Optimizing Information Retrieval: A Hybrid Model Leveraging MAR and RAPTOR Frameworks

George Washington University

Prepared by: Timur Abdygulov
Supervised by Amir H. Jafari
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Introduction

Retrieval-Augmented Generation (RAG):

- Combines retrieval mechanisms with large language models (LLMs).
- Enhances contextual understanding and reasoning capabilities.

Key Challenges in Retrieval Systems:

- Limited adaptability for dynamic queries.
- Poor handling of multi-hop reasoning and long-context synthesis.

Existing Models:

- **MAR:** Excels at static memory recall but struggles with evolving tasks.
- **RAPTOR:** Effective for dynamic and hierarchical reasoning but lacks memory persistence.

Contribution:

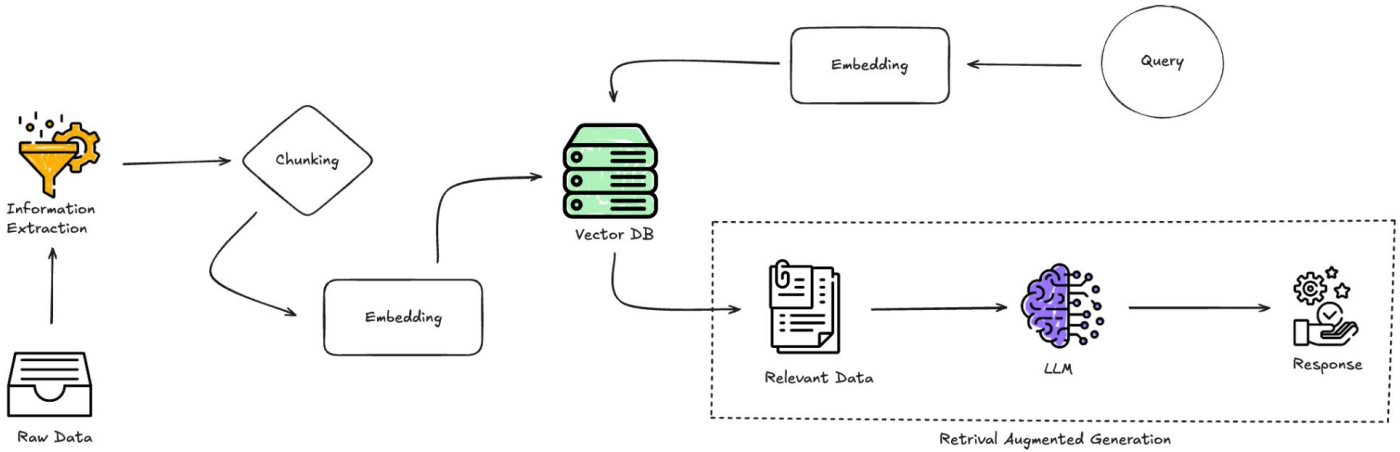
- Hybrid Model integrates MAR's memory with RAPTOR's hierarchical reasoning.
- Balances static recall and dynamic adaptability for diverse query challenges.

Methodology Overview

- Evaluation of Naive RAG, MAR, RAPTOR, and Hybrid Model.
- Integration with vector stores and generative models for response synthesis.
- Focus on modularity and extensibility.

