

# Multi-Model RAG System Evaluation: Comparing Open-Source LLMs on Transformer Architecture Knowledge

**Course:** DSCI 6004 - Natural Language Processing

**Term Project:** RAG System Development and LLM Comparison

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## ABSTRACT

Retrieval-Augmented Generation (RAG) systems combine large language models with information retrieval to provide factually grounded responses for knowledge-intensive tasks. As open-source LLMs proliferate, understanding their performance in RAG applications becomes crucial for practitioners. This paper evaluates Mistral-7B, a 7.3-billion parameter open-source model, in a RAG system applied to technical knowledge retrieval from the "Attention Is All You Need" paper. We implement a hybrid retrieval mechanism combining semantic vector search and BM25 keyword matching, evaluate model responses on 10 domain-specific questions about Transformer architecture, and analyze performance across dimensions of factual accuracy, completeness, and clarity. Our findings reveal that Mistral-7B achieves strong performance (4.5/5.0 average) with particular strengths in factual grounding (4.4/5.0 accuracy) and minimal hallucination. The model demonstrates appropriate epistemic humility by explicitly acknowledging context limitations rather than generating unsupported information. Response generation averaged 4.3 minutes per query with consistent quality across question types. These results indicate that open-source models can achieve production-grade performance in technical RAG applications, with retrieval quality emerging as the primary performance determinant. Our code and evaluation framework are available at [GitHub link].

**Keywords:** Retrieval-Augmented Generation, Large Language Models, Open-Source AI, Question Answering, Transformer Architecture

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## 1. INTRODUCTION

Retrieval-Augmented Generation (RAG) systems have emerged as a powerful paradigm for enhancing large language model (LLM) capabilities by grounding responses in retrieved factual

context (Lewis et al., 2020). As the landscape of open-source LLMs expands rapidly, understanding the comparative performance of different models in RAG applications becomes increasingly important for practitioners making deployment decisions.

This work addresses the need for systematic comparison of open-source LLMs in domain-specific RAG contexts. While proprietary models like GPT-4 demonstrate strong performance, open-source alternatives—such as Mistral-7B, LLaMA3-8B, and Phi-3-Mini—offer compelling advantages in terms of cost, privacy, customization, and local deployment. However, their relative performance across different tasks and domains remains underexplored, particularly in technical knowledge domains requiring precise information retrieval and synthesis.

We present a comprehensive evaluation of Mistral-7B integrated into a RAG pipeline applied to Natural Language Processing literature. Specifically, we evaluate this model on its ability to answer domain-specific questions about Transformer architecture using the seminal "Attention Is All You Need" paper (Vaswani et al., 2017) as our knowledge base. Our RAG system implements hybrid retrieval combining semantic vector search and keyword-based BM25 ranking, ensuring comprehensive context retrieval.

We evaluate model performance across 10 carefully designed questions spanning basic concepts, detailed mechanisms, architectural components, and advanced topics. For each response, we assess factual accuracy, completeness, clarity, and efficiency. Our analysis reveals distinct patterns in how the model handles technical content, with implications for model selection in specialized domains.

The remainder of this paper is organized as follows: Section 2 reviews related work in RAG systems and LLM evaluation. Section 3 describes our system architecture, the model evaluated, and our evaluation methodology. Section 4 presents comparative results across all questions. Section 5 provides in-depth analysis of performance patterns, model strengths and weaknesses, and key findings. Section 6 concludes with implications for practitioners and directions for future work.

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## 2. RELATED WORK

### 2.1 Retrieval-Augmented Generation

Retrieval-Augmented Generation was introduced by Lewis et al. (2020) as a method to enhance language model outputs by incorporating retrieved factual knowledge. RAG architectures combine a neural retriever with a sequence-to-sequence generator, allowing models to access and leverage large external knowledge bases without requiring all information to be encoded in

model parameters. This approach has proven effective for knowledge-intensive NLP tasks including question answering, fact verification, and long-form generation.

Recent work has explored various retrieval mechanisms within RAG systems. Dense retrieval using learned embeddings (Karpukhin et al., 2020) has shown advantages over traditional sparse methods for semantic matching. Hybrid approaches combining dense and sparse retrieval (Luan et al., 2021) have demonstrated improved performance by capturing both semantic similarity and lexical overlap. Our system adopts this hybrid approach, combining semantic search via sentence transformers with BM25 keyword matching.

## 2.2 Open-Source Large Language Models

The landscape of open-source LLMs has evolved dramatically since the release of models like GPT-2 (Radford et al., 2019). More recent open-source models achieve competitive performance with proprietary alternatives while enabling local deployment and customization.

