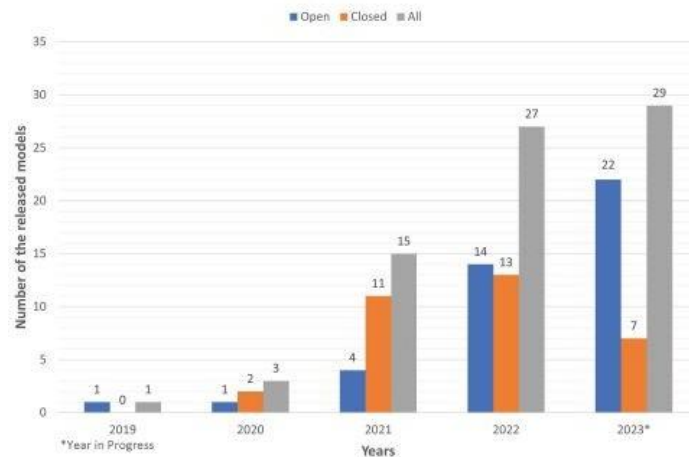


Figure 1: Trends illustrating the growth in the number of Large Language Model (LLM) introductions over the years. The figure showcases the significant increase in the development and introduction of LLMs, highlighting the dynamic evolution and rising prominence of these models in the field of artificial intelligence.

Pre-trained Language Models, a subtype of LLM, have showcased remarkable generalization abilities for text understanding and generation tasks. They are trained in a self-supervised setting on a substantial corpus of text, allowing them to learn complex language patterns and structures. Fine-tuning these models for specific tasks significantly enhances their performance, surpassing models trained from scratch. This realization has led researchers to experiment with scaling both model and dataset sizes, resulting in further improvements in generalization abilities.[3, 4]

Modern LLMs have reached a point where they can perform an array of tasks, including code generation, text generation, tool manipulation, reasoning, and understanding, in zero-shot and few-shot settings across diverse domains. Remarkably, these capabilities are achieved without the need for fine-tuning downstream tasks. Such extensive generalization was previously unattainable with smaller models, marking a significant advancement in language modeling.

The current state of LLMs has ignited enthusiasm and excitement within the research community, propelling efforts to enhance LLM architectures and training strategies. This ongoing development has given rise to a myriad of novel applications and use cases, further solidifying the pivotal role that LLMs play in shaping the future of natural language processing and AI. As LLMs continue to evolve [5] and become increasingly sophisticated, they hold immense promise in transforming the way we interact with machines and leverage language-based AI applications across various domains.

3 Evolution of Language Models

3.1 Historical overview of early language models

The trajectory of language models (LMs) is a captivating journey through the annals of artificial intelligence, marked by significant shifts and advancements. The early stages, originating in the 1950s and 1960s, were characterized by statistical models and rule-based approaches. These foundational models operated on n-gram probabilities and linguistic rules, attempting to predict the next word based on historical word occurrences in a sentence. However, these models were limited in their ability to understand complex linguistic structures.

In the 1970s and 1980s, Hidden Markov Models (HMMs) gained prominence for language modeling. HMMs could capture sequential dependencies, but their ability to model long-term relationships was constrained. Despite these limitations, HMMs represented an advancement in language understanding at that time.

The true revolution in language modeling began in the late 1990s and early 2000s with the advent of machine learning and neural networks. Feedforward Neural Networks and Recurrent Neural Networks (RNNs) made their debut, allowing for better modeling of contextual information and more intricate language patterns. However, RNNs were plagued by the vanishing or exploding gradient problem, making it difficult for them to capture long-term dependencies effectively.

In 2001, the introduction of the Long Short-Term Memory (LSTM) architecture, a variant of RNNs, alleviated the vanishing gradient problem and enabled more efficient modeling of long-range dependencies. LSTMs became a significant advancement in the field, setting the stage for subsequent breakthroughs in language modeling.

However, the seminal turning point in language modeling arrived in 2017 with the publication of "Attention is All You Need" by Vaswani et al., introducing the Transformer architecture. Transformers incorporated self-attention mechanisms, allowing the model to weigh the importance of each word in a sequence relative to others. This innovative architecture significantly outperformed previous models, serving as a cornerstone for modern pre-trained language models.