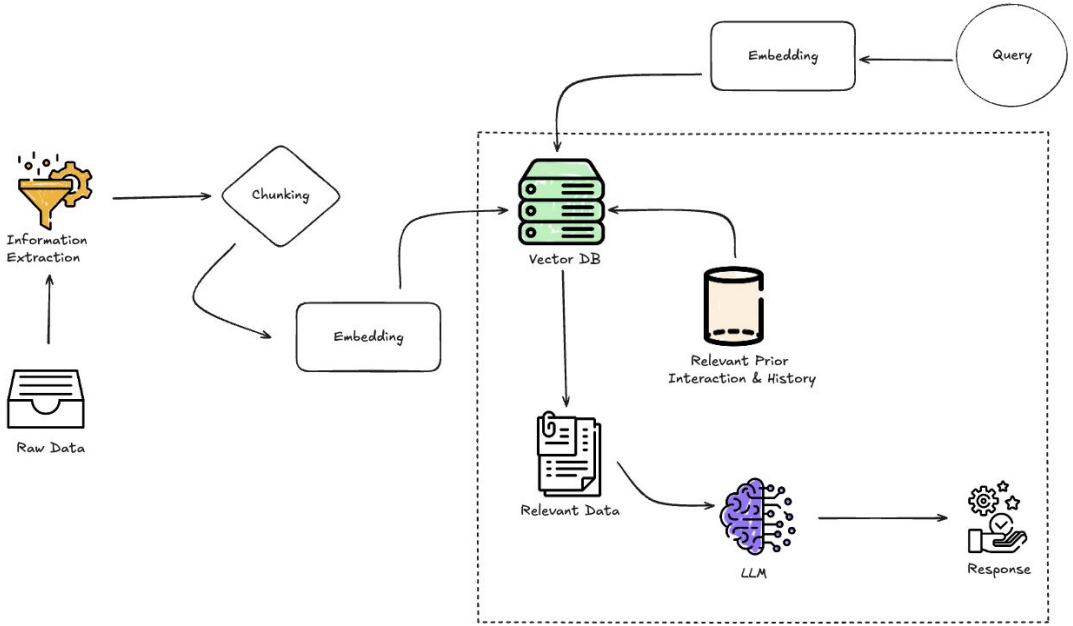
Hyperparameter	Value/Default	Description
chunk_size	1000	The maximum size of text chunks for splitting documents.
chunk_overlap	115	The number of overlapping characters between consecutive text chunks.
embedding_dim	1024	Dimension of the embeddings generated by the model.
batch_size	16 (embedding), 50 (indexing)	Batch size for document processing during embedding generation or indexing.
max_documents	Derived dynamically	The maximum number of documents stored, based on space and model embedding size.
avg_document_size	1000	Average size of documents in bytes, used for storage estimation.

Naive RAG



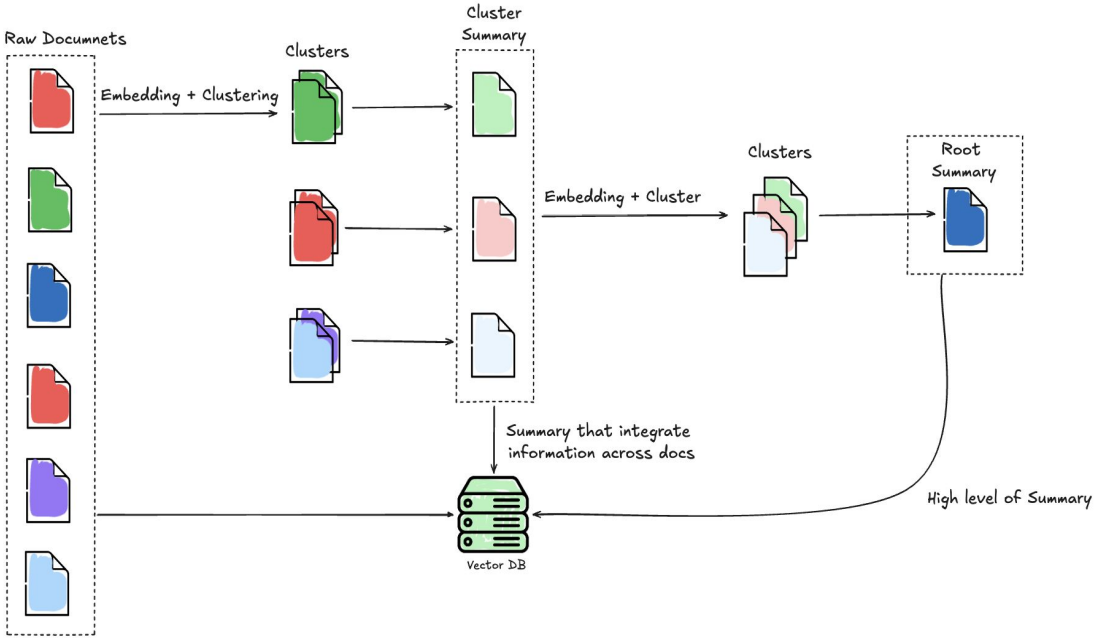
- Baseline RAG framework.
- Straightforward retrieval-to-generation pipeline.
- Effective for static, simple queries but limited in dynamic adaptability.