**LLaMA and LLaMA3:** The LLaMA family (Touvron et al., 2023) demonstrated that carefully trained smaller models can match or exceed the performance of larger models. LLaMA3 introduced architectural improvements and enhanced training procedures, achieving state-of-the-art results among open-source models in its parameter class.

**Mistral-7B:** Mistral-7B (Jiang et al., 2023) introduced grouped-query attention and sliding window attention mechanisms, enabling efficient processing while maintaining strong performance. The model has shown particular strength in reasoning and instruction-following tasks.

**Phi-3-Mini:** Microsoft's Phi-3 family (Abdin et al., 2024) focuses on efficiency, achieving strong performance with significantly fewer parameters through high-quality training data and targeted optimization. Phi-3-Mini demonstrates that careful data curation can partially compensate for reduced model scale.

## 2.3 LLM Evaluation and Comparison

Evaluating and comparing LLMs remains an active research challenge. Traditional benchmarks like MMLU (Hendrycks et al., 2021) and HumanEval (Chen et al., 2021) provide standardized comparisons but may not reflect performance in specific domains or applications. Task-specific evaluation, particularly in RAG contexts, provides more actionable insights for practitioners.

Recent work has begun examining open-source LLM performance in RAG systems (Asai et al., 2023), but comprehensive comparisons across multiple models and domains remain limited. Our work contributes to this gap by providing detailed comparison in a technical knowledge domain with fine-grained analysis of response quality dimensions.

## 2.4 Transformer Architecture

Our evaluation domain—Transformer architecture knowledge—is central to modern NLP. The original Transformer (Vaswani et al., 2017) introduced the attention mechanism as an alternative to recurrence, enabling parallel processing and better modeling of long-range dependencies. Understanding Transformer architecture remains fundamental for NLP practitioners, making it an ideal domain for evaluating technical knowledge retrieval and explanation capabilities.

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# 3. SYSTEM ARCHITECTURE AND METHODOLOGY

## 3.1 RAG Pipeline Overview

Our RAG system consists of four main components: document processing, retrieval, generation, and evaluation. The architecture is implemented using FastAPI for the backend API, ChromaDB for vector storage, and Ollama for local LLM deployment.

The pipeline operates as follows:

1. Document ingestion and preprocessing
2. Chunking and embedding generation
3. Hybrid retrieval (semantic + keyword)
4. Context-augmented generation
5. Response evaluation

## 3.2 Document Processing

We index the "Attention Is All You Need" paper (Vaswani et al., 2017) through the following pipeline:

1. **PDF Extraction:** Text is extracted using PyPDF2
2. **Chunking:** Documents are split into chunks of 500 characters with 50-character overlap to maintain context continuity
3. **Embedding:** Each chunk is embedded using the sentence-transformers/all-MiniLM-L6-v2 model (384-dimensional vectors)
4. **Indexing:** Embeddings are stored in ChromaDB with persistent storage for efficient retrieval

The chunk size of 500 characters was chosen to balance context completeness with retrieval precision. The 50-character overlap ensures that concepts split at chunk boundaries remain accessible through adjacent chunks.

### 3.3 Hybrid Retrieval Mechanism

We implement a hybrid retrieval approach combining two complementary methods:

#### **Semantic Search:**

- Converts query to embedding using sentence-transformers
- Performs cosine similarity search in vector space
- Captures conceptual similarity beyond exact keyword matching
- Returns top-k chunks ranked by similarity score

#### **Keyword Search (BM25):**

- Classical probabilistic retrieval algorithm
- Ranks documents by term frequency and inverse document frequency
- Captures exact terminology matches
- Particularly effective for technical terms

#### **Score Fusion:**

- Results from both methods are normalized to [0,1] range
- Scores are combined and re-ranked
- Final top-k chunks returned (k=4 in all experiments)

This hybrid approach ensures comprehensive retrieval: semantic search finds conceptually relevant content even when phrasing differs, while BM25 ensures technical terms are matched precisely.

### 3.4 Language Model

We evaluate Mistral-7B, deployed locally via Ollama:

#### **Model Specifications:**

- Parameters: 7.3 billion
- Context window: 8,192 tokens
- Architecture: Transformer decoder with grouped-query attention
- Deployment: Local execution via Ollama on consumer hardware

#### **Generation Configuration:**

- Temperature: 0.7 (moderate randomness for natural language)
- Maximum tokens: 500 per response

- Top-k sampling: Not explicitly set (model defaults)

All queries use consistent generation parameters to ensure fair comparison across questions.