The following years witnessed an explosion of advanced language models, including BERT (Bidirectional Encoder Representations from Transformers) and GPT (Generative Pre-trained Transformer). BERT, introduced by Devlin et al. in 2018, utilized a transformer-based architecture and bidirectional context to pre-train representations. GPT, developed by OpenAI, used a transformer decoder for autoregressive generation. These models demonstrated remarkable improvements in various natural

language processing tasks.

ELMO (Embeddings from Language Models), introduced by Peters et al. in 2018, also made significant contributions by generating word embeddings using the internal states of a bidirectional LSTM language model. These embeddings captured contextual information, enhancing language understanding.

In more recent times, PALM (Pattern Learning for Multimodal Language Understanding) and LLAMA (Language Model for Multimodal Analysis), have emerged as multimodal language models capable of processing and understanding both text and other modalities like images. PALM focuses on learning patterns and relations between modalities, while LLAMA emphasizes language understanding and multimodal analysis.

The history of LMs has witnessed an incredible evolution, evolving from early statistical and rule-based models to powerful transformer-based models, enabling a wide array of applications in natural language processing and multimodal understanding. This continuous evolution underscores the pivotal role of language models in shaping the AI landscape and the way we interact with machines.

4 Large Language Model

Language models (LMs) are fundamental in predicting the generative likelihood of word sequences, effectively estimating the probability of subsequent words by considering the contextual information from preceding words. Initially designed for text generation, recent studies have uncovered their potential to reformulate a diverse array of natural language processing (NLP) problems into a text-to-text format. This transformation has positioned LMs as the go-to solution for a wide range of text-related challenges.

The evolution of LMs can be delineated into four primary stages. Initially, statistical learning techniques formed the basis, termed statistical language models, employing the Markov assumption to predict subsequent words based on preceding words. Following this, neural networks, particularly recurrent neural networks (RNNs), were introduced, allowing the calculation of the likelihood of text sequences and the development of neural language models. Advancements led to contextualized word representations through models like ELMo and BERT, initiating the era of pre-trained language models (PLMs). Scaling up these models in terms of size and data significantly improved their performance on downstream tasks, giving rise to large language models (LLMs)[6].

Existing LLMs can be broadly categorized based on their architectures into encoder-decoder and decoder-only models. Encoder-decoder models, such as T5, transform input text into vectors using an encoder and utilize them to generate output texts. On the other hand, decoder-only models, exemplified by GPT, rely on the Transformer decoder architecture, using a self-attention mechanism to generate sequences of words from left to right.

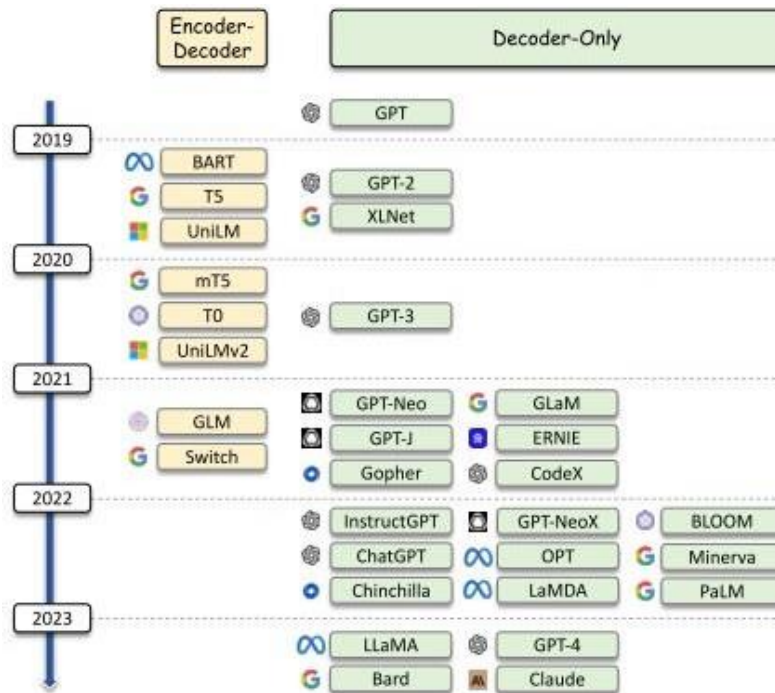


Figure 2: The Evolution of Large Language Models (LLMs) showcasing encoder-decoder and decoder-only structures.

