🔭 **TeleRAG**: Efficient Retrieval-Augmented Generation Inference with Lookahead Retrieval

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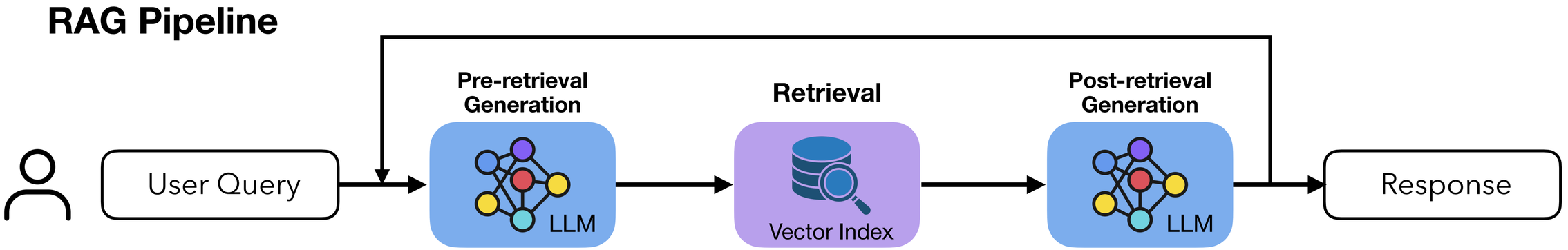
University of Washington, Harvard University, Shanghai Jiao Tong University


*equal contributions, ∞currently at Meta ☝

Retrieval-Augmented Generation (RAG)



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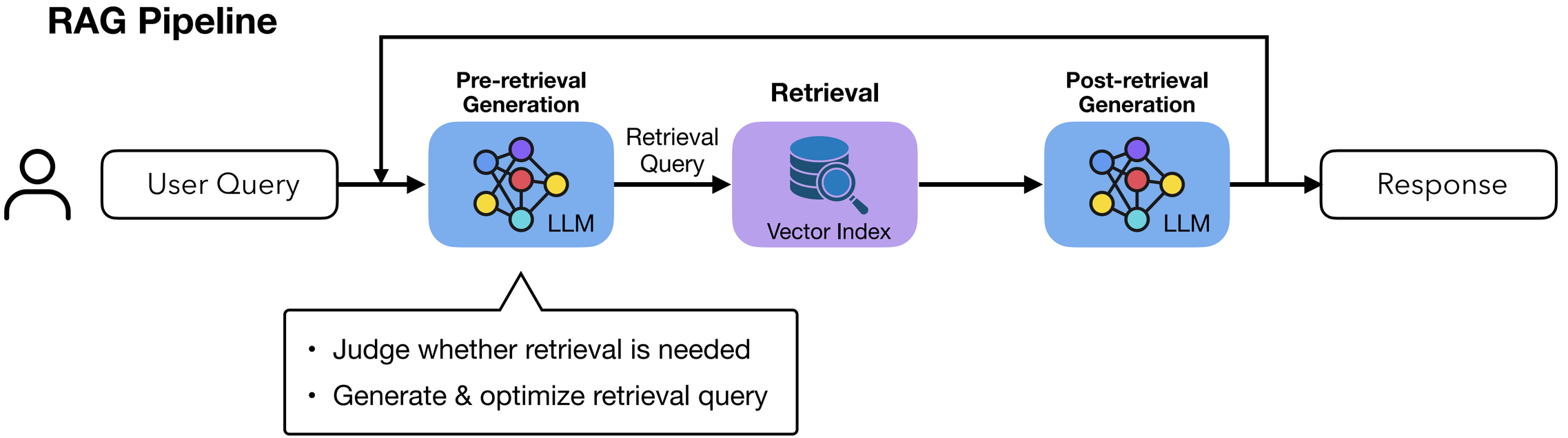

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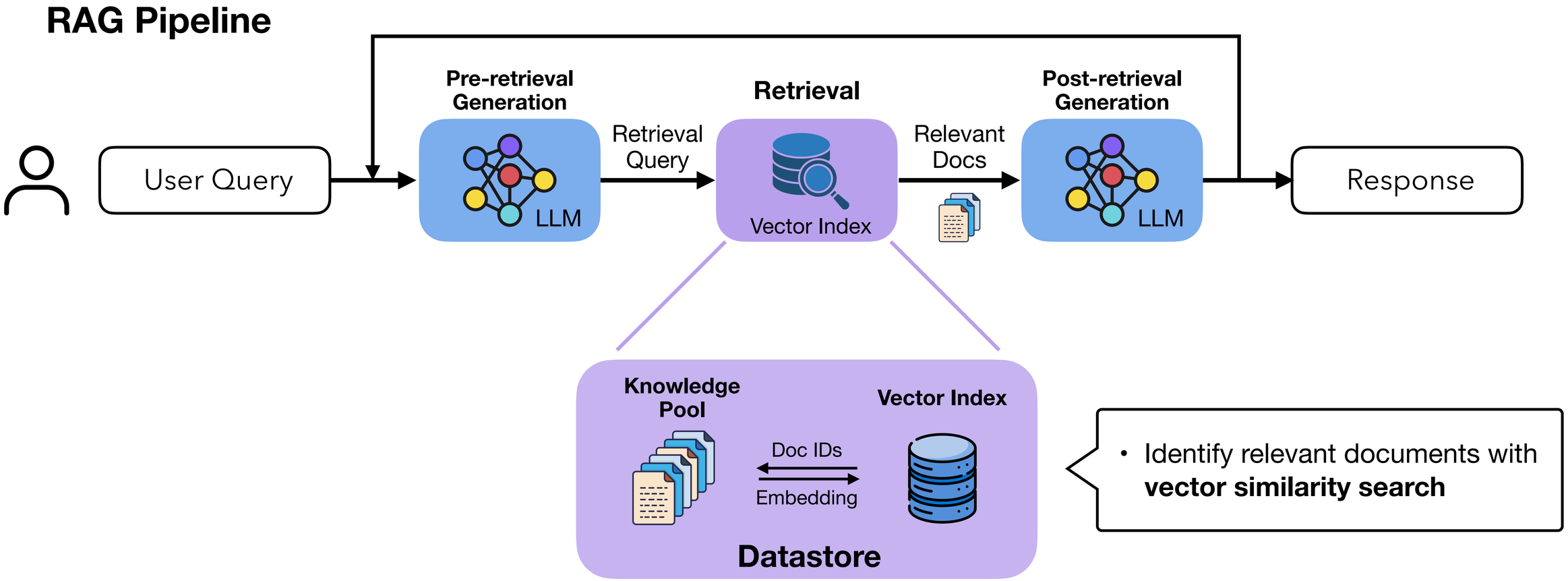

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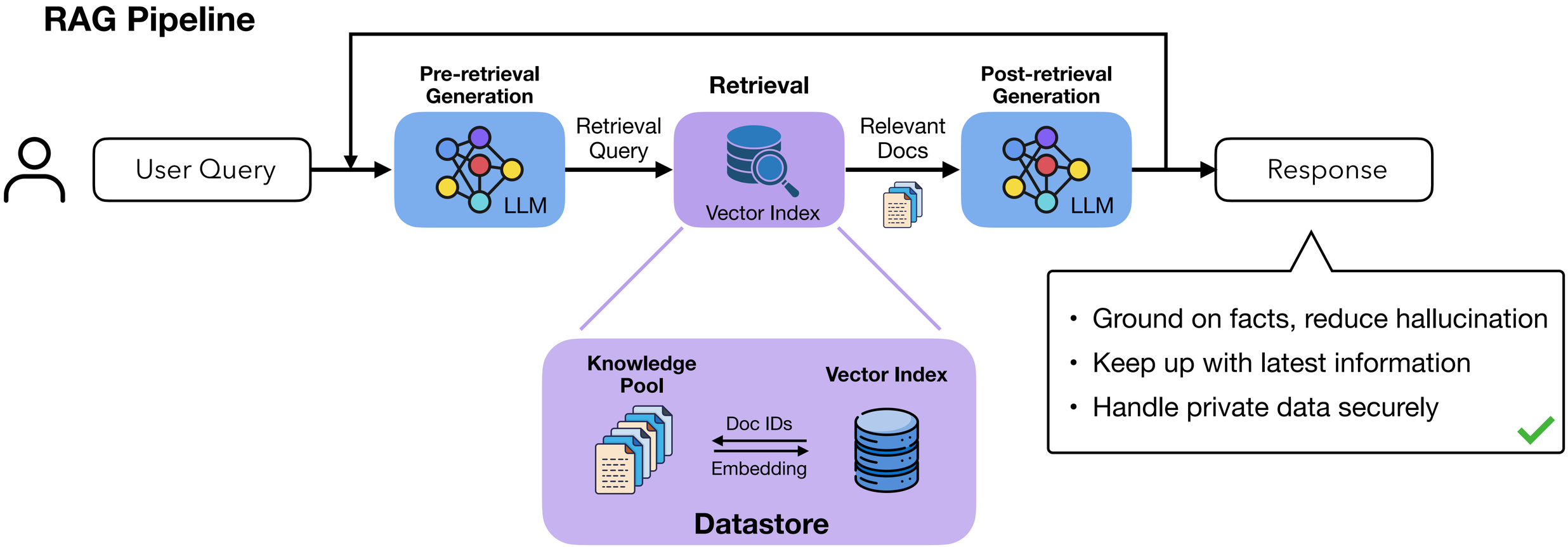
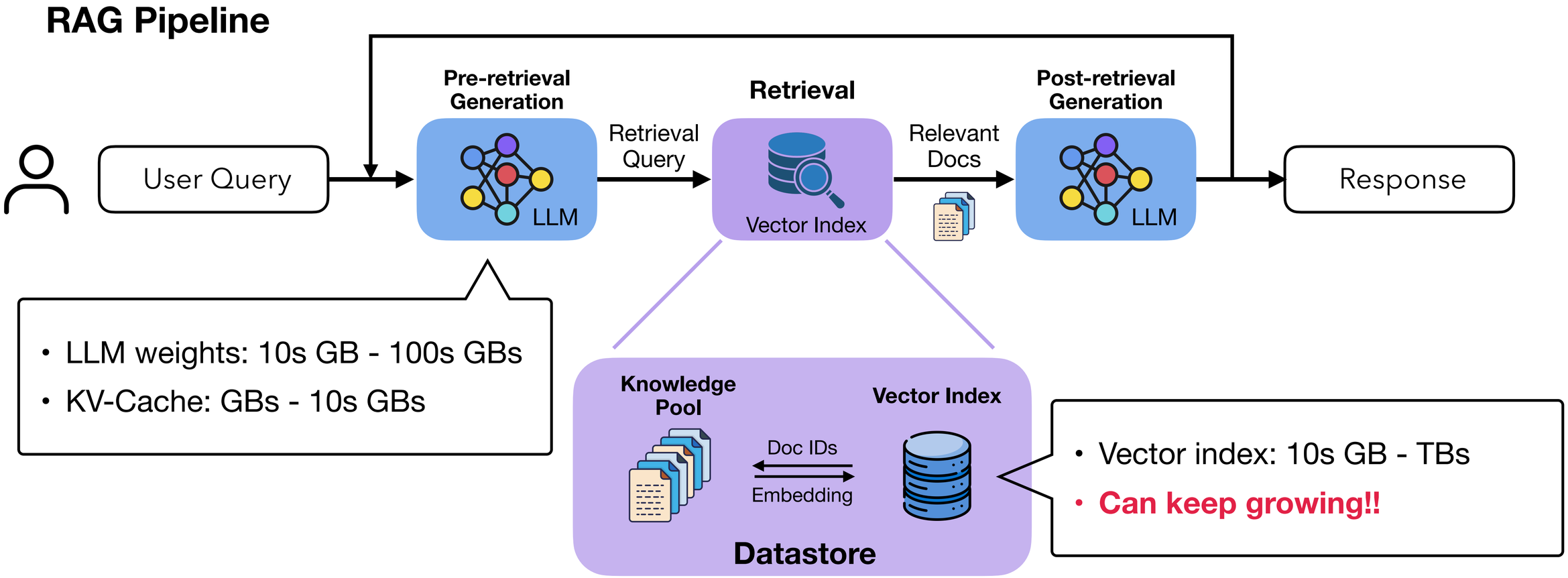
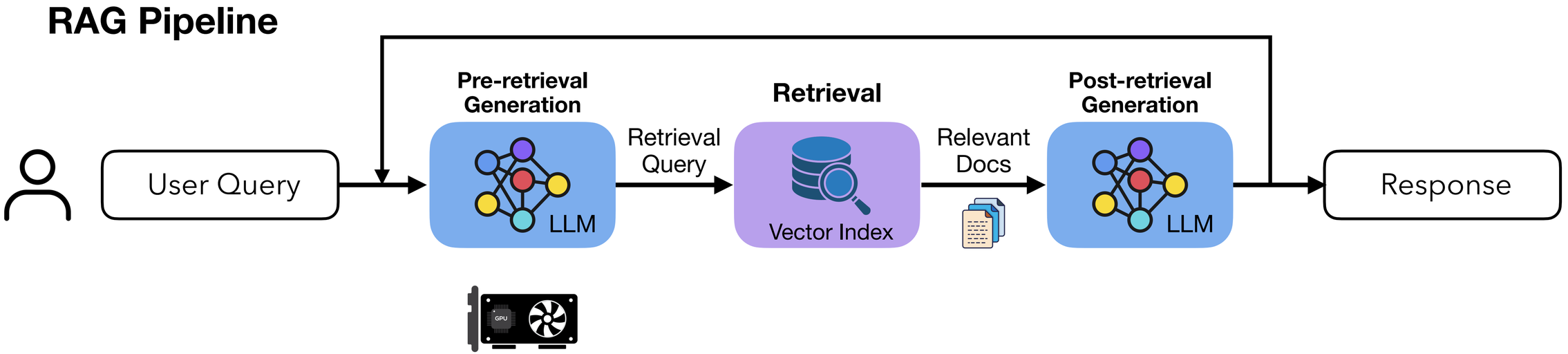