### 3.5 Evaluation Methodology

#### Question Set Design:

We developed 10 domain-specific questions covering diverse aspects of Transformer architecture:

- **Basic Concepts (2 questions):** Fundamental ideas accessible to learners
  - Q1: Main problem Transformers address
  - Q10: Applications of Transformers
- **Mechanisms (3 questions):** Technical operation details
  - Q2: Self-attention concept
  - Q4: Positional encoding
  - Q7: Masked self-attention
- **Architecture (2 questions):** Structural components
  - Q3: Multi-head attention advantages
  - Q6: Encoder-decoder architecture
- **Training/Implementation (2 questions):** Practical details
  - Q5: Layer normalization purpose
  - Q8: Variable-length sequence handling
- **Comparison (1 question):** Contrastive analysis
  - Q9: Computational advantages over RNNs

This distribution ensures coverage of different knowledge types and cognitive demands.

#### Evaluation Metrics:

For each model response, we assess:

1. **Factual Accuracy (1-5):** Correctness of information extracted from source document

- 5: All facts correct, no errors
- 4: Mostly accurate, minor errors/omissions
- 3: Generally accurate but missing key details
- 2: Some inaccuracies present
- 1: Major factual errors

2. **Completeness (1-5):** Coverage of key concepts relevant to question

- 5: Comprehensive coverage of all main aspects
- 4: Covers most aspects with minor gaps
- 3: Addresses main points but incomplete
- 2: Covers only some aspects
- 1: Very incomplete

3. **Clarity (1-5):** Organization and readability of response

- 5: Excellent structure, very clear
- 4: Well organized, mostly clear
- 3: Adequate organization, understandable
- 2: Somewhat unclear or disorganized
- 1: Confusing or poorly structured

4. **Response Time (seconds):** Generation latency from query submission to response completion

5. **Response Length (words/tokens):** Verbosity measure

**Evaluation Process:**

Each question is processed through the complete RAG pipeline:

1. Query submitted to hybrid retrieval system
2. Top-4 most relevant chunks retrieved
3. Chunks formatted with query into generation prompt
4. Model generates response based on provided context
5. Response manually scored across evaluation dimensions

Manual scoring was performed by the researchers with reference to the source document to verify factual claims.

### 3.6 Prompt Template

Responses are generated using the following prompt structure:

Context: [Retrieved chunk 1]

[Retrieved chunk 2]

[Retrieved chunk 3]

[Retrieved chunk 4]

Question: [User question]

Answer the question based on the provided context. Be specific and cite relevant information from the context.

This simple template proved effective, requiring no complex prompt engineering while still encouraging context utilization and citation.

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## 4. RESULTS

### 4.1 Overall Performance Summary

Table 1 presents the aggregate performance metrics for Mistral-7B across all 10 evaluation questions. The model demonstrated consistent performance with predictable response times and reliable factual grounding.

**Table 1: Mistral-7B Performance Summary**

Metric	Value
Total Questions Evaluated	10
Average Response Time	255.88 seconds (4.3 minutes)
Fastest Response Time	188.58 seconds (Q7: Masked self-attention)
Slowest Response Time	329.02 seconds (Q6: Encoder-decoder architecture)



Metric	Value
Response Time Range	140.44 seconds
Total Evaluation Time	42.6 minutes
Average Response Length	~150-200 words
Sources Retrieved per Query	4 chunks (consistent)

The response time variance (188-329 seconds) represents approximately 75% consistency, with longer responses (Q6: encoder-decoder architecture) requiring more generation time. No clear correlation was observed between question complexity and response time, suggesting that response length rather than conceptual difficulty drives generation duration.

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## 4.2 Question-by-Question Performance

**Table 2: Detailed Performance by Question**

Q#	Question	Time (s)	Category	Accuracy	Completeness	Clarity	Overall
1	Main problem Transformers address	220.93	Basic	5	5	5	5.0
2	Self-attention concept	240.42	Mechanism	5	5	4	4.7
3	Multi-headed attention advantages	255.93	Architecture	4	5	4	4.3
4	Positional encoding	328.58	Mechanism	3	3	4	3.3

Q#	Question	Time (s)	Category	Accuracy	Completeness	Clarity	Overall
5	Layer normalization purpose	238.35	Training	3	3	4	3.3
6	Encoder-decoder architecture	329.02	Architecture	5	5	5	5.0
7	Masked self-attention	188.58	Mechanism	5	5	5	5.0
8	Variable-length sequences	275.90	Implementation	4	4	4	4.0
9	Advantages over RNNs	260.63	Comparison	5	5	5	5.0
10	Applications of Transformers	220.49	Applications	5	5	5	5.0
<b>Average</b>		<b>255.88</b>		<b>4.4</b>	<b>4.5</b>	<b>4.5</b>	<b>4.5</b>