The emergence of LLMs, especially models like GPT-3 and its successors, which encompass over 100 billion parameters, presented challenges in fine-tuning due to the vast number of parameters. As a result, two primary methods have been established to leverage LLMs effectively: in-context learning (ICL) and parameter-efficient fine-tuning. ICL allows LLMs to understand and provide answers based on the provided input context, without requiring additional parameter tuning. Parameter-efficient fine-tuning aims to reduce the number of trainable parameters while maintaining performance, showcasing potential in optimizing memory usage.

In the realm of Information Retrieval (IR), applying LLMs presents unique challenges and opportunities. Leveraging the emergent abilities of LLMs, particularly in-context learning, has shown promise in addressing IR tasks without extensive fine-tuning. However, exploring efficient parameter tuning methods specific to IR tasks remains an exciting avenue for future research, promising advancements in leveraging LLMs for enhancing IR systems.

The evolutionary trajectory of Large Language Models (LLMs) traces a remarkable journey through various phases, showcasing the rapid advancement of language modeling technologies. Initially, language modeling relied on statistical learning techniques, where models calculated probabilities of words based on statistical patterns observed in the text. N-gram models were a classic example, predicting the likelihood of a word based on the preceding (n-1) words, exemplified by the utilization of bigram models.

With the advent of neural networks, a significant shift occurred in language modeling. Neural Language Models emerged, leveraging technologies such as Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks. These frameworks enabled models to capture contextual dependencies and represent words in a continuous vector space, vastly improving language understanding and generation.

Subsequently, the paradigm evolved into Pre-trained Language Models (PLMs), marking a revolutionary breakthrough. PLMs pre-train models on extensive text corpora, learning rich language representations in an unsupervised manner. The introduction of transformer-based architectures, notably with models like BERT (Bidirectional Encoder Representations from Transformers), propelled this phase. BERT employed masked language modeling, predicting masked words in a sentence using bidirectional context, vastly improving word representations.

The contemporary zenith of this progression is epitomized by Large Language Models (LLMs). These models, with billions of parameters, demonstrate unprecedented language understanding and generation capabilities. GPT-3 (Generative Pre-trained Transformer 3) serves as a sterling example, utilizing a transformer architecture with a staggering 175 billion parameters. This immense scale enables LLMs to generate highly coherent and contextually appropriate text across a spectrum of tasks, showcasing their ability to grasp the nuances and intricacies of human language comprehensively. This evolutionary perspective underlines the transformative journey from statistical learning techniques to intricate neural models, eventually leading to the era of massive pre-trained and highly potent LLMs. Each phase has played a crucial role in advancing language understanding and generation, paving the way for a new era of language processing.

This comprehensive overview sheds light on the evolution of LMs, highlighting their transformative journey and their pivotal role in reshaping the landscape of NLP, especially in the context of Information Retrieval.

5 LLM Architecture

The research investigates fundamental architectural designs integral to Large Language Models (LLMs): the encoder-decoder architecture and the decoder-only architecture. These structural frameworks have played a pivotal role in advancing language understanding and generation, laying the foundation for innovative applications across diverse domains.

The encoder-decoder architecture, a widely embraced structure in Natural Language Processing (NLP) tasks, comprises two essential components: an encoder and a decoder. The encoder processes the input sequence, generating a fixed-length context vector. Conversely, the decoder receives this context vector and produces the output sequence. Typically, recurrent layers such as LSTM or GRUs construct the encoder, processing the input sequentially and capturing contextual information. Attention mechanisms further enhance this architecture by enabling the decoder to selectively focus on different parts of the input during decoding.