Challenges of RAG: Large Memory



Common Deployment: CPU Off-loading Vector Index



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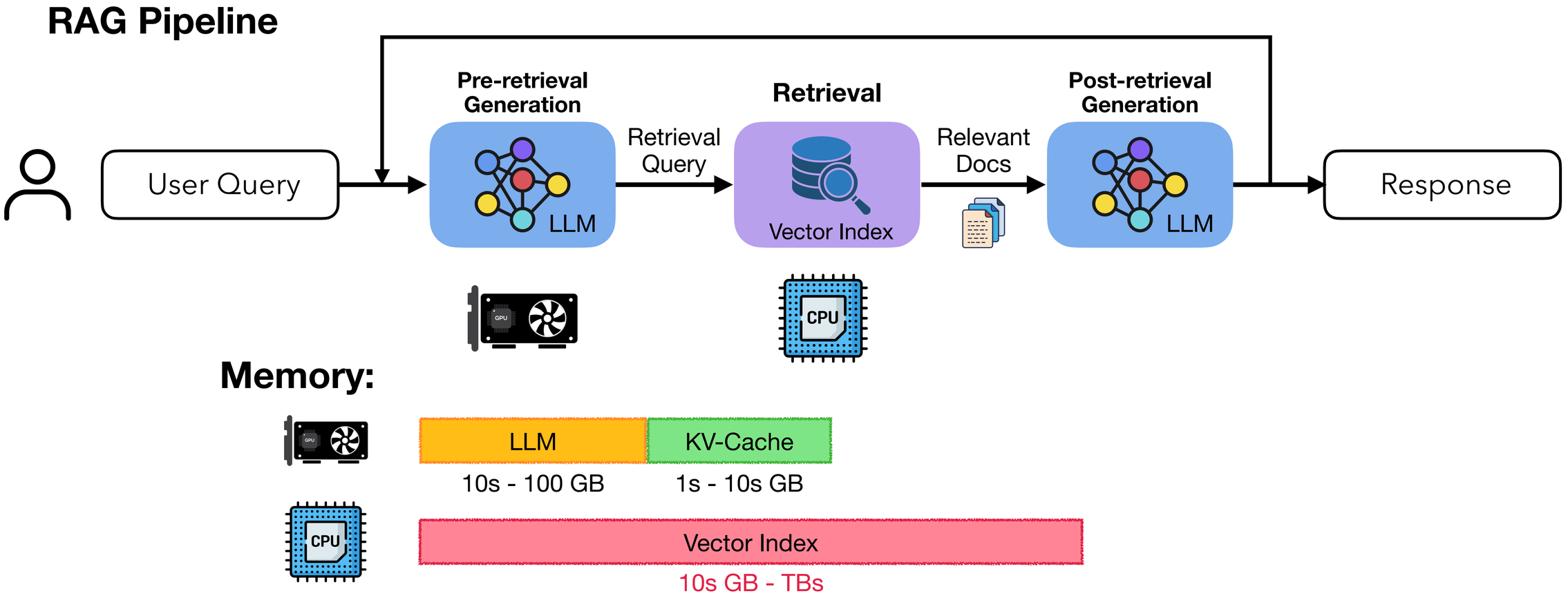

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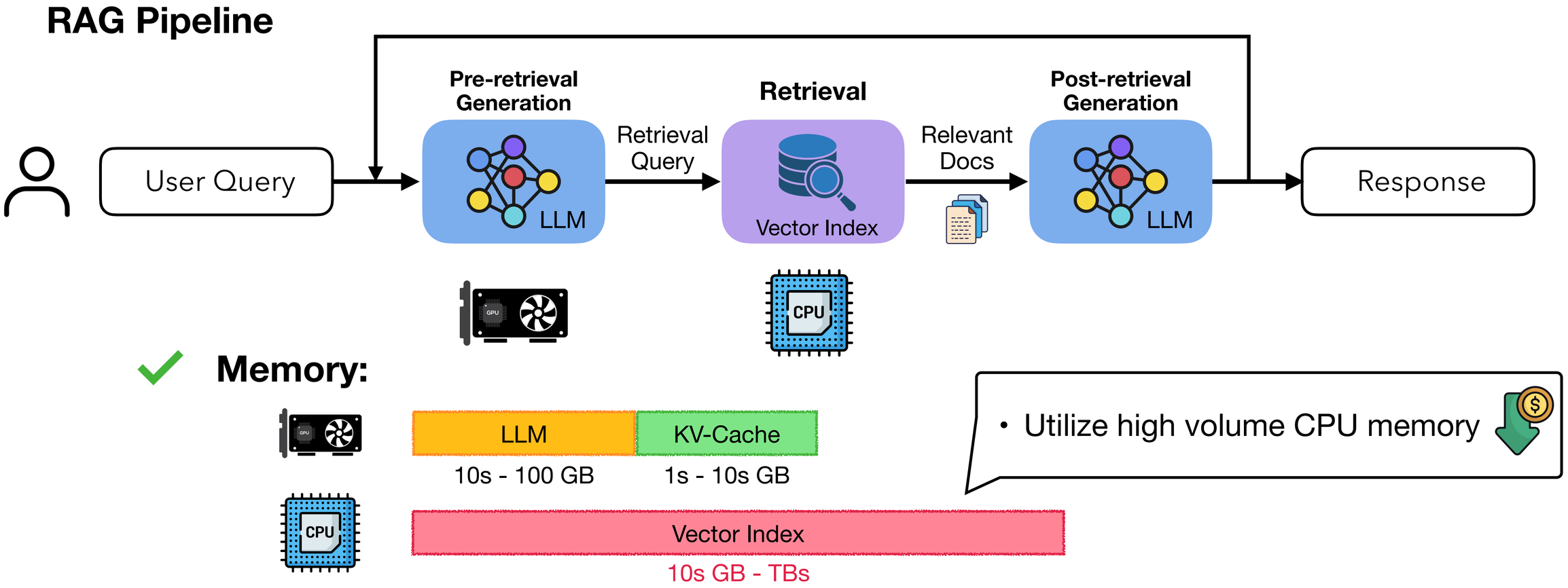
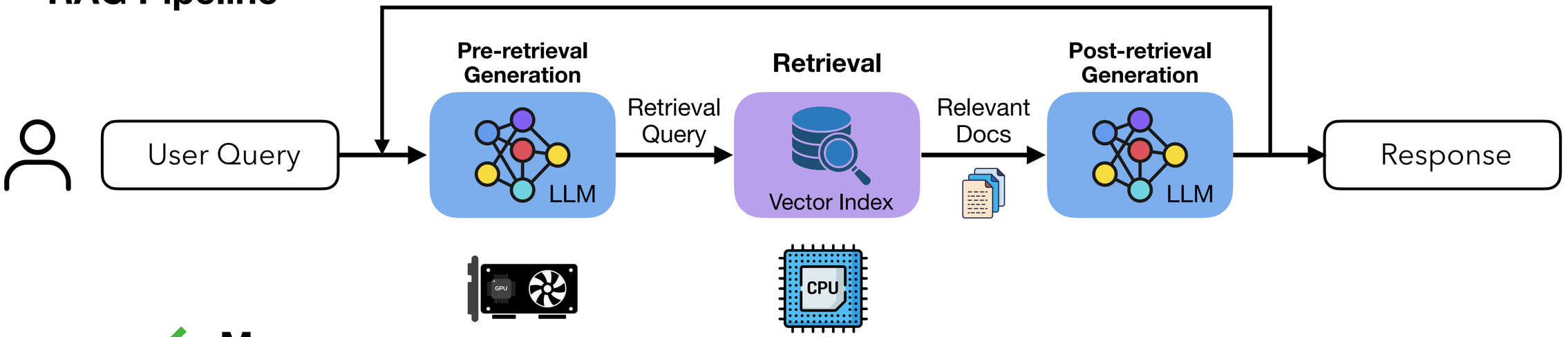
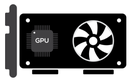


Common Deployment: CPU Off-loading Vector Index

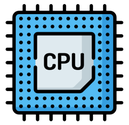
RAG Pipeline



✓ **Memory:**



LLM	KV-Cache
10s - 100 GB	1s - 10s GB



Vector Index
10s GB - TBs

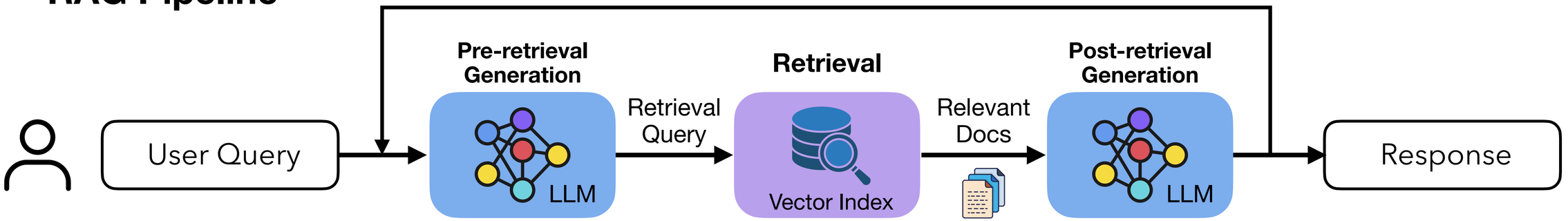
- Suffer from slow CPU retrieval

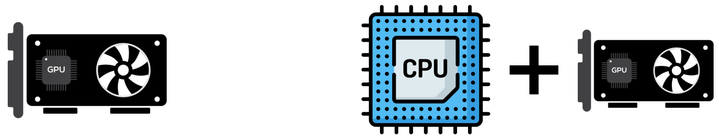
✗ **Latency:**

LLM Gen.	CPU Retrieval	LLM Gen.
200 - 500ms	300ms - 1s	200 - 500ms

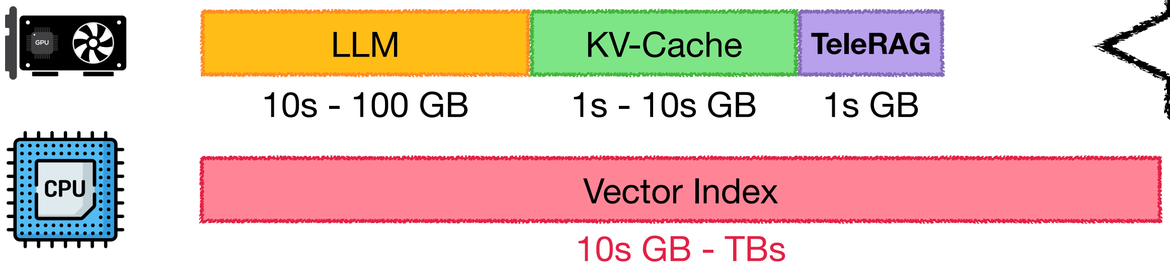
TeleRAG Goal: Fast Retrieval with Small GPU Memory

RAG Pipeline



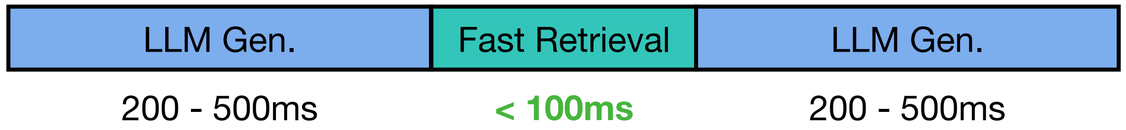


✓ **Memory:**



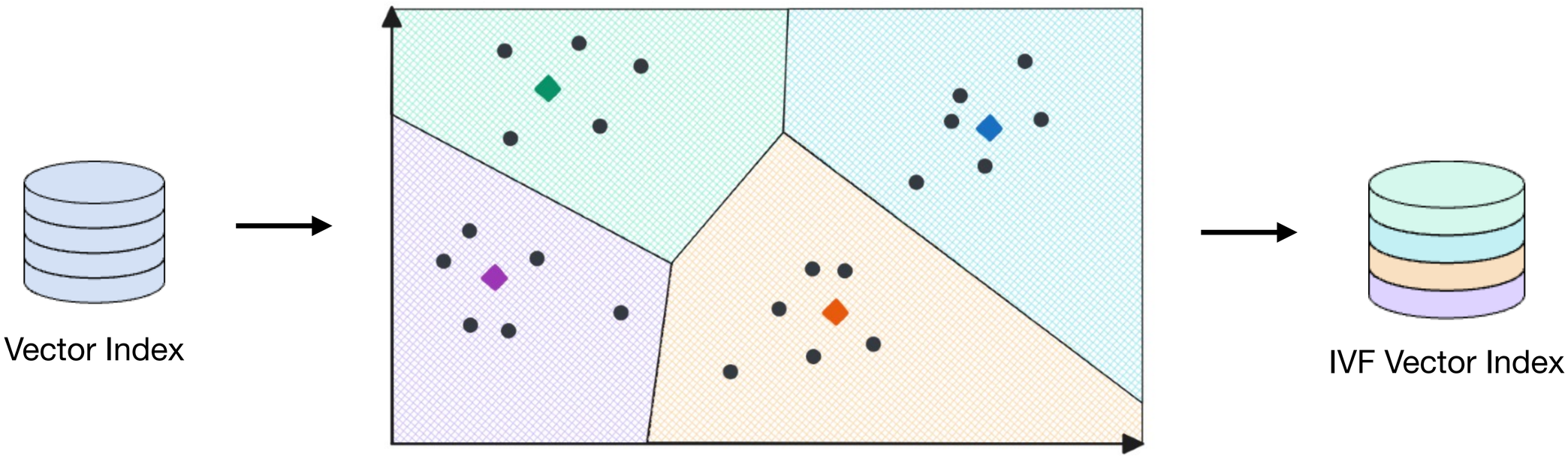
TeleRAG:
- GPU-like retrieval speed
- Minimal GPU memory requirement

✓ **Latency:**



Retrieval: Inverted File Index (IVF)

- Partition the datastore into multiple clusters based on vector similarity
- Two-step search: (1) **coarse-grained** on centroids (2) **fine-grained** in selected clusters
- **Speed up** the search process with high recall, but ***do not*** save memory