Memory-Augmented Retrieval (MAR)



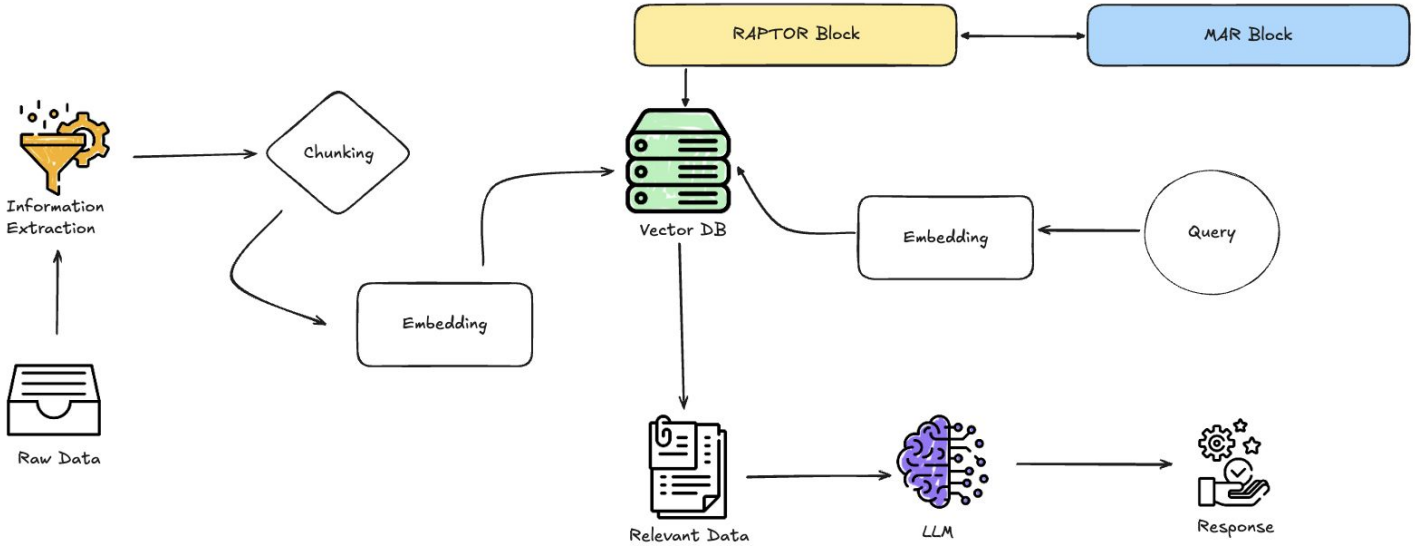
- Adds a memory database for recurring queries.
- Efficient for static tasks, limited for evolving contexts.

Recursive Abstractive Processing for Tree-Organized Retrieval (RAPTOR)



- Hierarchical document organization for multi-hop reasoning.
- Semantic clustering enhances contextual synthesis.
- Limited by lack of memory.

Hybrid Model (MAR + RAPTOR)

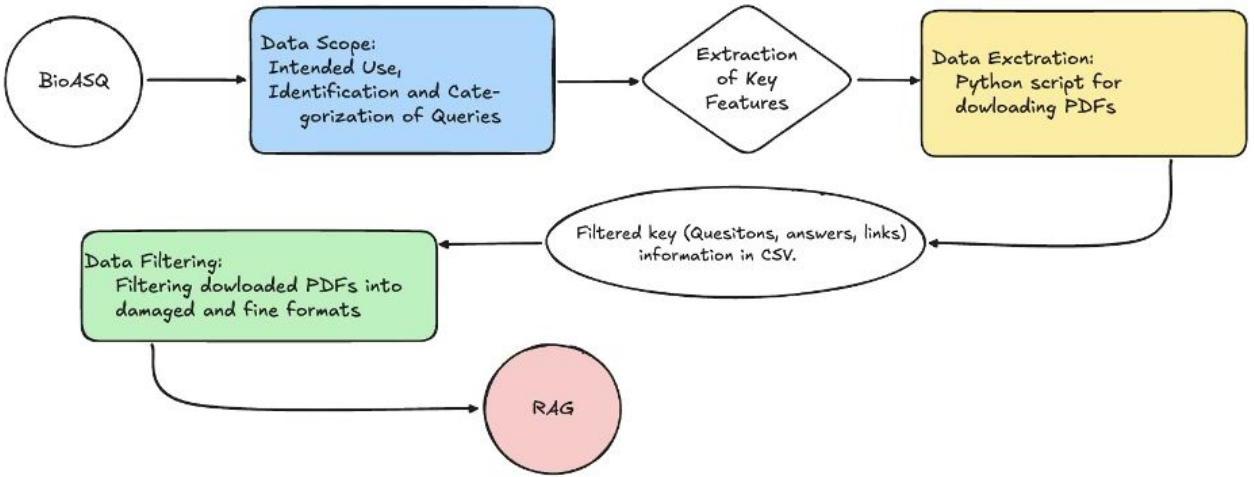


- Combines MAR's memory with RAPTOR's reasoning.
- Handles static, dynamic, and multi-layered queries.