In contrast, the decoder-only architecture revolves around a solitary transformer-based decoder, devoid of an explicit encoder. This architectural model generates the output sequence based on a learned positional representation of the input sequence. Initially introduced in encoder-decoder models, transformer-based architectures have been adapted for decoder-only models. They incorporate self-attention mechanisms, allowing the model to weigh the significance of each input token when generating the output token. The transformer decoder processes tokens in parallel, enhancing computational efficiency and significantly accelerating training and inference processes. These architectural paradigms

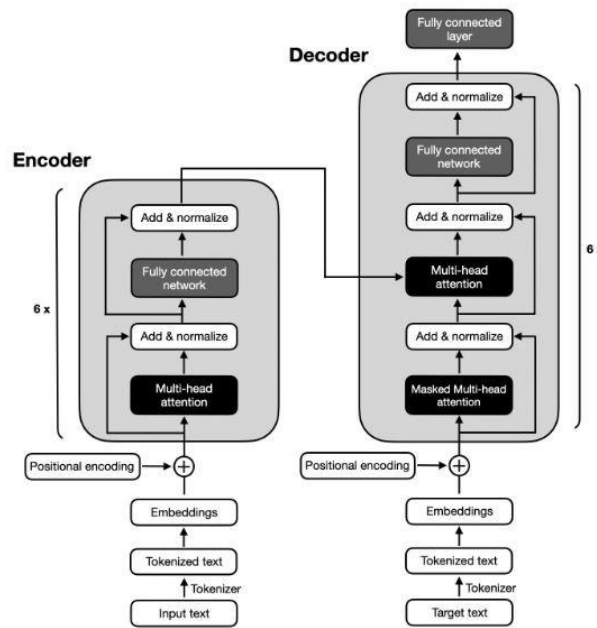


Figure 3: Encoder-Decoder architecture of Large Language Model

have significantly propelled the field of language modeling. Encoder-decoder architectures have notably augmented language understanding by efficiently capturing contextual relationships in both input and output sequences, crucial for translation and summarization tasks. On the other hand, the decoder-only architecture, particularly with transformer models, has immensely elevated generation capabilities. The self-attention mechanism’s ability to consider all input tokens simultaneously results in coherent and contextually appropriate text generation.

Understanding these architectural designs is fundamental in the development of sophisticated LLMs adept at both understanding and generating human-like text. Their flexibility and effectiveness continue to drive innovation, paving the way for a multitude of applications in the realm of natural language processing.

6 Large Language Model for Information Retrieval

Information Retrieval (IR) systems, notably search engines, have become an integral part of our daily lives, serving as primary tools for acquiring information. Over time, the trajectory of IR has evolved significantly, transitioning from term-based methods to an integration with advanced neural models. The integration of neural models has revolutionized the IR landscape by enabling a deeper understanding of complex contextual signals and semantic nuances.

Traditional term-based IR methods, although efficient in providing rapid responses, often struggle to capture intricate language patterns and context. In contrast, modern neural architectures, especially large language models (LLMs), have exhibited exceptional language understanding capacity. LLMs have proven to be a game-changer in natural language processing, showcasing remarkable abilities in language understanding, generation, generalization, and reasoning.

However, the integration of LLMs into IR systems is not without challenges. Data scarcity remains a concern, particularly in specialized domains where training data may be limited. Additionally, achieving interpretability in LLM-driven IR systems is a significant hurdle, as understanding the reasoning behind the model’s responses is crucial for building trust and reliability. Moreover, generating contextually

plausible yet accurate responses is a persistent challenge.

To address these challenges and leverage the strengths of both traditional and modern approaches, a blended approach is emerging. This approach combines the efficiency and rapid response capabilities of traditional term-based sparse retrieval methods with the powerful language understanding capacity of LLMs. By integrating LLMs into various components of IR systems, such as query rewriters, retrievers, rerankers, and readers, it is possible to enhance the accuracy and relevance of retrieved information.

The emergence of LLMs, such as ChatGPT and the hypothetical GPT-4, has sparked a wave of research focusing on leveraging these models to enhance IR systems. Researchers are exploring how LLMs can be utilized for tasks like query understanding, generating relevant search queries, improving document retrieval, and enhancing summarization of retrieved content.