IVF: Partition vector datastore into clusters

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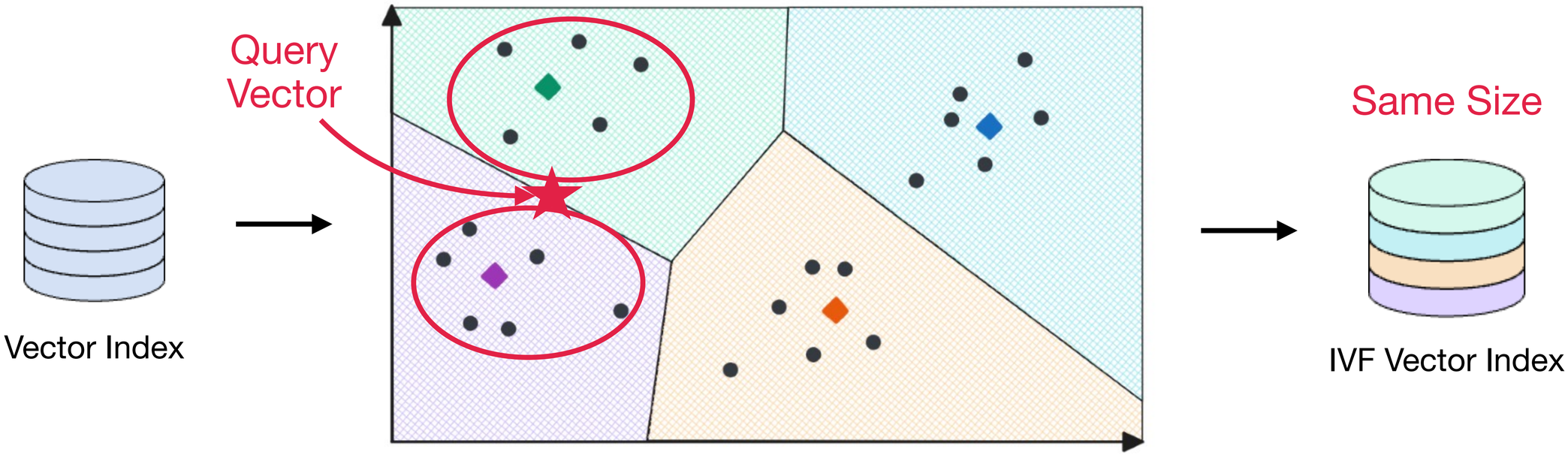
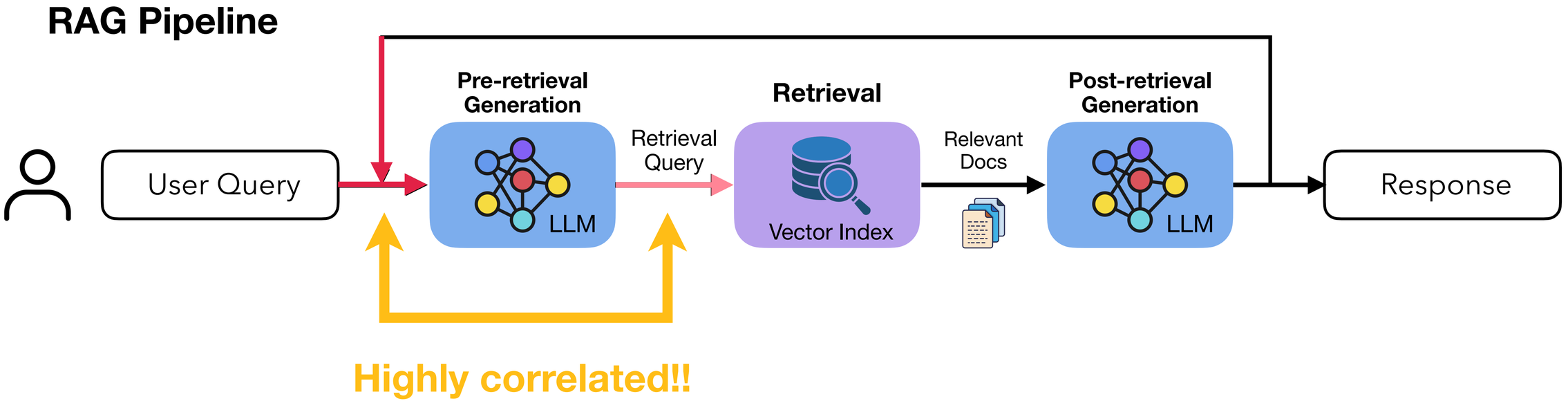
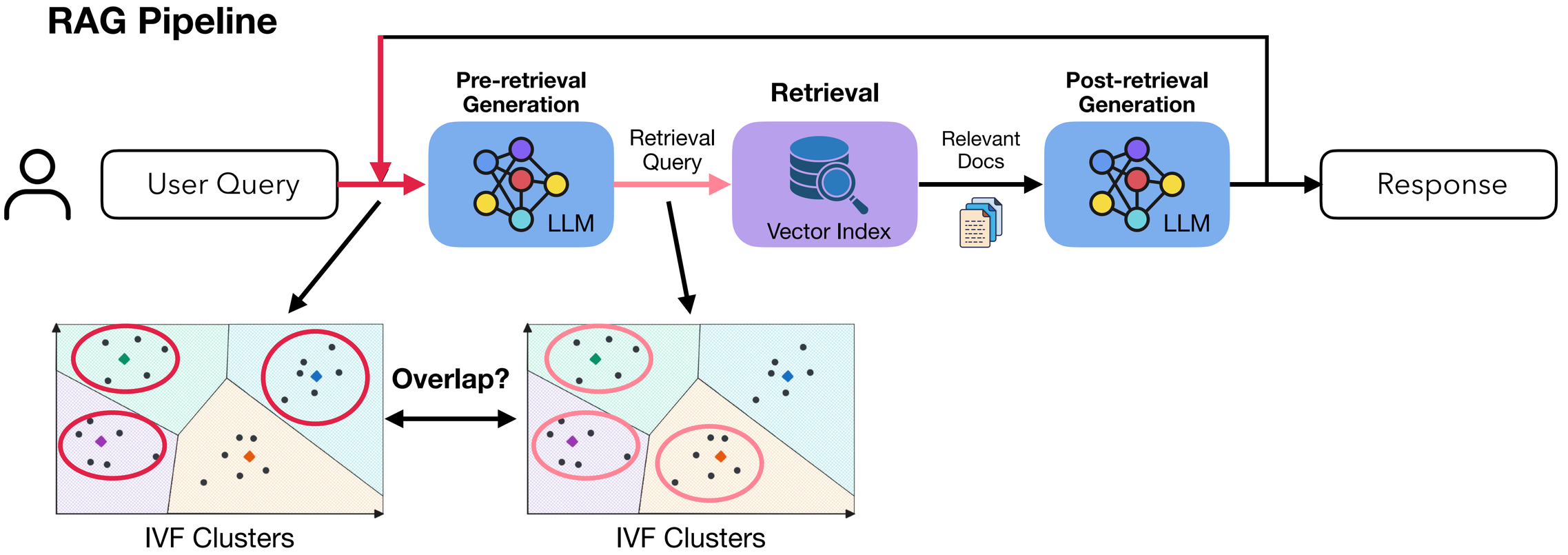


IVF: Partition vector datastore into clusters

Insight: Query Correlation Between Stages



IVF Cluster Overlapping Analysis



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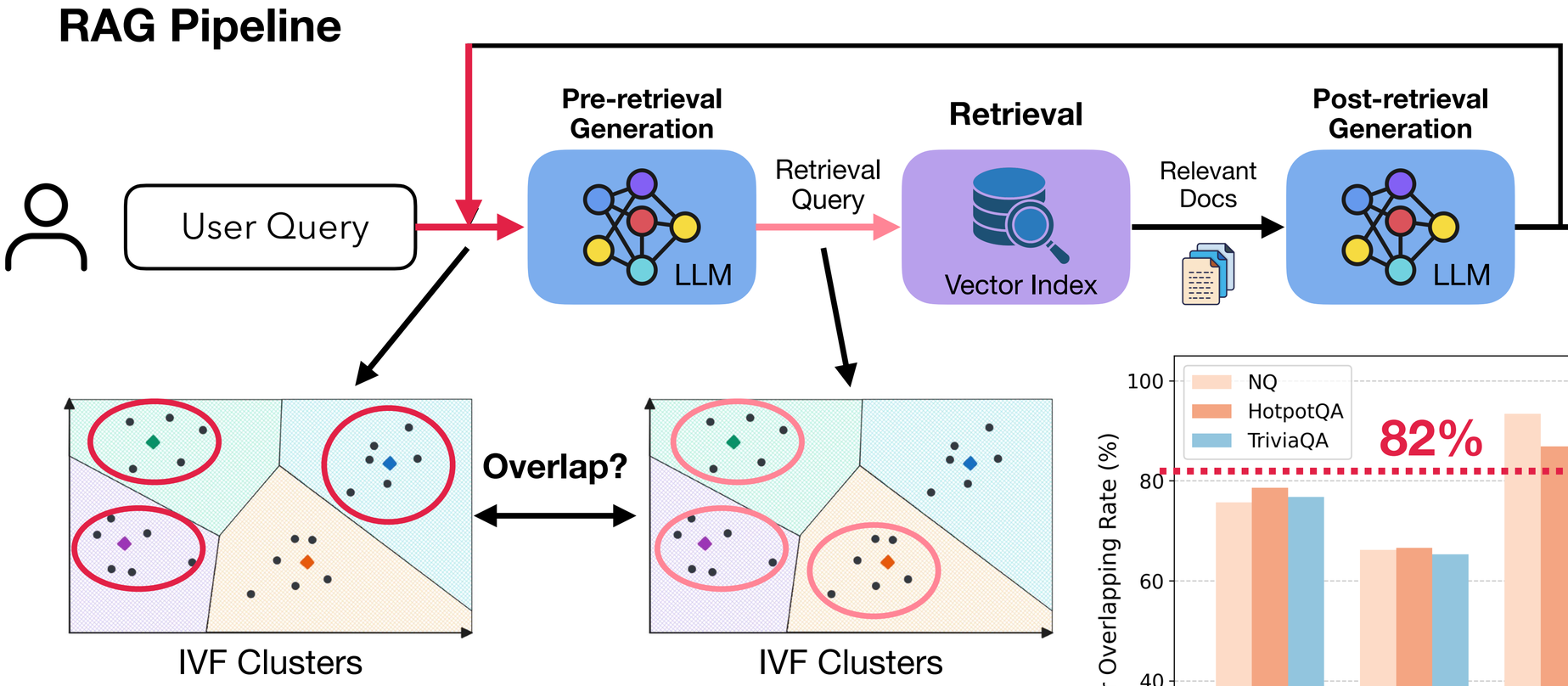
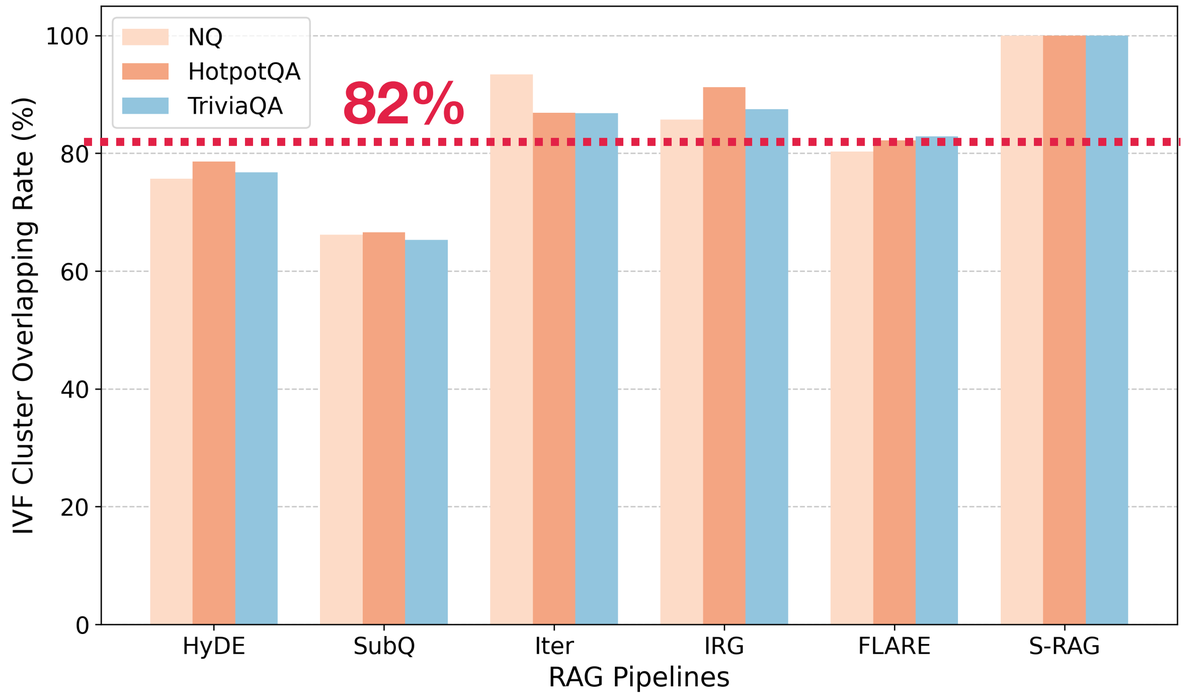
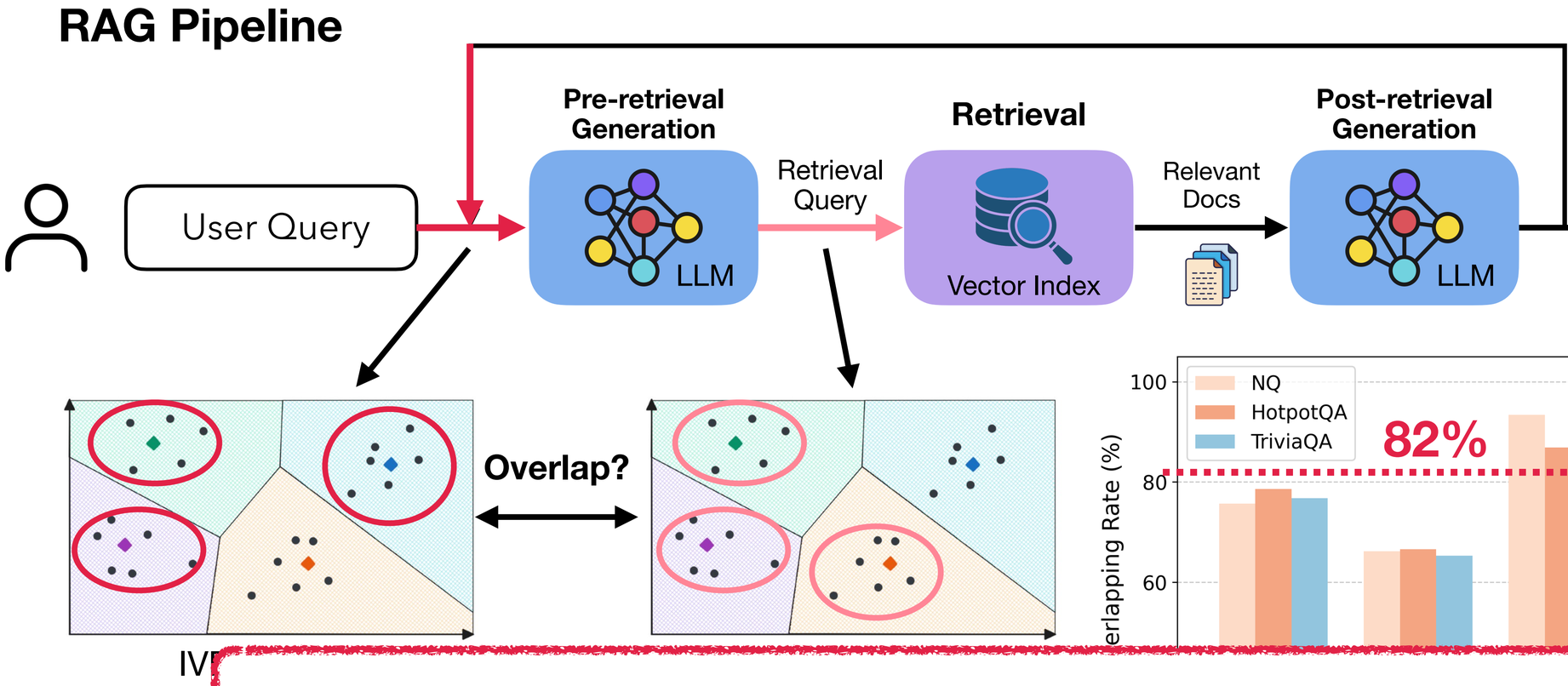
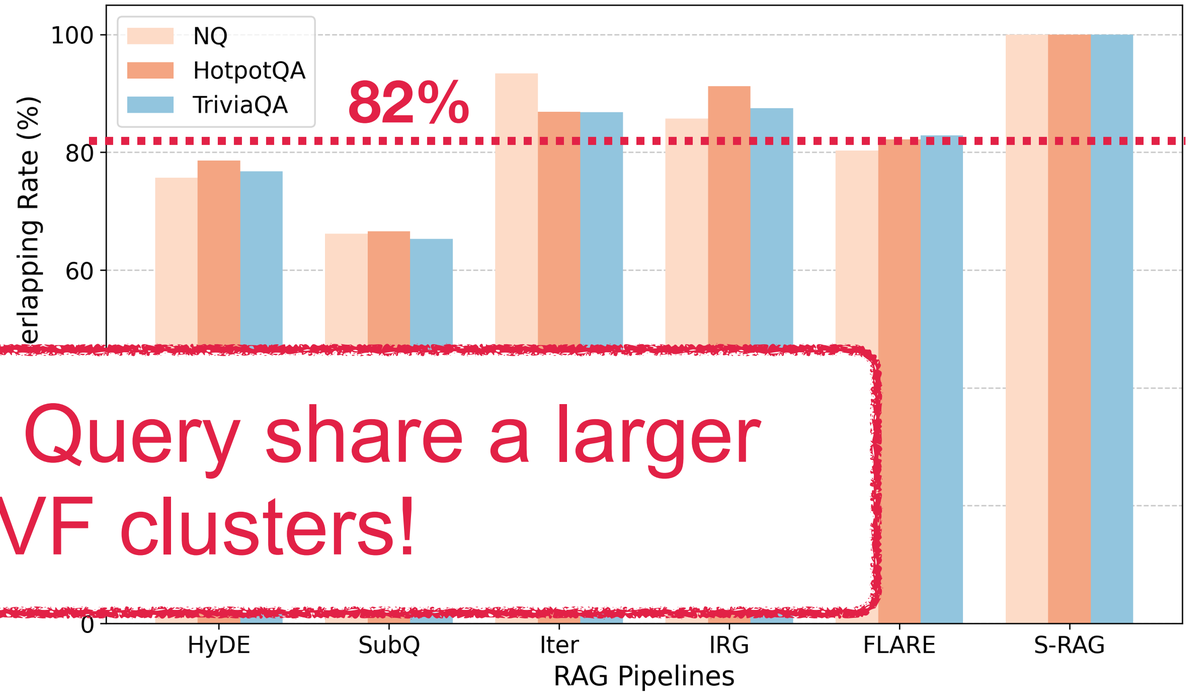




* Test on a IVF index with 4096 cluster.