#### Performance Distribution:

- Excellent (5.0): 5 questions (50%)
- Good (4.0-4.7): 3 questions (30%)
- Adequate (3.3): 2 questions (20%)

### 4.3 Performance by Question Category

Grouping questions by conceptual category reveals patterns in model performance:

Table 3: Performance by Category

Category	Questions	Avg Accuracy	Avg Completeness	Avg Clarity	Overall
Basic Concepts	Q1, Q10	5.0	5.0	5.0	5.0
Mechanisms	Q2, Q4, Q7	4.3	4.3	4.3	4.3
Architecture	Q3, Q6	4.5	5.0	4.5	4.7
Training/Implementation	Q5, Q8	3.5	3.5	4.0	3.7
Comparison	Q9	5.0	5.0	5.0	5.0

Key Observations:

- Strongest performance on basic concepts and comparisons (5.0 average)
- Consistently high performance on architectural questions (4.7 average)
- More variable performance on training/implementation details (3.7 average)
- Mechanism explanations show good but not perfect consistency (4.3 average)

4.4 Example Responses

To illustrate response quality, we present three representative examples spanning different performance levels:

Example 1: Excellent Response (Q1 - Score: 5.0)

**Question:** "What is the main problem that the Transformer model addresses compared to RNN-based models?"

**Response:** "The Transformer model addresses the main problem of sequential computation in comparison to Recurrent Neural Network (RNN)-based models by replacing recurrence with multi-headed self-attention. This allows for significantly more parallelization and can lead to a new state of the art in translation quality after being trained for as little as twelve hours on eight P100 GPUs, making it faster to train compared to RNN-based models. Additionally, the

Transformer outperforms RNN sequence-to-sequence models and even the Berkeley Parser when training only on a limited amount of data."

**Assessment:**

- **Factual Accuracy (5/5):** All information correctly extracted and paraphrased from source material
- **Completeness (5/5):** Addresses core problem (sequential computation), solution (self-attention), benefits (parallelization, training speed), and performance claims
- **Clarity (5/5):** Well-structured with logical flow from problem to solution to results
- **Context Utilization:** Excellent—includes specific technical details (GPU count, training time) and performance comparisons
- **Citations:** Properly references source sections [3], [4]

**Strengths:** Direct answer, specific evidence, clear explanation, no extraneous information.

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Example 2: Good Response with Inference (Q3 - Score: 4.3)

**Question:** "What are the advantages of using multi-head attention?"

**Response:** "The context provides information about the use and structure of multi-head attention, but it does not explicitly state its advantages compared to single-head attention. However, we can infer some potential advantages from the provided information:

1. Multi-head attention allows the model to jointly attend to information from different representation subspaces at different positions. This suggests that it may enable a more comprehensive understanding of the input sequence by considering various aspects simultaneously.
2. By using multiple heads with reduced dimensions, the total computational cost is similar to that of single-head attention with full dimensionality. This implies that multi-head attention can offer the benefits of focusing on different subspaces without significantly increasing the computational burden.
3. The context mentions that many of the attention heads exhibit behavior that seems related to the structure of the sentence, and it gives examples of this behavior in different heads from an encoder self-attention layer. This suggests that multi-head attention might help capture more nuanced patterns or structures within the input sequence."

**Assessment:**

- **Factual Accuracy (4/5):** Correctly infers advantages from available context; honest about gaps
- **Completeness (5/5):** Provides multiple advantages with supporting reasoning
- **Clarity (4/5):** Well-organized but slightly verbose with explicit inference acknowledgment
- **Context Utilization:** Strong—draws implications from available information without hallucinating

**Strengths:** Intellectual honesty, systematic inference, multiple supporting points. **Minor Limitation:** Could be more concise; acknowledges context limitations extensively.

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### Example 3: Adequate Response with Limitations (Q4 - Score: 3.3)

**Question:** "How does positional encoding work in Transformers?"

**Response:** "The context provides information about the use of positional encoding in Transformers, but it doesn't explicitly explain how the positional encoding works. However, it does mention that in the Transformer model, positional embeddings are used instead of sinusoidal positional encoding (row E in Table 3). The context doesn't provide further details about the learned positional embeddings, but it suggests that they might be a replacement for the sinusoidal positional encoding."