In this rapidly evolving research trajectory, it is imperative to consolidate existing methodologies and provide nuanced insights through a comprehensive overview. This survey aims to delve into the confluence of LLMs and IR systems, exploring critical aspects and methodologies that blend traditional and modern approaches. By understanding and advancing this integration, we can pave the way for more effective and efficient information retrieval systems, thereby enhancing user experiences and the utility of IR in various domains.

7 Integration Landscape

Integrating Large Language Models (LLMs) into Information Retrieval (IR) involves amalgamating the advanced capabilities of LLMs in natural language understanding and generation with the fundamental processes of an IR system. The goal is to enhance various components of IR, such as search relevance and query understanding. Consider a search engine that traditionally processes user queries based on keywords. With LLM integration, the system can now comprehend the context and intent behind the query. For example, a query like "Find scientific papers on climate change impacts" can be better understood using LLMs. The integration allows the system to provide more nuanced and contextually accurate search results, significantly improving the user's search experience.

8 Task Reformulation through Text-to-Text Format

LLMs possess the remarkable ability to reformulate a wide array of natural language processing tasks into a text-to-text format. This format involves translating the task into a language-based question or statement. For instance, in machine translation, a sentence in English could be reformulated as a question in the form of "Translate this sentence into French." By framing tasks in a text-to-text format, LLMs can effectively address an extensive spectrum of NLP tasks. This approach provides a more unified and adaptable way to handle diverse tasks. For example, the same underlying LLM model that translates can be repurposed for summarization by reformulating the task as "Summarize this article."

9 Pre-training and Fine-Tuning of LLM

Pre-training and Fine-tuning are foundational processes in the development of Large Language Models (LLMs). Pre-training involves training a language model on a vast corpus of text data in an unsupervised manner. The model learns to predict the next word in a sentence or mask a word and predict its value. Through this process, the model gains insights into linguistic structures, syntactic rules, and contextual nuances present in the text. The transformer-based model, like GPT and BERT, is a common architecture employed for pre-training. This step forms a foundational understanding of language.

Fine-tuning follows pre-training and tailors the pre-trained model for specific downstream tasks. This step involves training the model on task-specific labeled data in a supervised manner. Fine-tuning helps the model learn task-specific patterns and nuances that weren't captured during pre-training. It adapts the model to perform well in tasks like text classification, named entity recognition, text summarization, language translation, and more.

The process of fine-tuning includes modifying the model's architecture for the specific task, defining a task-specific objective function, and adjusting hyperparameters. Fine-tuning ensures that the model optimizes its understanding and performance for the designated task. It democratizes NLP tasks, making it easier for researchers and practitioners to achieve state-of-the-art results with less data and computational resources.

In essence, this two-step methodology, pre-training followed by fine-tuning, has revolutionized the field of natural language processing. It empowers the development of highly adaptable and proficient language models, allowing them to excel in various real-world applications, from sentiment analysis to language translation, and much more.

10 OCR and Large Language Models in Information Retrieval

This research article explores the amalgamation of Optical Character Recognition (OCR) and Large Language Models (LLMs) to augment Information Retrieval (IR) processes. OCR technology, which transforms images of text into machine-encoded text, and LLMs, known for language understanding and generation, converge to create a potent toolset for advancing information retrieval systems. This article delves into the technical aspects of these technologies, their integration, and the potential to revolutionize the retrieval and interaction with information.[7, 3, 8, 9, 10, 11]

In today's data-driven society,[12] effective Information Retrieval (IR) is pivotal. Technological advancements have resulted in a massive volume of textual data, necessitating efficient methods to access information. Optical Character Recognition (OCR) has played a crucial role in converting physical documents into digital, machine-readable formats. Simultaneously, Large Language Models (LLMs) have garnered attention for their language understanding and generation capabilities, significantly impacting natural language processing tasks.

11 Optical Character Recognition (OCR) with LLM

OCR is a technology that converts various document types, including scanned paper documents, PDF files, or images captured by digital devices, into editable and searchable data. The process involves image preprocessing, character segmentation, feature extraction, and character recognition. Image preprocessing enhances the input image's quality, while character segmentation isolates individual characters. Feature extraction captures critical characteristics of each character, and character recognition maps these features to the corresponding characters.