IVF Cluster Overlapping Analysis

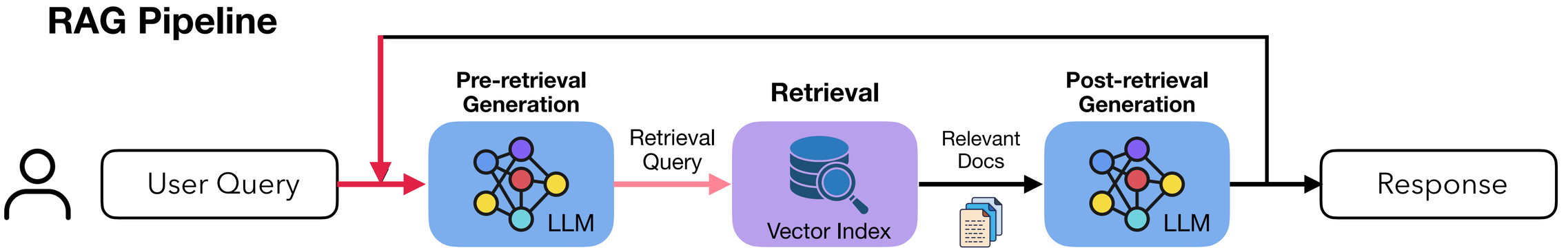




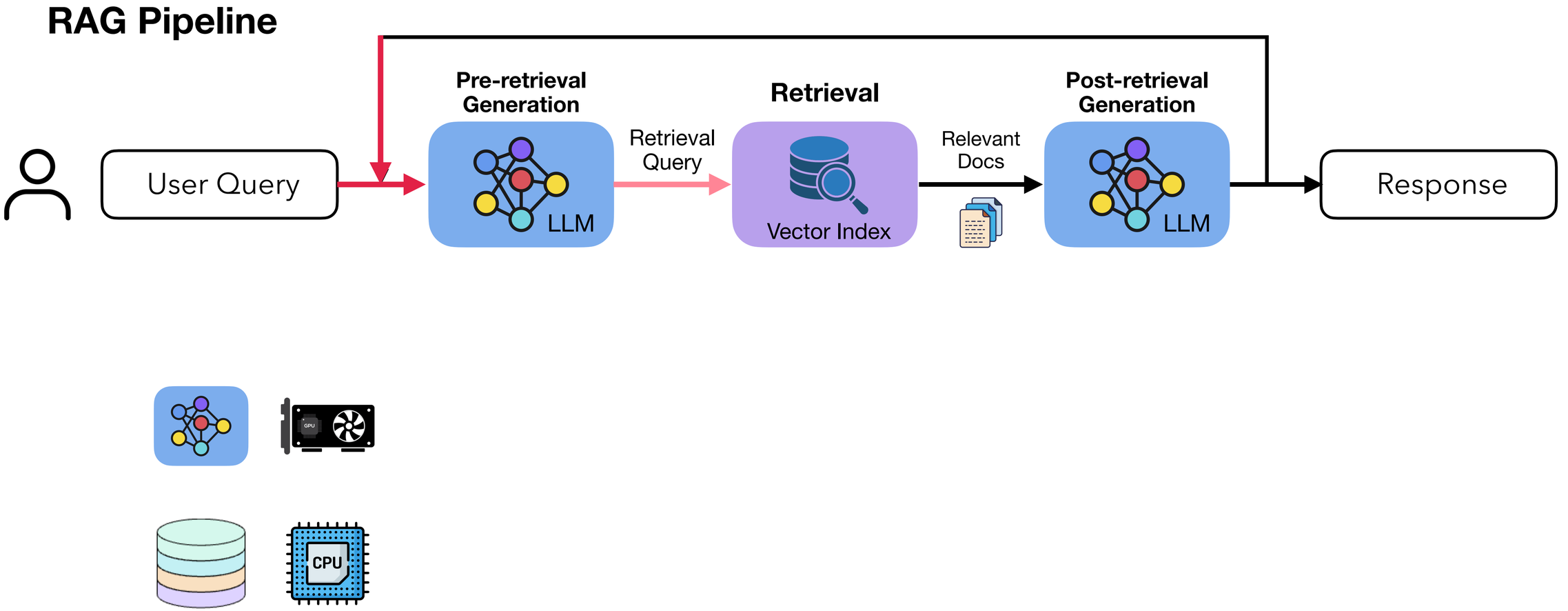
User Query and Retrieval Query share a larger portion of their IVF clusters!

* Test on a IVF index with 4096 cluster.

TeleRAG: Lookahead Retrieval



TeleRAG: Lookahead Retrieval



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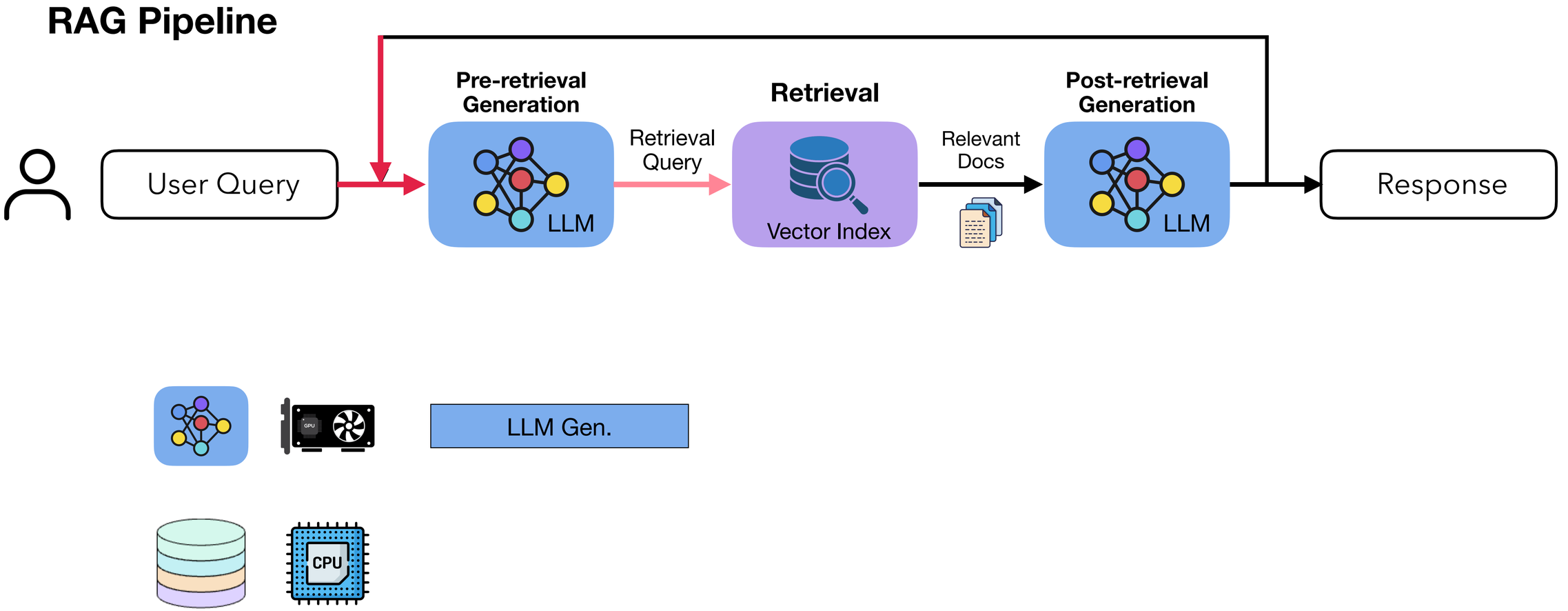

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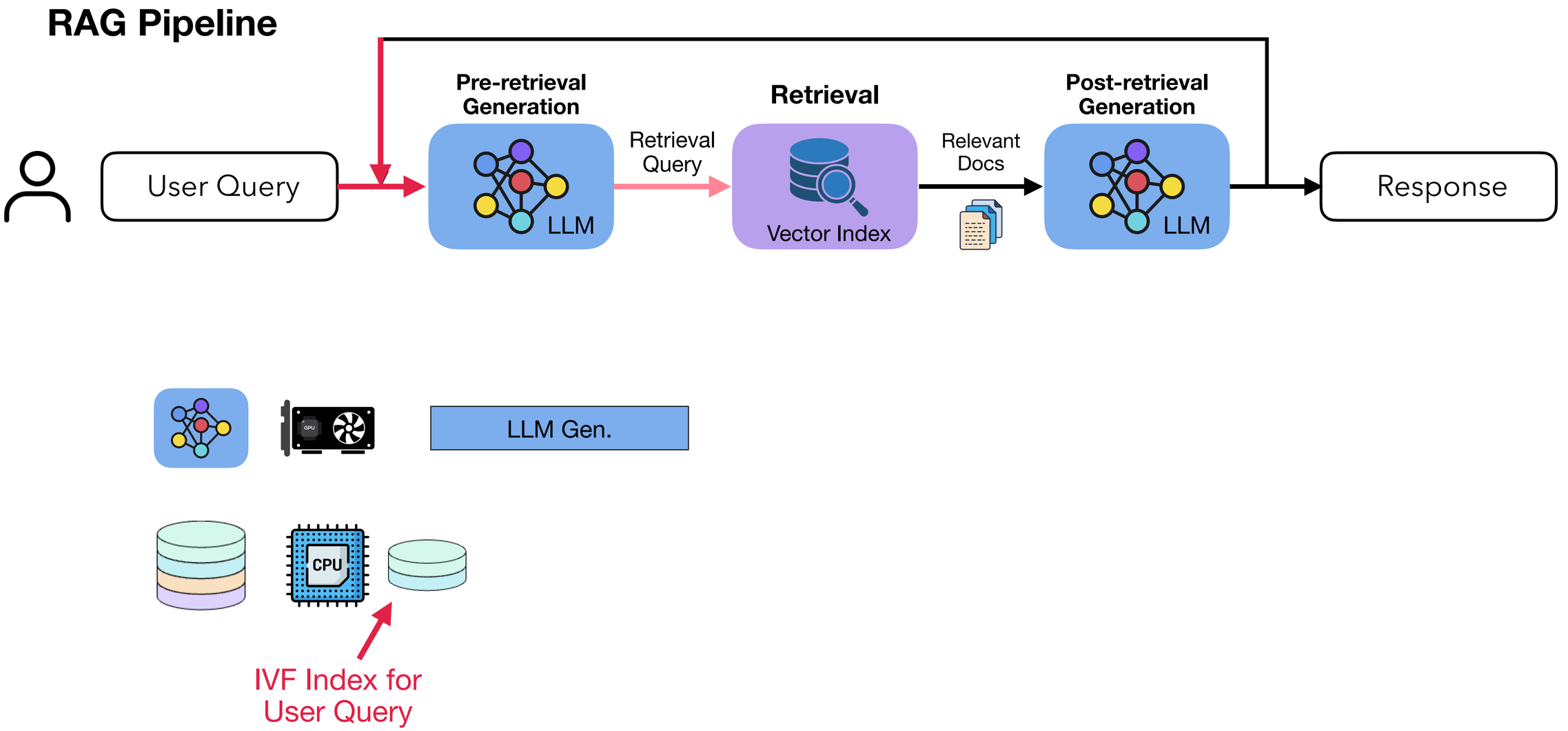

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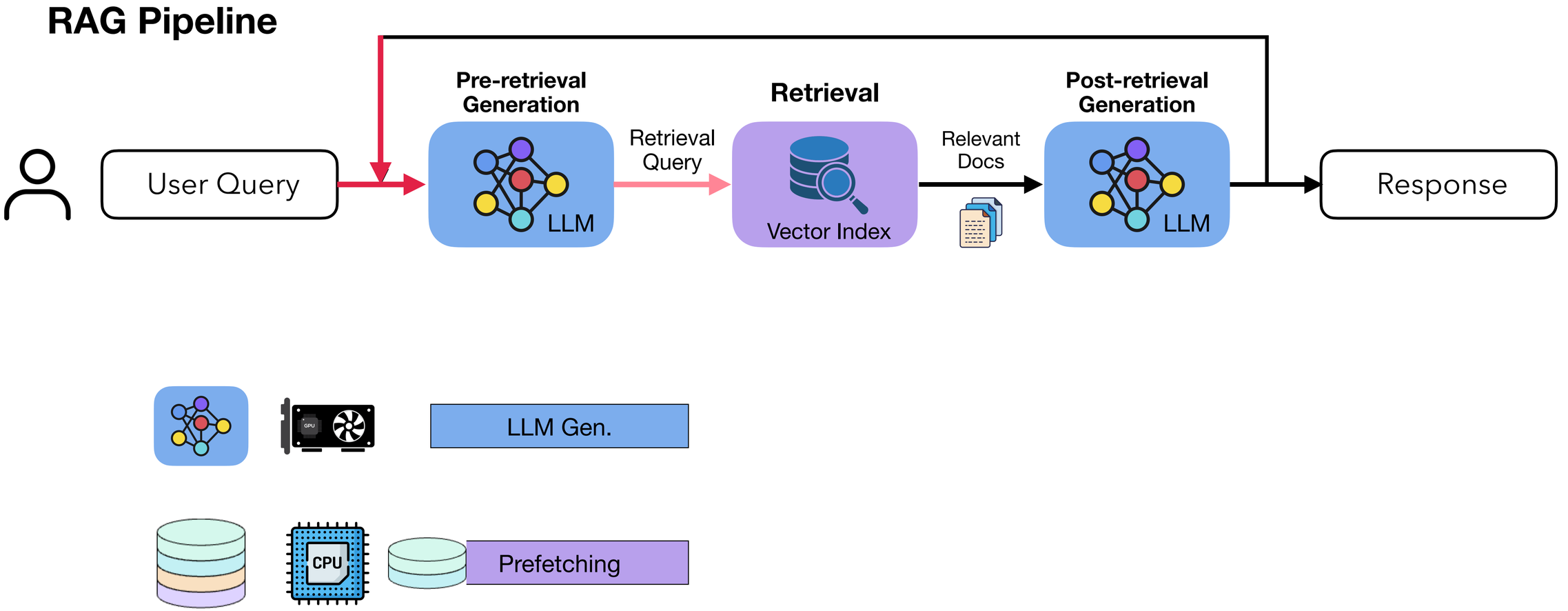