In general, positional encoding is a method used to provide the model with information about the position of each token within the sequence. This is important because transformer models lack inherent understanding of the order of tokens in a sequence, unlike recurrent neural networks (RNNs). The use of positional encoding allows the Transformer to incorporate this positional information into its computations."

#### **Assessment:**

- **Factual Accuracy (3/5):** Partially accurate—correctly identifies purpose but conflates learned embeddings with sinusoidal encoding
- **Completeness (3/5):** Explains general concept but lacks mechanism details that are present in source document
- **Clarity (4/5):** Clear explanation of purpose and motivation
- **Context Utilization:** Moderate—acknowledges context limitations but may have missed available information

**Strengths:** Honest about gaps, explains purpose clearly, avoids hallucination. **Limitations:** Incomplete retrieval or utilization of available context; mechanism details missing.

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## 4.5 Response Characteristics

**Citation Behavior:** Mistral-7B consistently referenced source sections when available, typically using bracketed citation format [X], [Y]. Citations appeared in 60% of responses, primarily those with strong factual grounding (Q1, Q2, Q6).

**Admission of Uncertainty:** Notably, the model explicitly acknowledged when retrieved context was insufficient (Q4, Q5), using phrases like "The context provides information about... but it doesn't explicitly explain..." This behavior demonstrates appropriate epistemic humility rather than hallucination.

**Response Structure:** Most responses followed a consistent pattern:

1. Direct answer to question (1-2 sentences)
2. Supporting explanation or elaboration
3. Additional context or implications
4. Citations when available

**Technical Terminology:** The model appropriately used technical terms from the source material (e.g., "multi-headed self-attention," "representation subspaces," "residual connections") while maintaining accessibility through clear explanations.

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## 4.6 Performance Anomalies

Two questions (Q4: Positional Encoding, Q5: Layer Normalization) received notably lower scores (3.3 vs. 4.5 average). Analysis reveals:

**Possible Causes:**

1. **Retrieval Gaps:** Relevant technical details may not have been in top-4 retrieved chunks
2. **Explanation Depth:** These topics may be explained more technically in the source, requiring more synthesis
3. **Context Distribution:** Information may be distributed across multiple non-retrieved sections

**Model Response:** Rather than hallucinating, the model acknowledged limitations and provided general explanations grounded in the information available.

**Implication:** This behavior suggests the model prioritizes factual accuracy over response completeness, a desirable property for applications requiring reliability.

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## 4.7 Timing Analysis

### Response Time Distribution:

- Fastest 25%: 188-230 seconds (avg 209s) - Q1, Q7, Q10
- Middle 50%: 238-276 seconds (avg 254s) - Q2, Q5, Q8, Q9
- Slowest 25%: 329 seconds - Q4, Q6

### Observations:

- Longest responses (Q6: encoder-decoder architecture) took most time
- Complex multi-part questions didn't consistently require more time
- Consistency suggests stable generation process

### Practical Implications:

- Predictable performance for production deployment (~4 minutes per query)
  - Suitable for non-real-time applications (documentation lookup, educational Q&A)
  - May require optimization for interactive use cases
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## 5. ANALYSIS AND DISCUSSION

### 5.1 Overall Performance Assessment

Mistral-7B demonstrated strong performance in our RAG evaluation, achieving an overall average score of 4.5/5.0 across factual accuracy, completeness, and clarity dimensions. This performance level indicates that the model is well-suited for technical domain question answering when provided with appropriate retrieved context.

The model exhibited consistent behavior across the evaluation, with 80% of questions receiving scores of 4.0 or higher. Only two questions (Q4, Q5) fell into the "adequate" range (3.3/5.0), and these represented instances where the model appropriately acknowledged insufficient context rather than hallucinating information.

### Key Performance Indicators:

- **Factual Accuracy:** 4.4/5.0 average - High reliability with minimal hallucination
- **Completeness:** 4.5/5.0 average - Thorough coverage of available information
- **Clarity:** 4.5/5.0 average - Consistently well-structured explanations

- **Response Time:** 4.3 minutes average - Predictable and consistent
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## 5.2 Performance Patterns by Question Type

Analysis of performance across question categories reveals distinct patterns that provide insights into model strengths and limitations.

### Basic Conceptual Questions (Q1, Q10)

**Performance: 5.0/5.0**

The model excelled at straightforward factual questions requiring direct information extraction and basic synthesis. When asked about the main problem Transformers address, the model provided a complete answer including the problem (sequential computation), the solution (self-attention), and supporting evidence (training time, performance metrics).

**Pattern:** The model performs optimally when questions map directly to specific topics in the paper, relevant information is concentrated in retrievable chunks, and answers require synthesis of clearly related concepts.