LLMs, like GPT-3, BERT, and T5, are neural network-based models trained on extensive text data. They excel at understanding and generating human-like text, making them versatile for a multitude of Natural Language Processing (NLP) tasks. LLMs use attention mechanisms and deep architectures to capture intricate linguistic patterns and generate coherent, contextually relevant responses.

Integrating OCR and LLM technologies revolutionizes information retrieval. OCR converts images and scanned documents into machine-readable format, enabling further processing by LLMs for language understanding and generation. This fusion widens the scope of IR by allowing search and comprehension

of text within images or scanned documents.

OCR preprocessing of images and scanned documents enables LLMs to analyze and generate insights based on the extracted text, facilitating a deeper understanding of document content. Combining OCR and LLMs allows for multimodal understanding. Text extracted through OCR, when processed by LLMs, can be supplemented with additional context or translated into different languages, enhancing information accessibility and usability.

The integration of OCR and LLMs presents exciting prospects for information retrieval. Continued advancements in OCR technology, along with evolving capabilities of LLMs, are expected to enhance the accuracy, efficiency, and breadth of information retrieval systems. Addressing ethical considerations and potential biases in these technologies will be imperative for their responsible deployment.

The fusion of OCR and LLMs represents a significant milestone in the field of Information Retrieval. This convergence unleashes new possibilities by seamlessly transitioning from physical documents or images to accessible and analyzable digital content. As technology progresses, the integration of OCR and LLMs is set to reshape how we retrieve, comprehend, and interact with information, ushering in a new era of knowledge accessibility and understanding.

11.1 Case Study: Digitizing Historical Archives

A tangible application of OCR and LLM integration is in digitizing historical archives. OCR can convert old manuscripts into machine-encoded text, enabling LLMs to analyze and comprehend the digitized content, facilitating more effective study and preservation of historical documents

12 Conclusion

In conclusion, this research article provides a comprehensive exploration of the synergistic integration of Optical Character Recognition (OCR) technology and Large Language Models (LLMs) to advance Information Retrieval (IR) processes. The amalgamation of OCR, which transforms diverse document types into machine-readable formats, with LLMs, renowned for their language understanding and generation capabilities, presents a powerful solution for the challenges in today's data-centric society.

The research delves into the technical intricacies of OCR and LLMs, highlighting their seamless integration and the potential to revolutionize information retrieval. By investigating their collaborative capabilities, the study contributes to the evolving landscape of natural language processing and IR systems.

The article navigates through the historical evolution of language models, emphasizing the transformative journey from statistical language models to the emergence of Large Language Models (LLMs) with significant parameter scales, exemplified by models like GPT-3. The survey comprehensively reviews recent advances in LLMs, focusing on pre-training, adaptation tuning, utilization, and capacity evaluation.

Furthermore, the research discusses the fundamental architectural designs of LLMs, including the encoder-decoder and decoder-only architectures, shedding light on their roles in advancing language understanding and generation. The integration of LLMs into IR systems is explored, acknowledging the challenges such as data scarcity and interpretability while emphasizing a blended approach that combines traditional term-based methods with the capabilities of LLMs.

The study also addresses the task reformulation through a text-to-text format, showcasing LLMs' ability to adapt to diverse natural language processing tasks. The crucial processes of pre-training and fine-

tuning in LLM development are elucidated, emphasizing their role in achieving state-of-the-art results across various applications.

A significant portion of the research is dedicated to the integration of OCR and LLMs in information retrieval. OCR, with its ability to convert images and scanned documents into machine-readable formats, combined with the language understanding and generation capabilities of LLMs, widens the scope of IR by enabling search and comprehension of text within images. This integration holds promise for multimodal understanding and opens new possibilities for information retrieval.

In summary, the research underscores the transformative potential of integrating OCR and LLMs in advancing information retrieval processes. As OCR technology continues to evolve, coupled with the sophistication of LLMs, the accuracy, efficiency, and breadth of information retrieval systems are expected to witness significant enhancements. The responsible deployment of these technologies, considering ethical considerations and potential biases, will be crucial in shaping the future of knowledge accessibility and understanding. This convergence marks a significant milestone, ushering in a new era of seamless transition from physical documents to accessible and analyzable digital content.

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