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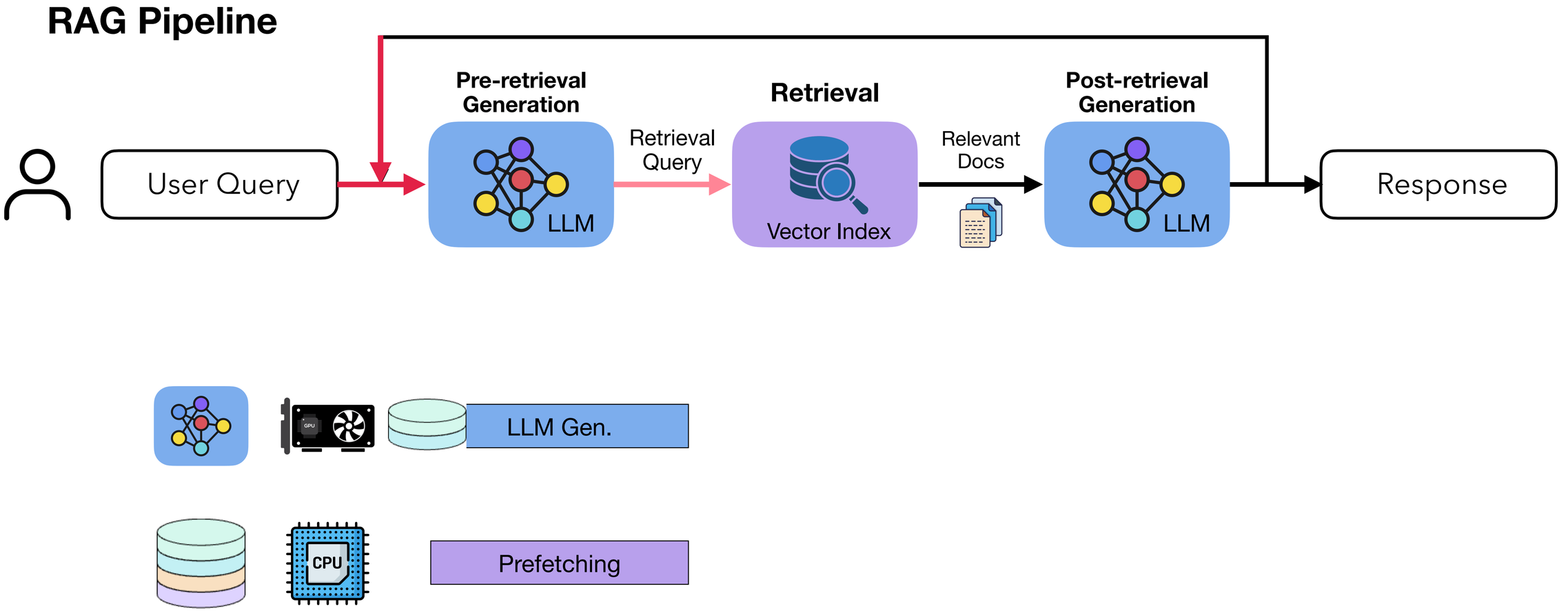

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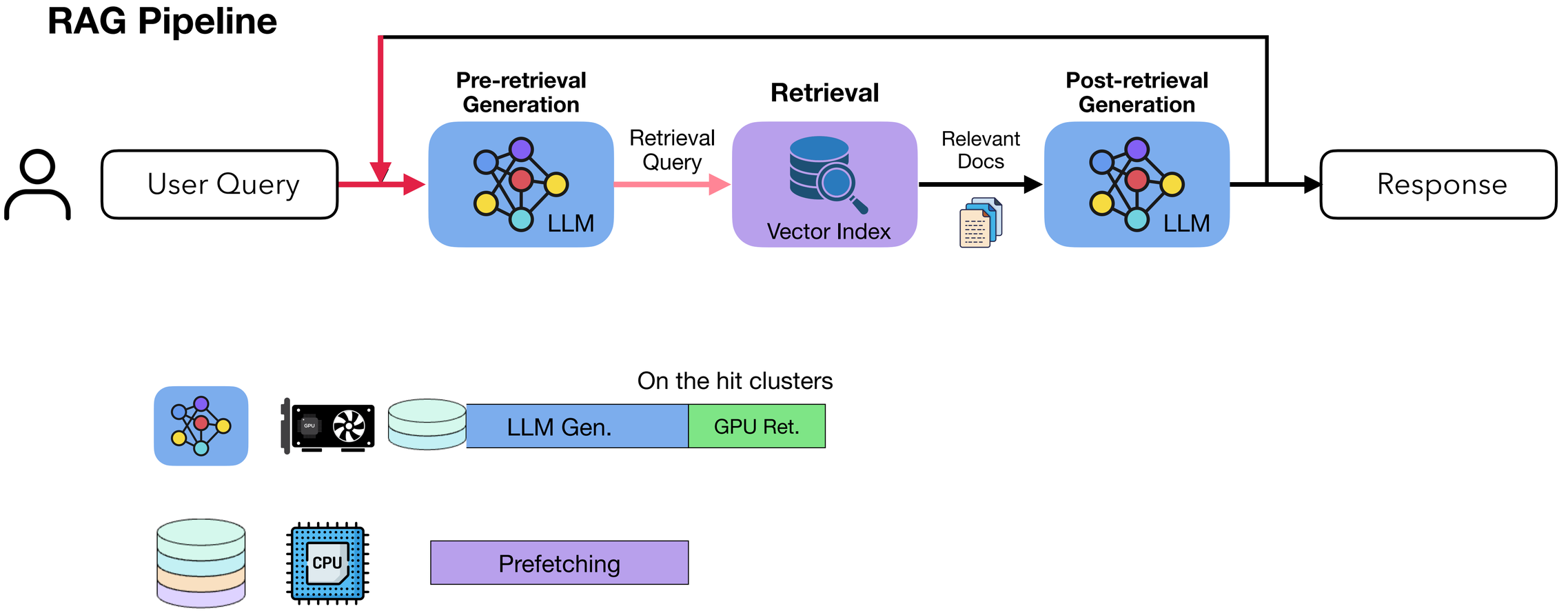

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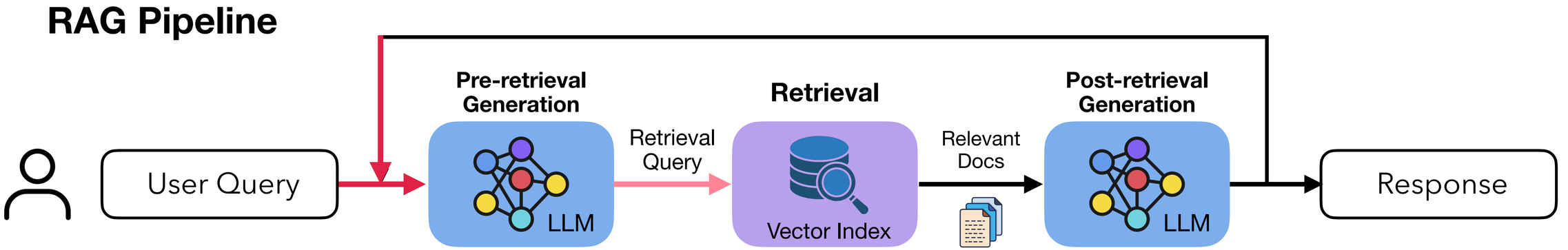

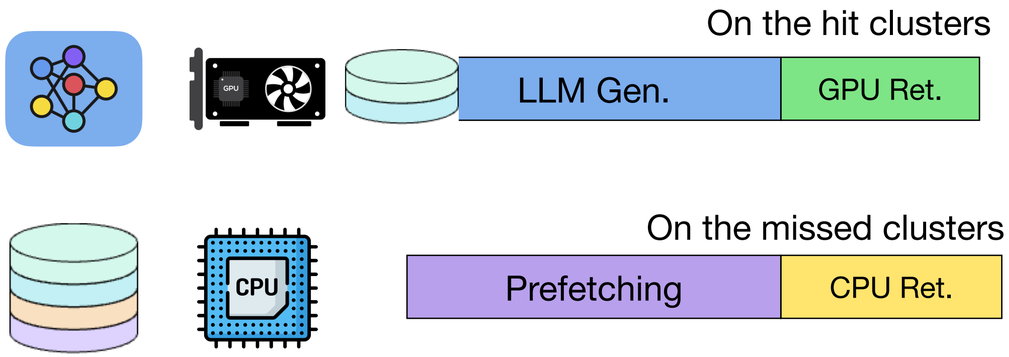

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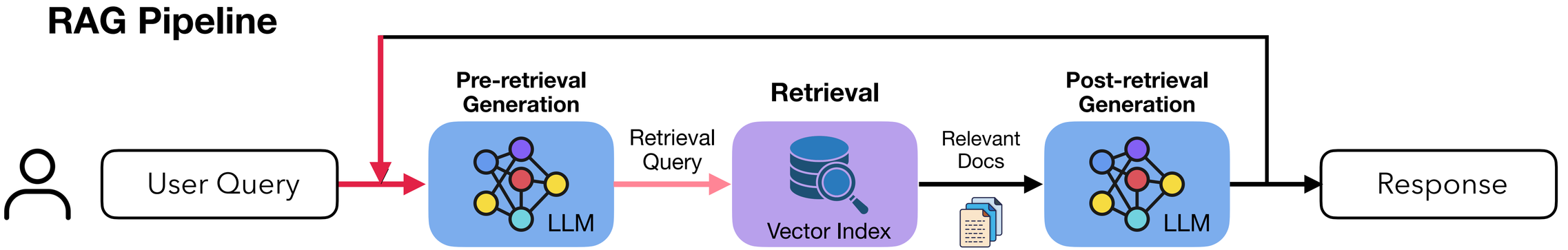

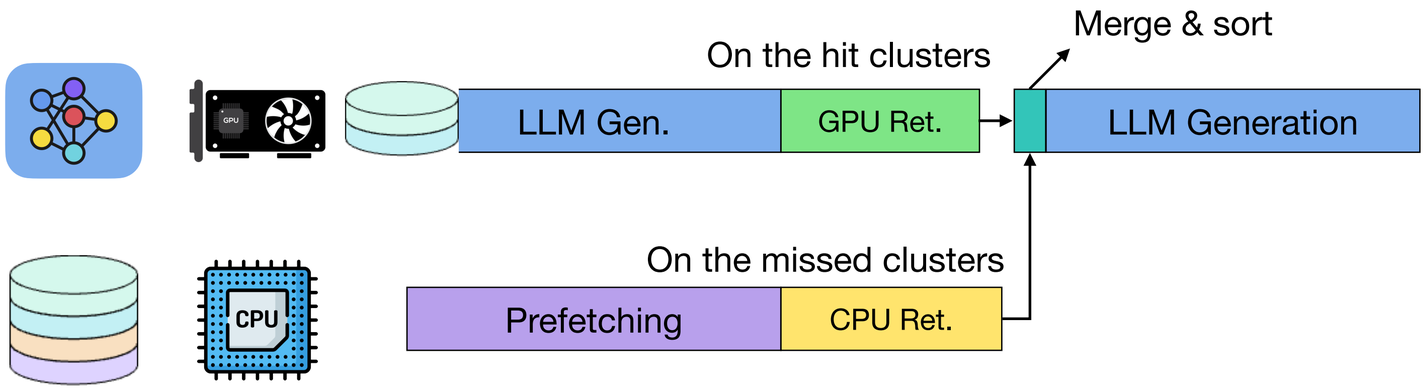

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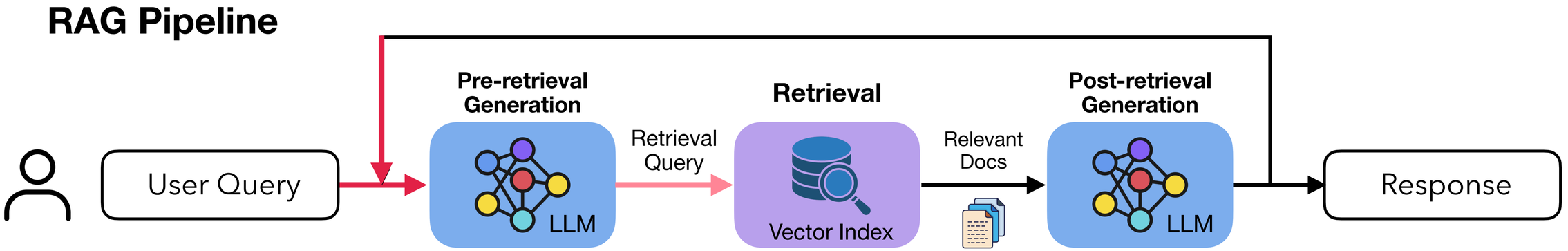
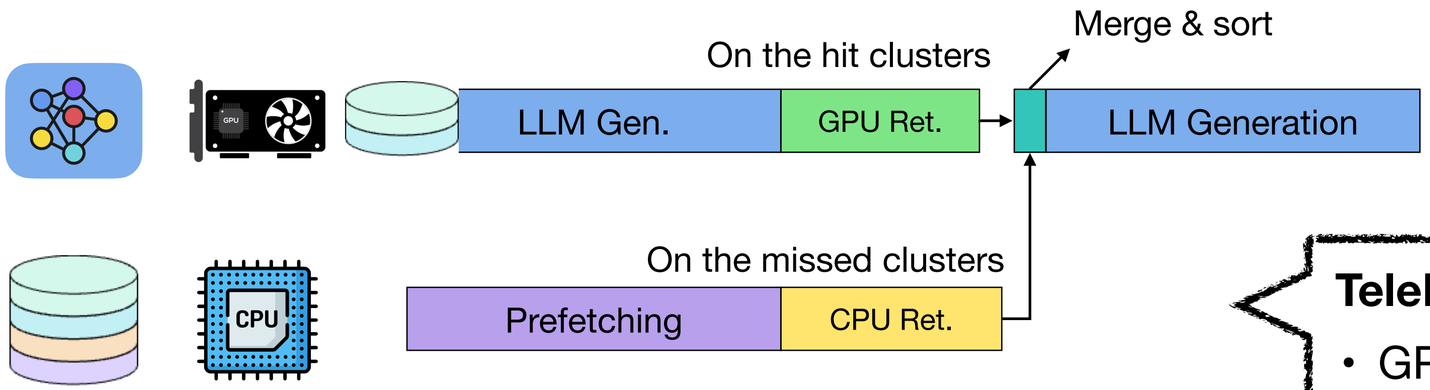
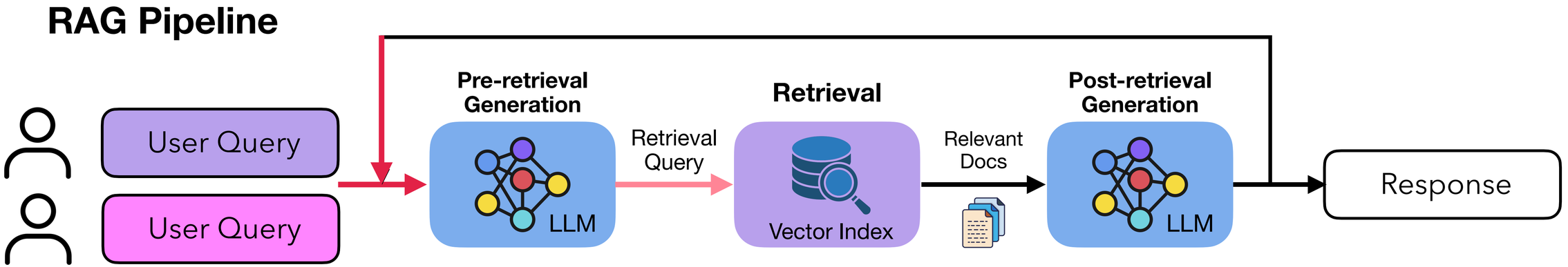