Retrieval System: ChromaDB

- **Role in Retrieval Systems:**
  - Facilitates efficient semantic search through embedding-based matching.
  - Acts as the backbone for storing and retrieving high-dimensional vector representations of documents.
- **Chosen System: ChromaDB**
  - Scalable and low-latency query processing.
  - Supports dense, hybrid (dense + keyword), and multimodal retrieval.
- **Key Features of ChromaDB:**
  - Seamless integration with frameworks like LangChain and modern embedding models.
  - Handles high-dimensional embeddings (e.g., 1024 dimensions).
  - Optimized for hybrid retrieval methods (semantic and keyword-based).
- **Advantages:**
  - Scalability for large datasets.
  - High-speed processing with minimal latency.
  - Compatibility with adaptive and hierarchical retrieval methods.

Dataset Description



- BioASQ biomedical dataset.
- Query types: Static, Dynamic, and Multi-layered.
- Thorough data preprocessing for consistency.

Categorized Biomedical Queries

ID	Question	Category
1	Is Hirschsprung disease a Mendelian or a multifactorial disorder?	M
2	List signaling molecules (ligands) that interact with the receptor EGFR?	S
3	Are long non-coding RNAs spliced?	M
4	Is RANKL secreted from the cells?	S
5	Which miRNAs could be used as potential biomarkers for epithelial ovarian cancer?	M
6	Which acetylcholinesterase inhibitors are used for treatment of myasthenia gravis?	S
7	Has Denosumab (Prolia) been approved by FDA?	D
8	Which are the different isoforms of the mammalian Notch receptor?	S
9	Orteronel was developed for treatment of which cancer?	D
10	Is the monoclonal antibody Trastuzumab (Herceptin) of potential use in the treatment of prostate cancer?	D
11	Which are the Yamanaka factors?	S
12	Where is the protein Pannexin1 located?	S
13	Which currently known mitochondrial diseases have been attributed to POLG mutations?	M

- **Static Queries** involve retrieving straightforward, factual information that relies on pre-existing, often unchanging knowledge.
- **Dynamic Queries** require contextual reasoning and the ability to handle evolving information, such as updates to regulatory statuses or therapeutic applications.
- **Multi-Layered Queries** demand evidence aggregation and multi-hop reasoning, where answers must be synthesized across multiple sources or involve complex reasoning steps.
- A total of **47 PDFs** were used

Frequency of Biomedical Queries

ID	Question	Frequency
1	Is Hirschsprung disease a Mendelian or a multifactorial disorder?	2
2	List signaling molecules (ligands) that interact with the receptor EGFR?	4
3	Are long non-coding RNAs spliced?	4
4	Is RANKL secreted from the cells?	3
5	Which miRNAs could be used as potential biomarkers for epithelial ovarian cancer?	6
6	Which acetylcholinesterase inhibitors are used for treatment of myasthenia gravis?	2
7	Has Denosumab (Prolia) been approved by FDA?	2
8	Which are the different isoforms of the mammalian Notch receptor?	2
9	Orteronel was developed for treatment of which cancer?	3
10	Is the monoclonal antibody Trastuzumab (Herceptin) of potential use in the treatment of prostate cancer?	7
11	Which are the Yamanaka factors?	7
12	Where is the protein Pannexin1 located?	4
13	Which currently known mitochondrial diseases have been attributed to POLG mutations?	2

Embedding Model Evaluation

- High-performance embeddings offer accuracy at higher computational costs.
- Lightweight embeddings balance efficiency and speed.

Embedding Model	Top 1 Accuracy (%)	Top 10 Accuracy (%)
bert-large-nli	75.0	87.5
instructor-xl	87.5	87.5
msmacro	87.5	87.5
mxbai-embed-large	87.5	87.5
roberta-base	37.5	87.5
roberta-large	62.5	62.5
dunzhang/stella_en_1.5B_v5	1	80.3
nvidia/NV-Embed-v2	1	80.5

Embedding Resource Utilization

- High-performance embeddings require substantial GPU memory.
- Lightweight models suitable for simpler tasks.