### Mechanism Explanation Questions (Q2, Q4, Q7)

**Performance: 4.3/5.0 average (range: 3.3-5.0)**

Performance on mechanism explanations showed more variability. The masked self-attention response (Q7) was comprehensive, explaining both the mechanism and its purpose with clear structure and appropriate technical detail. However, the positional encoding response (Q4) acknowledged context gaps and provided general explanation but missed specific mechanism details.

**Pattern:** Performance depends on whether mechanism details are explicitly stated in retrieved chunks, the distribution of relevant information across document sections, and specificity of technical explanation in source material.

### Architectural Questions (Q3, Q6)

**Performance: 4.7/5.0**

Architectural questions about system structure received consistently high scores. The model effectively handled multi-component questions, systematically describing the encoder structure, decoder structure, and their relationship while maintaining clear organization.



**Pattern:** The model excels at questions requiring systematic enumeration of components, hierarchical organization, and description of structural relationships between elements.

#### Training/Implementation Details (Q5, Q8)

**Performance: 3.7/5.0**

Questions about training practices and implementation details received lower scores. For layer normalization purpose (Q5), the model acknowledged that the context didn't explicitly state the purpose but correctly inferred the general motivation based on common deep learning practices.

**Pattern:** When specific details are not in retrieved context, the model acknowledges limitations explicitly, provides general knowledge inference when appropriate, and avoids confident statements about uncertain information.

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## 5.3 Key Findings

### Finding 1: Exceptional Factual Grounding with Minimal Hallucination

**Observation:** Across all 10 questions, we observed zero clear instances of hallucination—the generation of information not grounded in retrieved context or general model knowledge.

**Evidence:**

- Q4 and Q5 responses explicitly acknowledged context limitations rather than inventing details
- Specific metrics (e.g., "eight P100 GPUs," "twelve hours") were accurately extracted from source
- No contradictions with source material were detected

**Analysis:** This behavior represents a critical strength for production RAG systems. The model's tendency to acknowledge uncertainty when context is insufficient prevents the propagation of false information, a known weakness in many LLM applications.

**Implication:** Mistral-7B demonstrates appropriate epistemic humility in RAG contexts, making it suitable for applications where factual accuracy is paramount (technical documentation, educational materials, professional knowledge bases).

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## Finding 2: Effective Context Utilization with Appropriate Citation

**Observation:** The model effectively extracted and synthesized information from retrieved chunks, often including explicit citations to source sections.

**Evidence:**

- 60% of responses included bracketed citations ([3], [4], etc.)
- Responses incorporated specific details from multiple chunks
- Technical terminology matched source material usage

**Analysis:** Citation behavior indicates that the model actively tracks which information comes from which sources, enabling verification and building user trust. The synthesis of information across multiple chunks (up to 4 per query) demonstrates capability beyond simple extraction.

**Example:** The self-attention response (Q2) synthesized information about the mechanism definition, its distinction from RNN-based approaches, computational complexity advantages, and multi-head implementation details—requiring integration of information from at least three distinct conceptual discussions.

**Implication:** The model can handle reasonably complex synthesis tasks within the RAG paradigm, not merely extracting isolated facts.

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## Finding 3: Performance Depends Critically on Retrieval Quality

**Observation:** The two lowest-scoring responses (Q4: 3.3, Q5: 3.3) both involved questions where the model acknowledged insufficient context, despite relevant information existing in the source document.

**Evidence:**

- Q4: "The context provides information about the use of positional encoding in Transformers, but it doesn't explicitly explain how the positional encoding works."
- Q5: "The context provides that layer normalization is used in Transformer models. However, it does not explicitly state the purpose of layer normalization."

**Analysis:** Several factors may explain these gaps:

1. **Chunk Boundary Issues:** Relevant explanations may have been split across chunks
2. **Query-Document Mismatch:** Retrieval may have prioritized chunks mentioning terms without prioritizing explanatory chunks

### 3. **Technical Density:** Some concepts may be explained implicitly in the source

**Implication:** RAG system performance is bounded by retrieval effectiveness. Even capable LLMs cannot compensate for inadequate context. This emphasizes the importance of retrieval mechanism optimization, chunk size tuning, and potentially larger top-k values for complex questions.

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#### Finding 4: Consistent Response Times Independent of Question Complexity

**Observation:** Response generation time showed relatively low variance (188-329 seconds) and did not correlate strongly with apparent question difficulty.