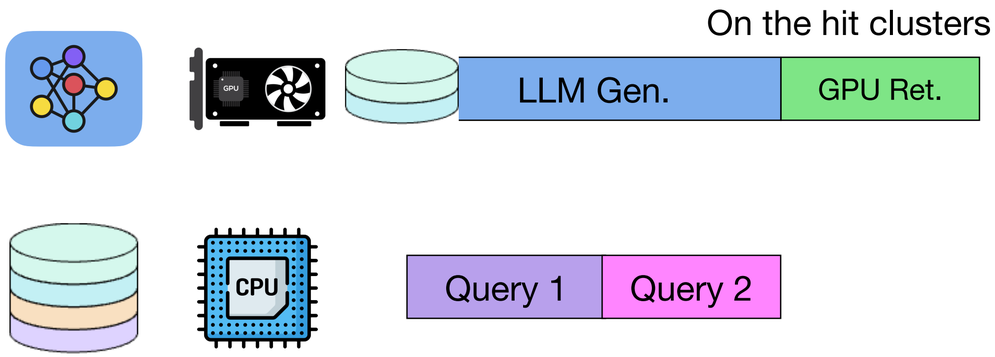


TeleRAG:

- GPU-like retrieval speed
- Minimal GPU memory requirement

Challenge of TeleRAG: Prefetching for Multi-Query

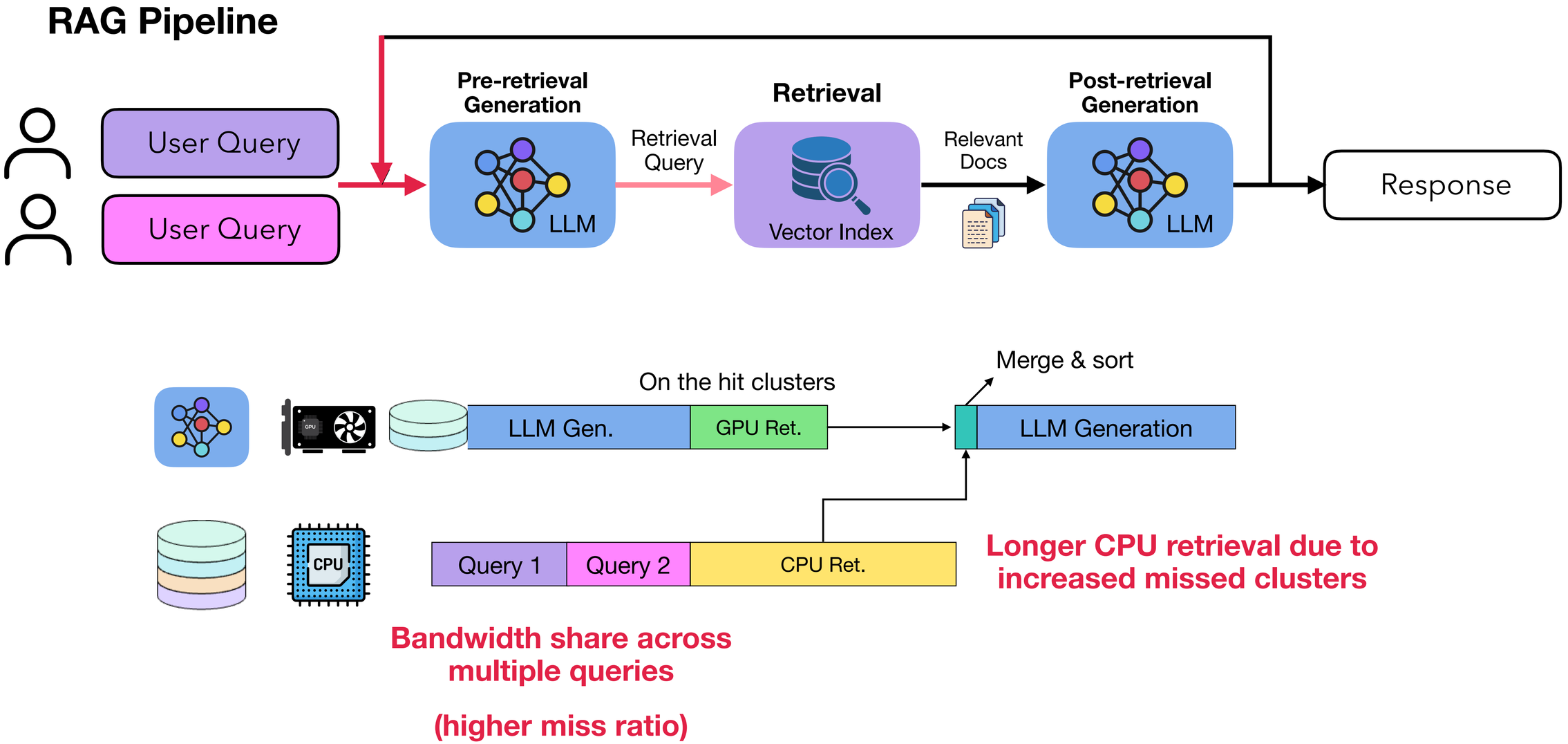




Bandwidth share across multiple queries

(higher miss ratio)

Challenge of TeleRAG: Prefetching for Multi-Query



TeleRAG: Batching (Prefetching Scheduler)

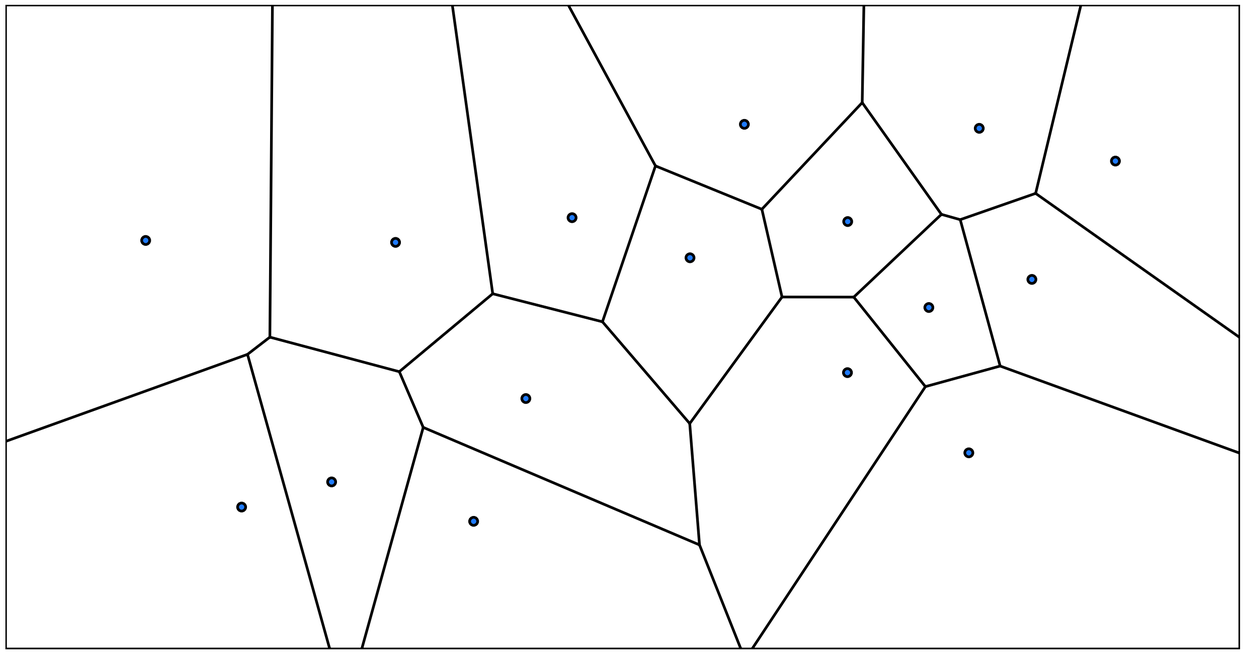
- Different queries can have diverse cluster sets

Query A

Query B

Query C

Query D



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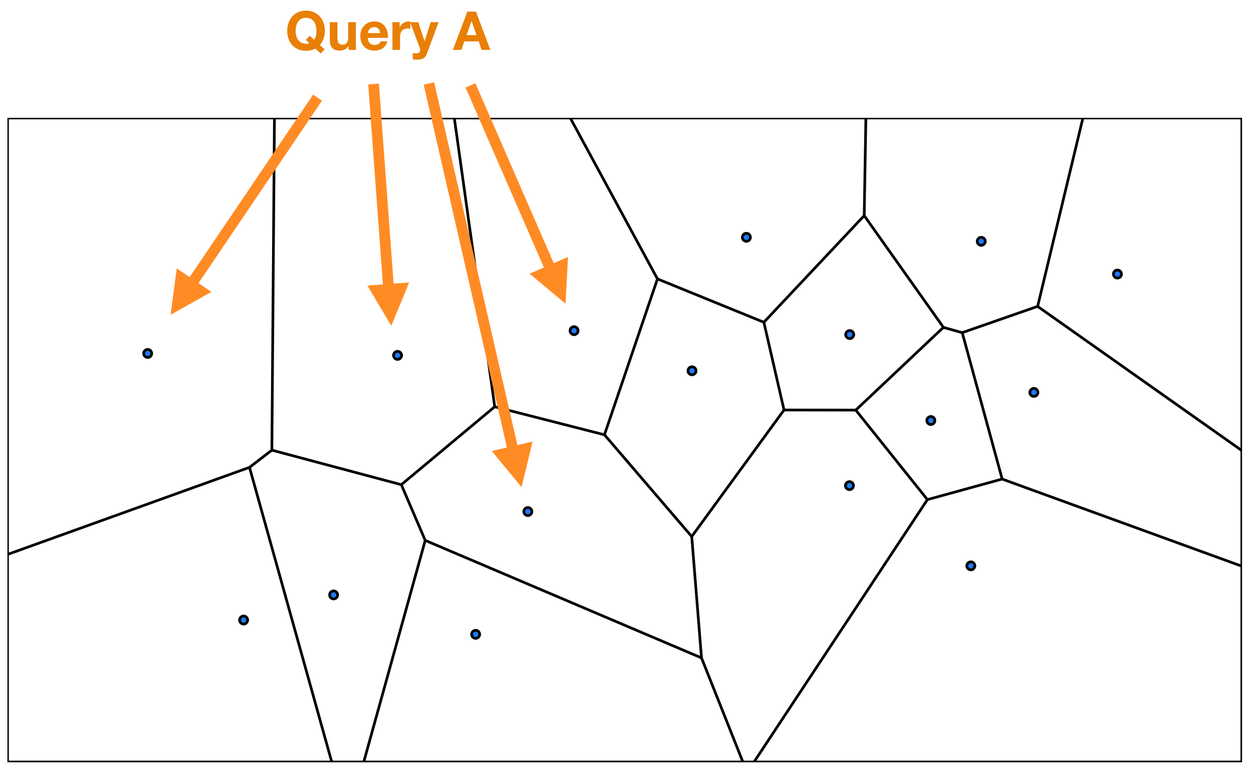

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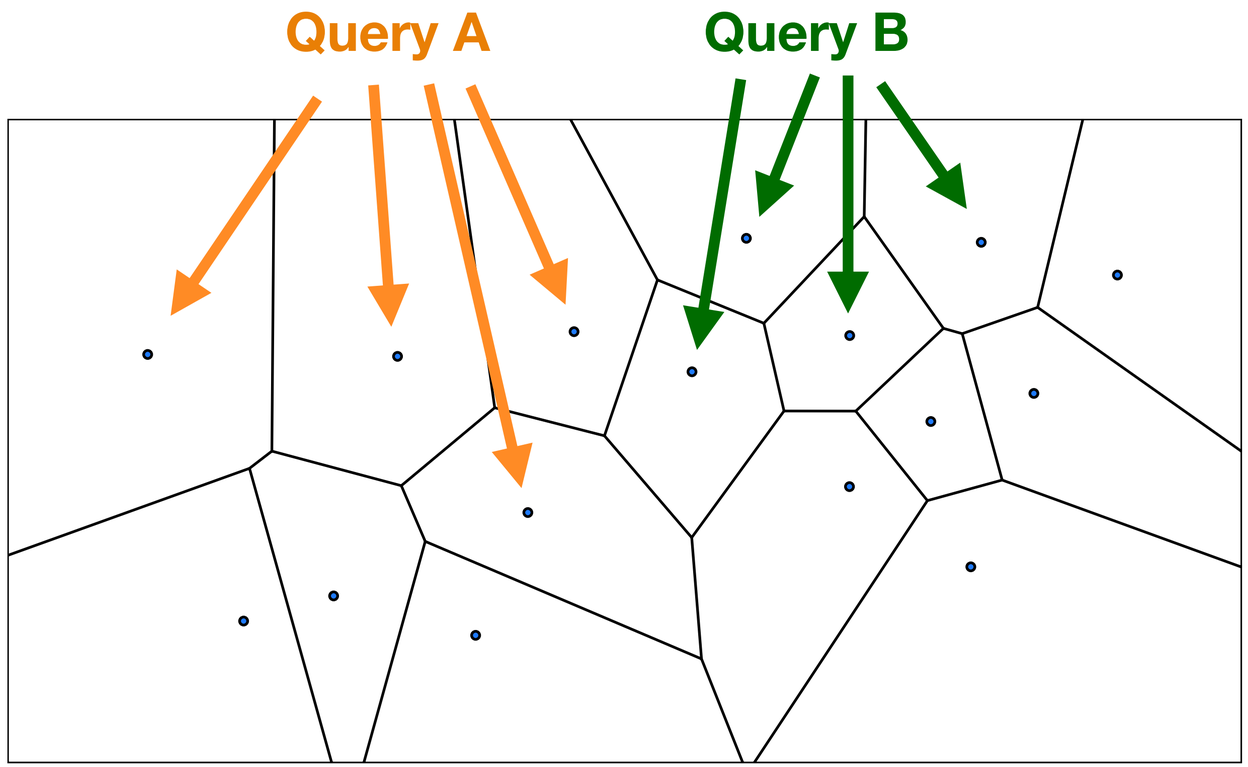
Query C

