Improving LLMs performance with RAG

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**Abstract —** **Large Language Models (LLMs) have revolutionized access to knowledge, enabling anyone with an internet connection to explore a vast array of topics. However, LLMs are inherently limited by their training data and struggle with subjects beyond their pre-trained knowledge. This challenge is even more pronounced in smaller LLMs, which, due to their reduced parameter count, have a lower capacity to capture complex or niche information. With the growing interest in deploying LLMs on edge devices or local systems, improving their performance is crucial. In this study, we explore how Retrieval-Augmented Generation (RAG) can enhance the inference capabilities of small LLMs by dynamically incorporating relevant context from a vector database. Our research evaluates the extent to which RAG can bridge the performance gap between small and large LLMs, making them more viable for real-world applications**.

Keywords — LLM, RAG, Retrieval-Augmented Generation, Small Language Models, Vector Databases

# Background

The introduction of Multi-Head Attention transformer-based Large Language Models (LLMs) [1] revolutionized how people learn, work, and interact with technology. OpenAI popularized these models through their online web chat tool, ChatGPT, making advanced AI-driven conversations accessible to the general public.

Before LLMs, computer-based search primarily relied on string matching or heuristic-based algorithms in platforms like Google and Bing. These approaches, while effective, often required users to formulate precise queries and manually filter through results. The advent of LLMs fundamentally changed this dynamic by enabling users to engage in natural language interactions. Instead of merely retrieving keyword-based results, LLMs interpret queries contextually and generate human-like responses, giving users the impression of conversing with an intelligent assistant.

This transformation not only enhanced search and information retrieval but also expanded how people process and synthesize knowledge. By leveraging attention mechanisms and text embeddings, LLMs facilitate semantic search, allowing users to explore topics more intuitively and extract deeper insights from their queries.

However, running inference-based pipelines on those LLMs is only possible in very powerful data centers as it’s massively dependent on a very high number of GPUs and energy availability – which are significant issues in resource constrained environments. LLMs are also very high energy consumers which makes it also very expensive to run on scale. That has created the need of having to explore and design Small Language Models (SM) that, in nature, are similar to LLMs but rely on a much smaller number of parameters hance have more lightweight inference in terms of GPU requirements and energy consumption.

| Dimension | LLMs | SMs |
| --- | --- | --- |
| Accuracy | state-of-the-art | decent |
| Generality | general purpose | task specific |
| Efficiency | resource intensive | resource efficient |
| Interpretability | low interpretable | high interpretable |

Table 1: comparisons of dimensions between LLMs and SMs

Since knowledge is encoded in parameters in language models, it’s not surprising that SMs have worse overall performance in inference tasks against their large counterparts. It’s also less capable of generalizing and handle broad spectrum of information [2].

There are many techniques such as fine-tuning, knowledge distillation or Retrieval Augmented Generation (RAG) can be used to make SMs more competitive against LLMs. This document aims to explore the use of RAG in the scope of Question / Answer task in fixed knowledge domain as a tool to make SMs a viable option in resource constrained setups.

# Experiment and Contributions

Our objective is to investigate whether and to which extent RAG can help Small Language Models improve or match performance of larger models.

## The experiment

Our exploration involved the following high-level steps: first we ask a given set of questions to various models, then we evaluate their answers by sending the answer and ground truth to a judge, then we ask the same dataset of questions along with some context data – fetched from a vector database – and process the answers to the judge. The judge itself is a Large Language Model; we selected Open AI’s GPT-4o-mini but in future work it’s worth exploring more capable models such as Open AI’s *o3* models that have higher reasoning capabilities. In this research it wasn’t possible due to its high cost per 1M tokens.

The dataset we use in this experiment is the Harry Potter book series and the Harry Potter Trivia Questions [3]

## The compared models

In our research, selected models from various vendors and of various sizes and divided them in four high level buckets: tiny (2B or less parameters), small (3B – 7B parameters), medium (8B – 14B parameters) and large (100B parameters or more).

* Tiny: qwen2.5-0.5b, deepseek-r1-1.5b, qwen2.5-1.5b, gemma3-1b, gemma2-2b.
* Small: llama3.2-3b, llama2-7b.
* Medium: gemma3-12b, deepseek-r1-14b
* Large: GPT-4o-mini

## The Objective and Contributions

With this experiment we aim to investigate whether RAG can help small LLMs match the performance of larger models in closed domain Question-Answer tasks.

Our contributions are:

* Compare small and large LLMs in a closed-domain QA task (Harry Potter books).
* Evaluate the impact of RAG-enhanced retrieval on smaller models.
* Provide quantitative analysis using multiple evaluation metrics

# Related Work

The rise of Large Language Models has prompted an active research community to examine not only their capabilities but also the practical trade-offs between model size, domain specialization, and augmentation strategies such as retrieval augmented generation (RAG). This section highlights relevant research exploring the performance of domain-specific LLMs, the role of small models in the LLM ecosystem, and recent findings on the limitations of smaller LLMs in multi-step tasks.

There has been investigations where scientists question the necessity of training specialized domain-specific models in light of the capabilities of general-purpose LLMs like GPT-3.5 and GPT-4[4]. Some of the findings suggest that general-purpose LLMs, when given sufficient context through prompt engineering or retrieval, can perform competitively with domain-specific models. This supports the idea that retrieval-augmented generation (RAG) may compensate for gaps in internal model knowledge, especially for more generalizable models—an idea central to our study, where we test whether smaller LLMs can similarly benefit from retrieval in a closed-domain QA task. Another study in this space highlights the growing relevance of small LLMs for edge and privacy-sensitive applications [5]. The survey emphasizes techniques such as distillation and RAG to improve their utility without increasing model size — aligning with our focus on enhancing small models through retrieval.

In contrast, there’s also research demonstrating that small models struggle with complex tasks requiring reasoning and tool use. While our setting is simpler — closed-domain QA — this reinforces the motivation to explore whether small LLMs, aided by retrieval, can still perform competitively in targeted applications [6].

|  |  |  |
| --- | --- | --- |
| Model | No RAG | RAG |
| deepseek-r1-1.5b | 0.2163 | 0.2959 |
| deepseek-r1-14b | 0.6306 | 0.6653 |
| gemma2-2b | 0.3531 | 0.4122 |
| gemma3-12b | 0.4939 | 0.3878 |
| gemma3-1b | 0.2735 | 0.2939 |
| gpt-4o-mini | 0.5857 | 0.449 |
| llama2-7b | 0.2408 | 0.2857 |
| llama3.2-3b | 0.3082 | 0.4673 |
| qwen2.5-0.5b | 0.1184 | 0.2959 |
| qwen2.5-1.5b | 0.2612 | 0.3857 |

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*a**b* 

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| --- | --- | --- | --- |
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