Model Name	GPU Memory Used (GB)	Total Parameters (Millions)	Loaded in 8-bit
mixedbread-ai/mxbai-embed-large-v1	1.25	335.14	No
dunzhang/stella_en_1.5B_v5	3.48	1543.27	Yes
dunzhang/stella_en_1.5B_v5	9.25	1543.27	No
sentence-transformers/all-MiniLM-L6-v2	0.08	22.71	No
meta-llama/Meta-Llama-3-8B-Instruct	10.42	8030.26	Yes

Results Summary

- Hybrid Model achieves balanced performance across query types.
- MAR excels in static recall; RAPTOR in multi-hop reasoning.
- Embedding strategies influence performance and scalability.

- MAR:
  - Answered: 11 out of 13 questions
  - Very Close to Ideal: 7
  - Correct Answer: 6
- RAG:
  - Answered: 11 out of 13 questions
  - Very Close to Ideal: 7
  - Correct Answer: 5
- RAPTOR:
  - Answered: 8 out of 13 questions
  - Very Close to Ideal: 3
  - Correct Answer: 3
- RAPTOR+Memory:
  - Answered: 10 out of 13 questions
  - Very Close to Ideal: 6
  - Correct Answer: 5

Question	Ideal Answer	MAR Answer	RAG Answer	RAPTOR Answer	Hybrid Answer
Is Hirschsprung disease a Mendelian or a multifactorial disorder?	Hirschsprung disease is both Mendelian and multifactorial, depending on the context.	✅ Matches ideal answer	✅ Matches ideal answer	❌ Incorrect	✅ Matches ideal answer
List signaling molecules (ligands) that interact with the receptor EGFR?	The 7 EGFR ligands are EGF, BTC, EPR, HB-EGF, TGF-α, AREG, and EPG.	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer
Are long non-coding RNAs spliced?	Yes, long non-coding RNAs are spliced through the same pathway as mRNAs.	✅ Matches ideal answer	✅ Matches ideal answer	❌ Unclear or incomplete answer	❌ Unclear or incomplete answer
Is RANKL secreted from the cells?	Yes, RANKL is secreted by osteoblasts.	✅ Matches ideal answer	❌ Does not mention secretion	❌ Incomplete answer	✅ Matches ideal answer
Which miRNAs could be used as potential biomarkers for epithelial ovarian cancer?	miR-200a, miR-100, miR-141, miR-200b, miR-200c, miR-203, etc.	✅ Matches ideal answer	❌ Partial match	❌ Partial match	✅ Matches ideal answer
Which acetylcholinesterase inhibitors are used for treatment of myasthenia gravis?	Pyridostigmine and neostigmine.	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer
Has Denosumab (Prolia) been approved by FDA?	Yes, approved by the FDA in 2010.	❌ Not answered	❌ Not answered	✅ Matches ideal answer	❌ Not answered
Which are the different isoforms of the mammalian Notch receptor?	Notch-1, Notch-2, Notch-3, Notch-4.	❌ Not answered	❌ Not answered	❌ Not answered	❌ Not answered
Orteronel was developed for treatment of which cancer?	Castration-resistant prostate cancer.	✅ Matches ideal answer	❌ Not answered	❌ Incorrect	✅ Matches ideal answer
Is the monoclonal antibody Trastuzumab (Herceptin) of potential use in the treatment of prostate cancer?	Controversial, but it can be used in HER2 overexpressing prostate cancer.	✅ Matches ideal answer	✅ Matches ideal answer	❌ Incorrect	❌ Not answered
Which are the Yamanaka factors?	OCT4, SOX2, MYC, and KLF4 transcription factors.	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer
Where is the protein Pannexin1 located?	Localized to the plasma membranes.	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer	✅ Matches ideal answer
Which currently known mitochondrial diseases have been attributed to POLG mutations?	Recessive PEO and MNGIE.	❌ Partial match	❌ Partial match	❌ Partial match	❌ Partial match

Discussion

- Hybrid Model mitigates trade-offs between memory and reasoning.
- Embedding selection critical to balancing accuracy and scalability.
- Limitations include semantic clustering errors and resource demands.

Conclusion

- Hybrid Model: A robust solution for diverse retrieval tasks.
- Combines strengths of MAR and RAPTOR.
- Future directions: Adaptive clustering, multimodal retrieval, and dynamic embeddings.

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Thank you