Query D



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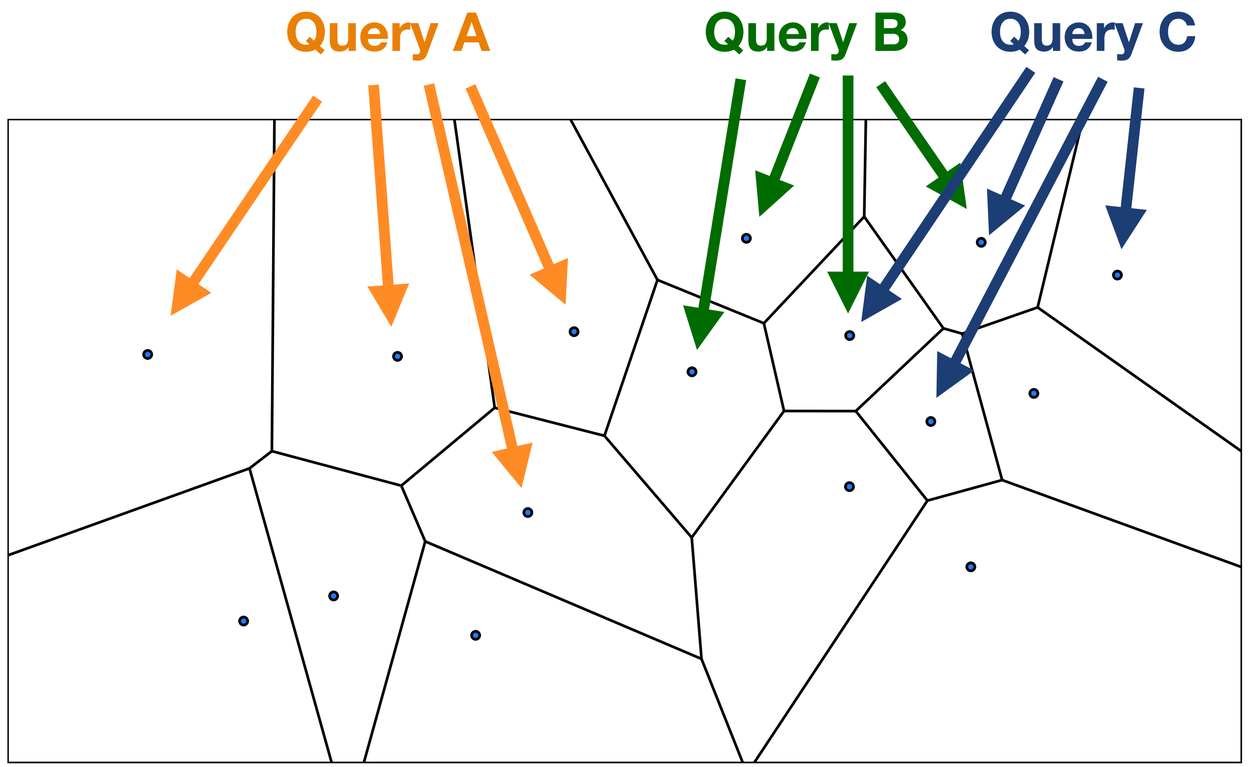

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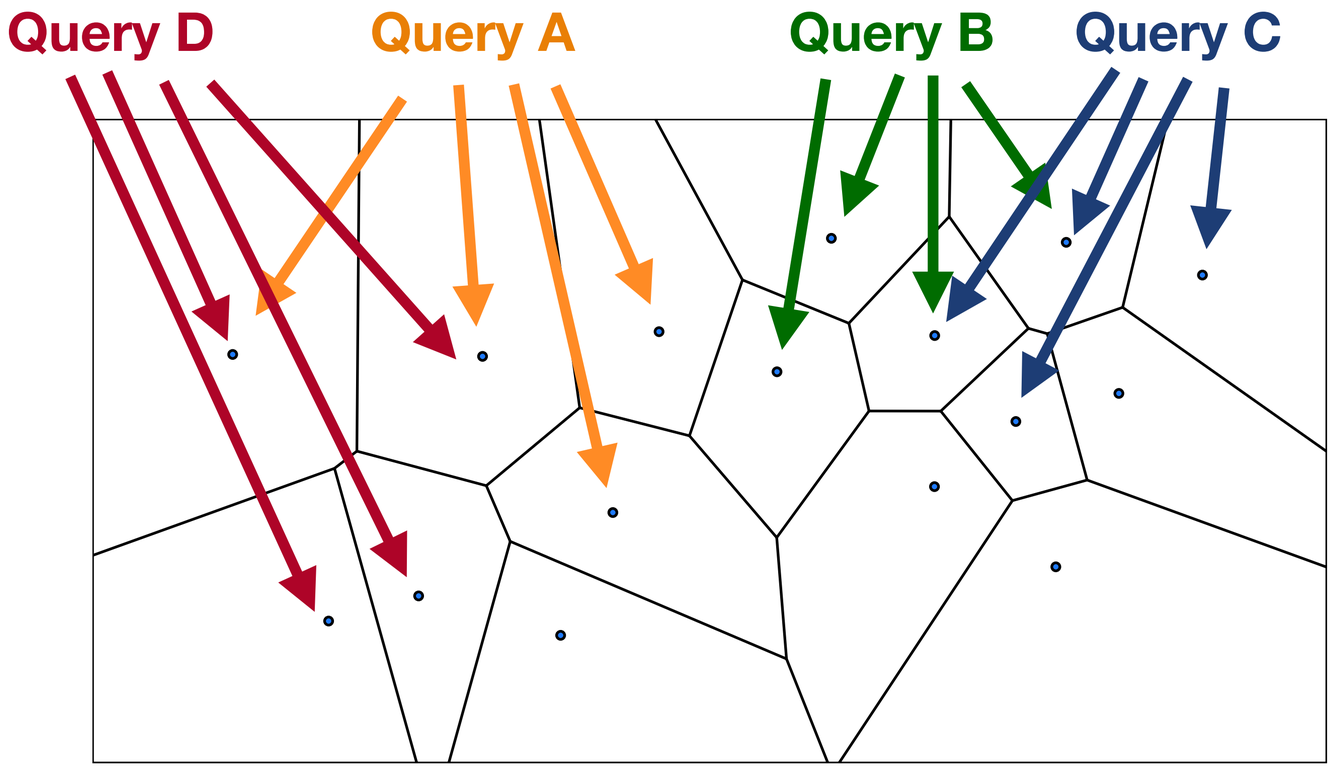

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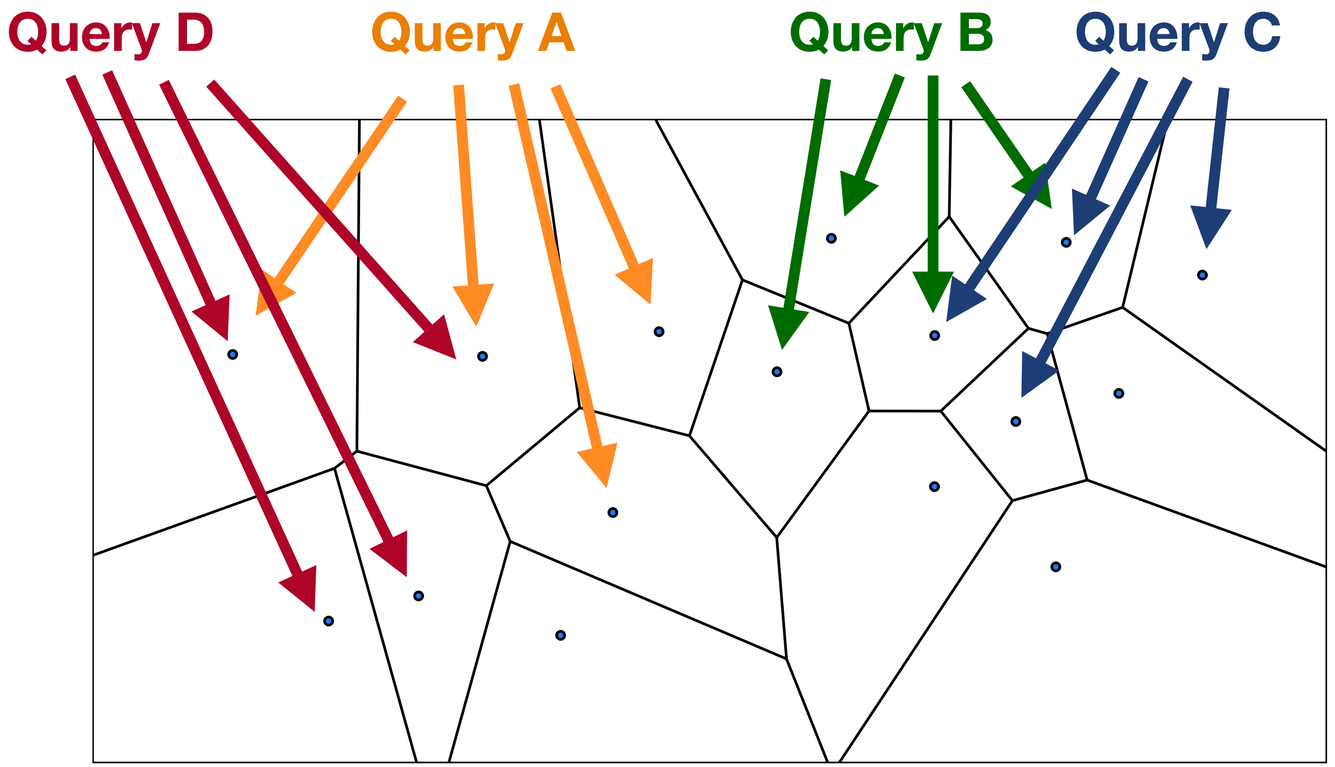
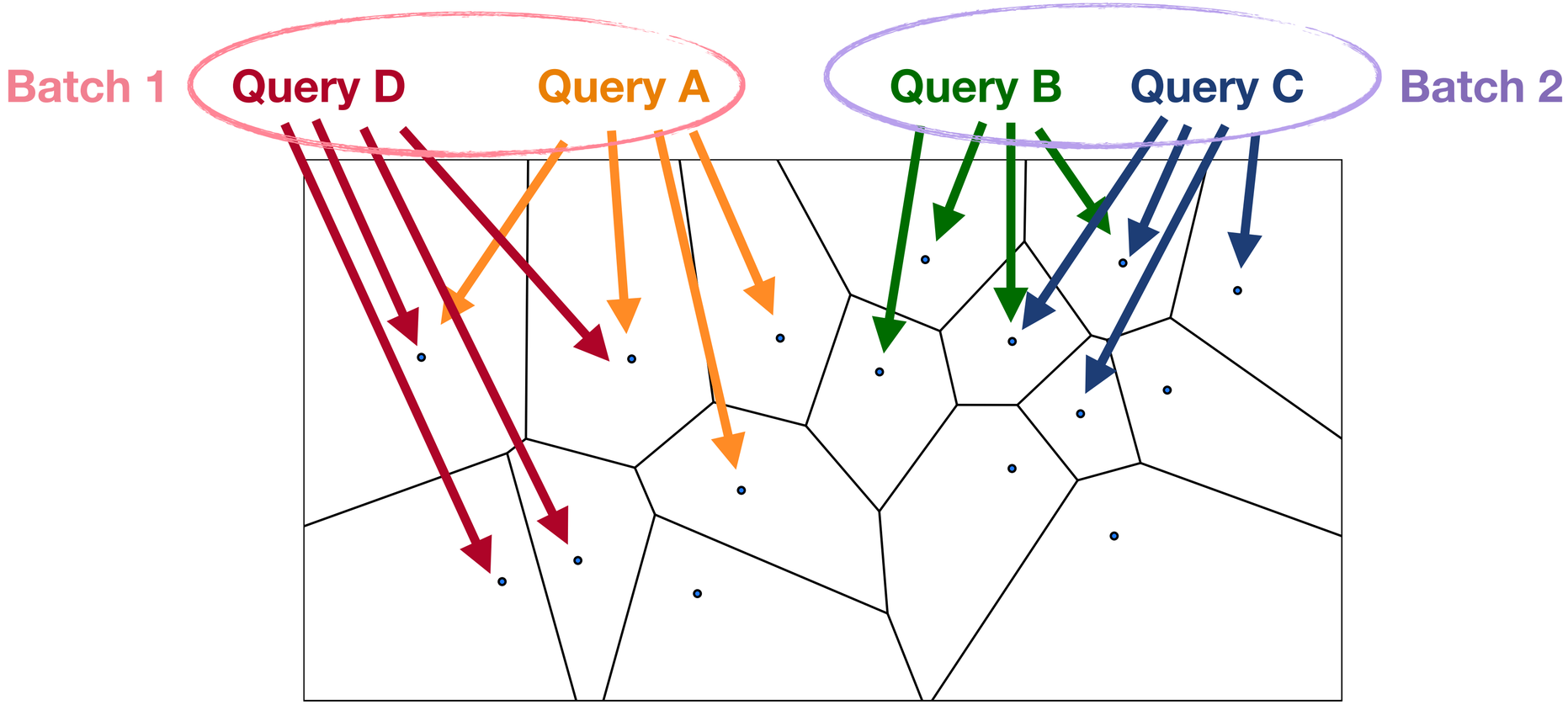


Ineffective batching strategies (e.g., pairing Query A with B, and Query C with D) can severely degrade prefetching performance.