**Evidence:**

- Simple Q1 (basic concept): 221 seconds
- Complex Q6 (multi-part architecture): 329 seconds
- Advanced Q9 (comparison): 261 seconds

**Analysis:** Similar timing across difficulty levels suggests that generation time is primarily determined by response length rather than reasoning complexity. This contrasts with some findings suggesting that complex reasoning requires more "thinking time."

**Implication:** Response time is predictable for capacity planning. Organizations can reliably estimate throughput (approximately 14-15 queries per hour) and resource requirements for given query volumes.

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#### Finding 5: Explicit Acknowledgment of Knowledge Gaps

**Observation:** When retrieved context was insufficient, the model consistently acknowledged limitations explicitly rather than attempting to answer confidently with potentially incorrect information.

**Evidence:**

- Multiple instances of phrases like "The context provides information... but it doesn't explicitly explain..."
- Responses then provided general knowledge inferences clearly marked as such

**Analysis:** This behavior pattern represents a significant strength for trustworthy AI systems. The model distinguishes between information directly supported by retrieved context,

reasonable inferences from available information, and general knowledge when specific details are unavailable.

**User Experience:** This transparency enables users to understand confidence levels, identify when additional context might be needed, and make informed decisions about information reliability.

**Comparison:** Many LLMs either refuse to answer entirely or generate plausible but potentially incorrect information when context is insufficient. Mistral-7B's middle-ground approach of acknowledging gaps while providing useful general information represents practical utility balanced with honesty.

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## 5.4 Model Strengths for RAG Applications

Based on our evaluation, Mistral-7B exhibits the following strengths:

1. **Factual Accuracy and Reliability:** Maintains high fidelity to source material with essentially zero hallucination (perfect scores on 60% of questions)
  2. **Appropriate Epistemic Humility:** Explicitly acknowledges insufficient context rather than confidently stating unsupported information
  3. **Effective Multi-Chunk Synthesis:** Integrates information from multiple retrieved chunks into coherent responses
  4. **Clear, Well-Structured Explanations:** Organizes responses logically with average clarity score of 4.5/5.0
  5. **Appropriate Technical Terminology:** Uses domain vocabulary correctly without over-simplification
  6. **Predictable, Consistent Performance:** Response times and quality levels stable across queries
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## 5.5 Model Limitations and Areas for Improvement

1. **Sensitivity to Retrieval Quality:** Performance degrades when relevant information is not in retrieved chunks (mitigation: increase top-k, improve chunking strategy)

2. **Limited Cross-Chunk Reasoning:** Evidence of multi-hop reasoning across non-adjacent sections is limited
  3. **Verbosity in Uncertainty Acknowledgment:** Responses spend considerable text explaining limitations (mitigation: prompt engineering for conciseness)
  4. **Response Time for Interactive Use:** Average 4.3-minute response time unsuitable for real-time applications (mitigation: smaller models, GPU acceleration)
  5. **Single-Document Scope:** Multi-document synthesis capabilities remain untested
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## 5.6 Implications for RAG System Design

Our findings suggest several practical recommendations:

### Retrieval Configuration:

- Invest heavily in retrieval optimization as primary performance bottleneck
- Use hybrid retrieval (semantic + keyword)
- Tune chunk size carefully (500 characters with 50-character overlap worked well)
- Consider dynamic top-k based on query complexity

### Use Case Suitability:

- **Strong fit:** Technical documentation, educational applications, professional knowledge bases
- **Moderate fit:** Customer support (if response time acceptable)
- **Poor fit:** Real-time conversational interfaces, high-throughput applications

### Prompt Engineering:

- Simple prompts work well ("Answer based on context")
- Clear instructions to cite sources encourage citation
- Explicit permission to acknowledge uncertainty reduces hallucination

### Quality Monitoring:

- Monitor retrieval quality as primary performance indicator
- Track response times for capacity planning
- Sample responses periodically for hallucination detection

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## 5.7 Broader Implications

### For Practitioners:

1. Open-source models achieve production-grade RAG performance
2. Retrieval quality is critical—even capable LLMs cannot compensate for poor retrieval
3. Local deployment is feasible for non-real-time applications

### For Researchers:

1. Epistemic humility (acknowledging gaps) deserves study as a safety property
2. Question-by-question analysis reveals patterns masked by aggregate metrics
3. Retrieval-generation interaction needs better understanding

### For the Field:

1. Effective RAG systems no longer require proprietary models
  2. Sensitive documents can remain on-premises
  3. Cost-effectiveness through open-source + local deployment
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## 6. CONCLUSION

### 6.1 Summary of Findings

This work presents a systematic evaluation of Mistral-7B in a Retrieval-Augmented Generation system applied to technical knowledge retrieval, specifically focusing on Transformer architecture concepts from the "Attention Is All You Need" paper.

Our evaluation across 10 domain-specific questions reveals that Mistral-7B demonstrates strong performance in technical RAG applications. Key findings include:

1. **Factual Accuracy:** The model maintains high factual accuracy when provided with relevant retrieved context, with minimal hallucination observed across all test cases (4.4/5.0 average).
2. **Response Quality:** Responses are well-structured and clear, with an overall average score of 4.5/5.0 across accuracy, completeness, and clarity dimensions.

3. **Performance Variation:** Performance was strongest on conceptual questions and architectural descriptions (5.0 average), with more variation on training/implementation details where context was less complete (3.7 average).
4. **Practical Viability:** With response times averaging 4.3 minutes, the model is suitable for non-real-time applications requiring accurate, contextually grounded responses.

## 6.2 Model Selection Insights

For practitioners deploying RAG systems in technical domains, our findings suggest:

- **Mistral-7B is well-suited** for technical documentation, educational Q&A, and knowledge base applications where factual accuracy and clear explanations are prioritized over response speed
- **The hybrid retrieval approach** (semantic + keyword search) proves effective for technical content, ensuring relevant context is available to the model
- **Retrieval quality** emerges as the primary determinant of RAG system performance, suggesting that optimization efforts should focus on this component

## 6.3 Limitations

Several limitations should be noted:

1. **Evaluation Scope:** Our evaluation focuses on a single technical document. Performance may vary across different domains and document types.
2. **Question Set:** While our 10 questions cover diverse aspects of Transformer architecture, a larger question set would provide more robust statistical analysis.
3. **Manual Scoring:** Response quality assessment relies on manual scoring, which introduces subjectivity. Future work could incorporate automated evaluation metrics.
4. **Single Document Context:** Real-world RAG systems often operate over larger knowledge bases with multiple documents, which may present additional challenges.
5. **Single Model:** Comprehensive comparison with LLaMA3-8B and Phi-3-Mini would provide additional insights into relative performance.

## 6.4 Future Work

Several directions for future research emerge from this work:

1. **Extended Model Comparison:** Evaluating additional open-source models (LLaMA3, Phi-3, Gemma, Qwen) would provide broader insights into the current landscape
2. **Multi-Document RAG:** Extending evaluation to scenarios requiring synthesis across multiple documents would test more complex reasoning capabilities
3. **Automated Evaluation:** Developing reliable automated metrics for technical accuracy and explanation quality would enable larger-scale evaluations
4. **Domain Variation:** Replicating this evaluation across different technical domains (medical, legal, scientific) would test generalization of findings
5. **Prompt Engineering:** Investigating the impact of different prompting strategies on response quality in RAG contexts
6. **Feature Enhancements:** Implementing automatic document summarization, intelligent query routing (RAG vs. general knowledge), and automated quiz generation would increase practical utility

## 6.5 Concluding Remarks

The proliferation of capable open-source LLMs presents both opportunities and challenges for building production RAG systems. Our evaluation demonstrates that careful model selection and evaluation is essential, as performance characteristics vary significantly across models and use cases.

Mistral-7B, as evaluated in this work, represents a strong candidate for technical RAG applications where accuracy and clarity are paramount. The model's tendency to acknowledge uncertainty when context is insufficient, combined with strong factual grounding and clear explanations, makes it particularly suitable for applications requiring trustworthy information retrieval.

However, the optimal choice depends on specific requirements around response time, resource constraints, and the nature of the knowledge domain. Our findings emphasize that retrieval quality is the primary performance determinant—even excellent models cannot compensate for poor context retrieval.

As the open-source LLM ecosystem continues to evolve rapidly, ongoing evaluation and comparison work remains crucial for guiding practitioners in building effective, reliable RAG systems. This work contributes to that effort by providing detailed performance analysis and practical insights for deploying Mistral-7B in technical knowledge domains.

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## APPENDIX A: COMPLETE QUESTION SET

1. What is the main problem that the Transformer model addresses compared to RNN-based models?
2. Explain the concept of self-attention in Transformers.
3. What are the advantages of using multi-head attention?
4. How does positional encoding work in Transformers?
5. What is the purpose of layer normalization in Transformers?
6. Describe the encoder-decoder architecture of the Transformer.
7. What is masked self-attention and why is it used?
8. How do Transformers handle variable-length sequences?
9. What are the computational advantages of Transformers over RNNs?
10. What are some major applications of the Transformer architecture?

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**END OF PAPER**

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