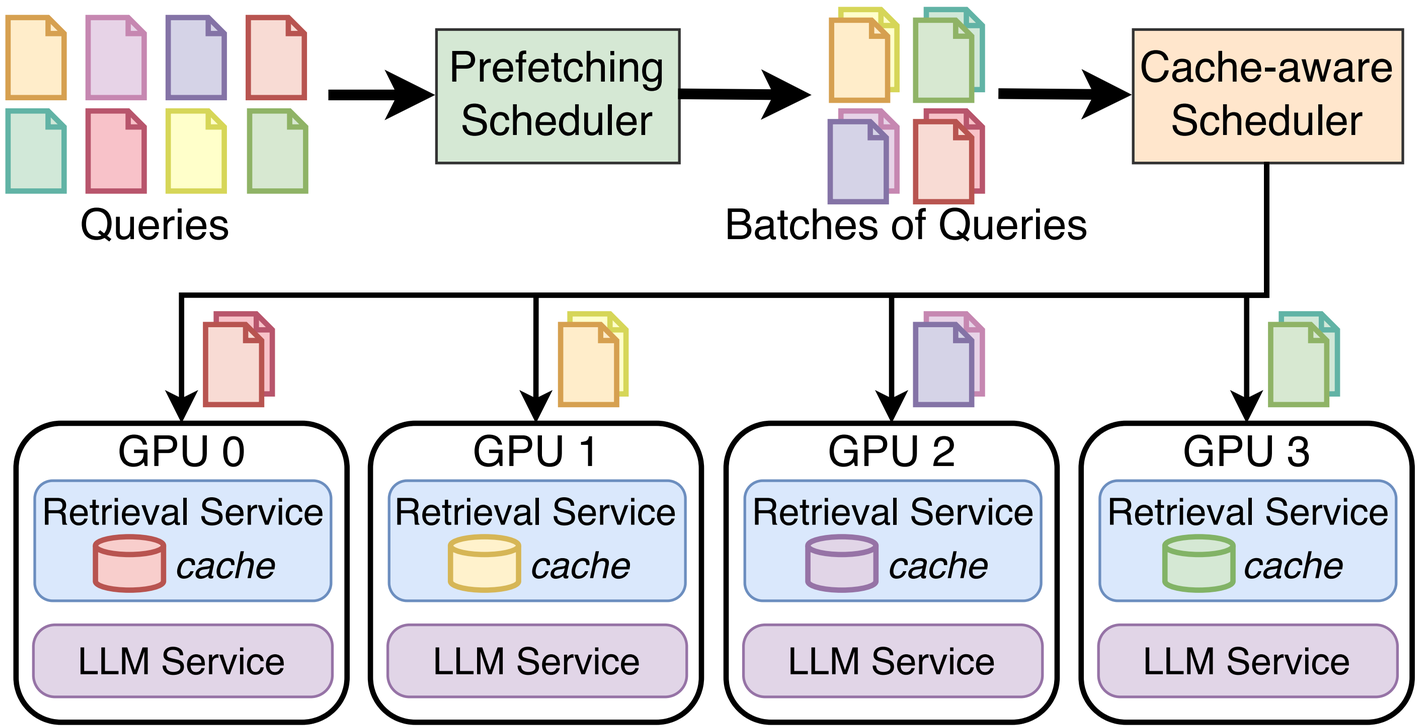
TeleRAG: Batching (Prefetching Scheduler)

- Different queries can have diverse cluster sets
- Solution: group queries with **higher semantic similarity**



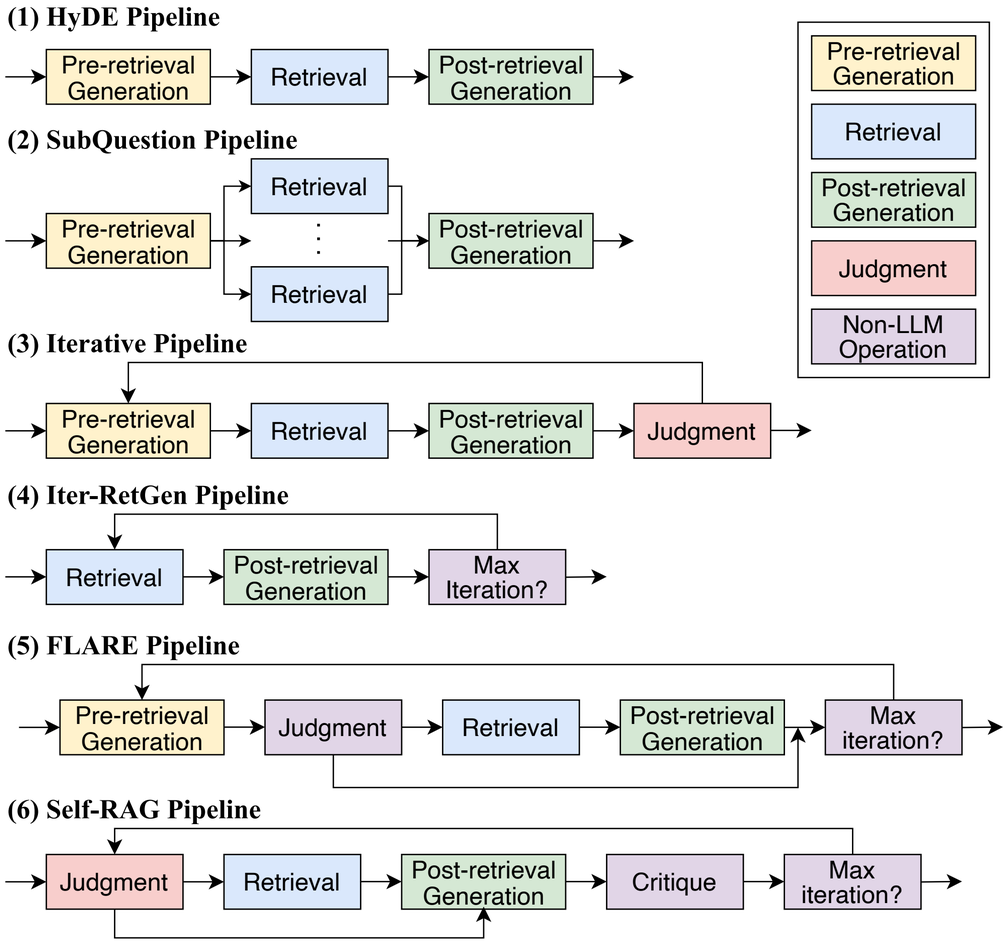
TeleRAG: Caching & Cache-aware Scheduling

- **Caching**: keep most frequently used IVF clusters in GPU memory
- **Cache-aware scheduling**: assign micro-batches based on cache locality



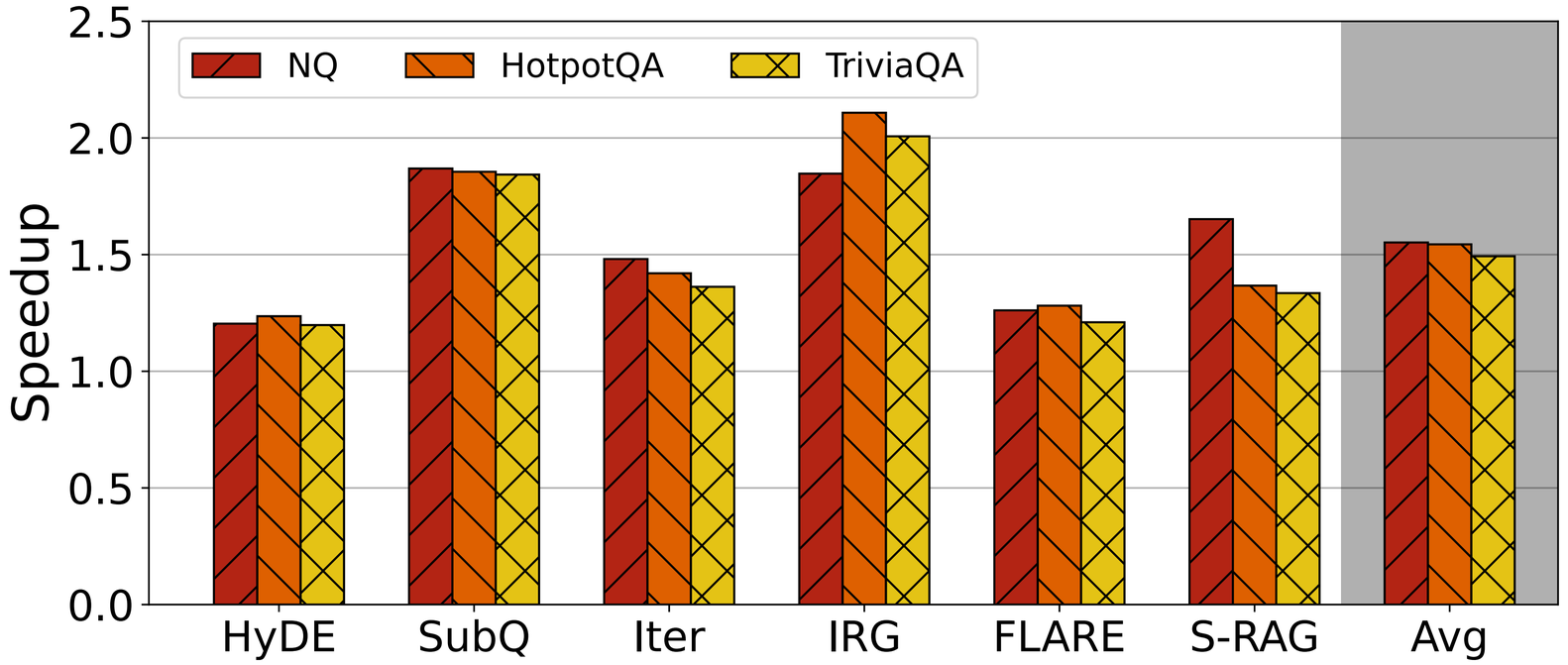
Evaluation Setup

- Evaluated on six representative RAG pipelines
- Retrieval index: 61GB IVF index with 4096 clusters
- Tested on three popular QA datasets:
  - NQ, TriviaQA and HotpotQA
- Baseline: Faiss-CPU + SGLang for LLM inference



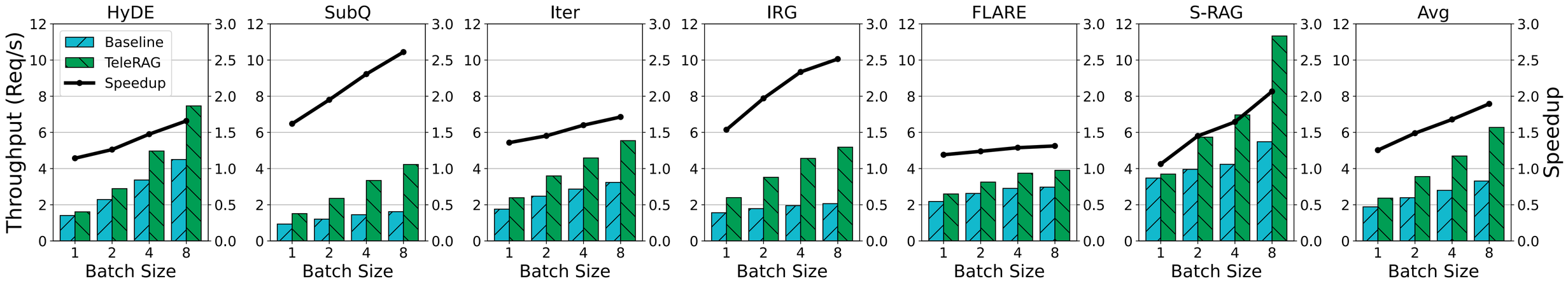
End-to-End Latency on RTX 4090 (24GB)

- With Llama3.2-3B LLM
- Over **1.5x** latency speedup on average



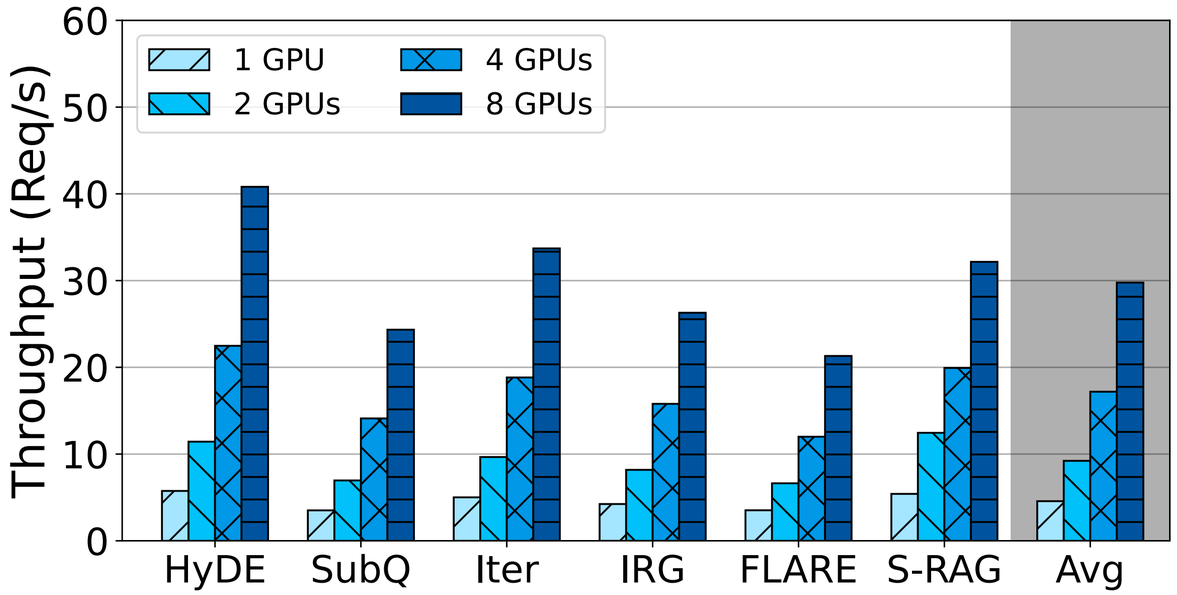
Throughput Enhancement on H100

- With Llama3-8B LLM on NQ dataset
- Increased throughput with a larger batch size
- Achieve 1.9x throughput increase at batch size 8 on average



Multi-GPU Scaling

- With Llama3-8B LLM on NQ dataset
- Evaluated on a 8-H200 node
- Strong scaling thanks to the prefetching and cache-aware schedulers



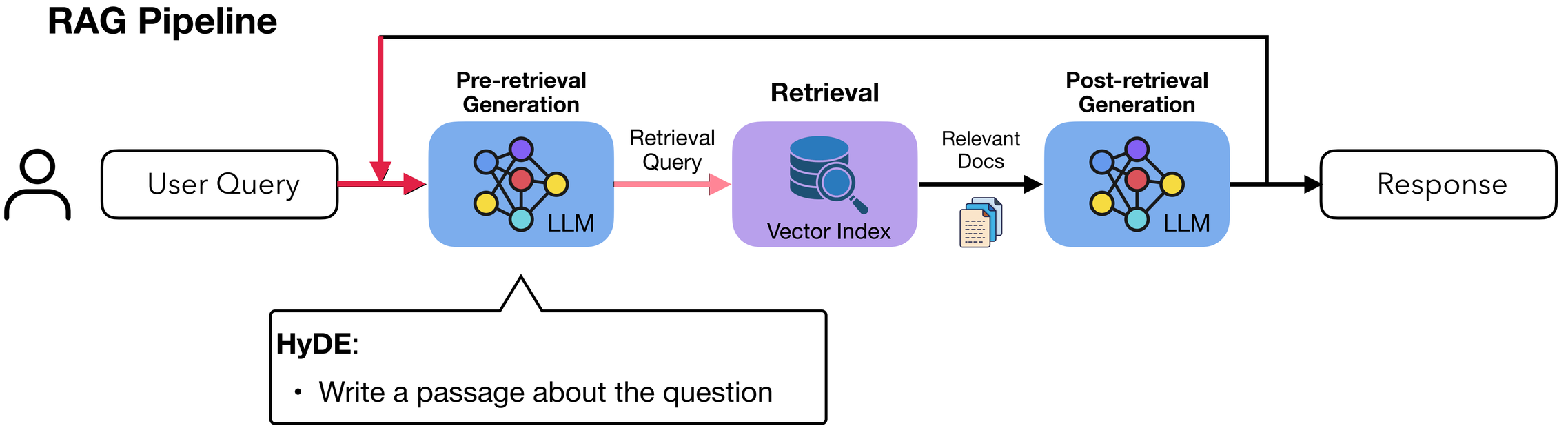
Conclusion

- We found **high similarity** between queries of **different stages** in RAG
- We proposed **lookahead retrieval** which prefetches IVF index data to GPU memory during LLM generation stage
- Alongside the lookahead retrieval, we designed optimizations for **batching, caching, and multi-GPU scheduling**
- With these, **TeleRAG** achieves high RAG performance from single to multi-GPU scenarios with reduced GPU memory usage

Q & A

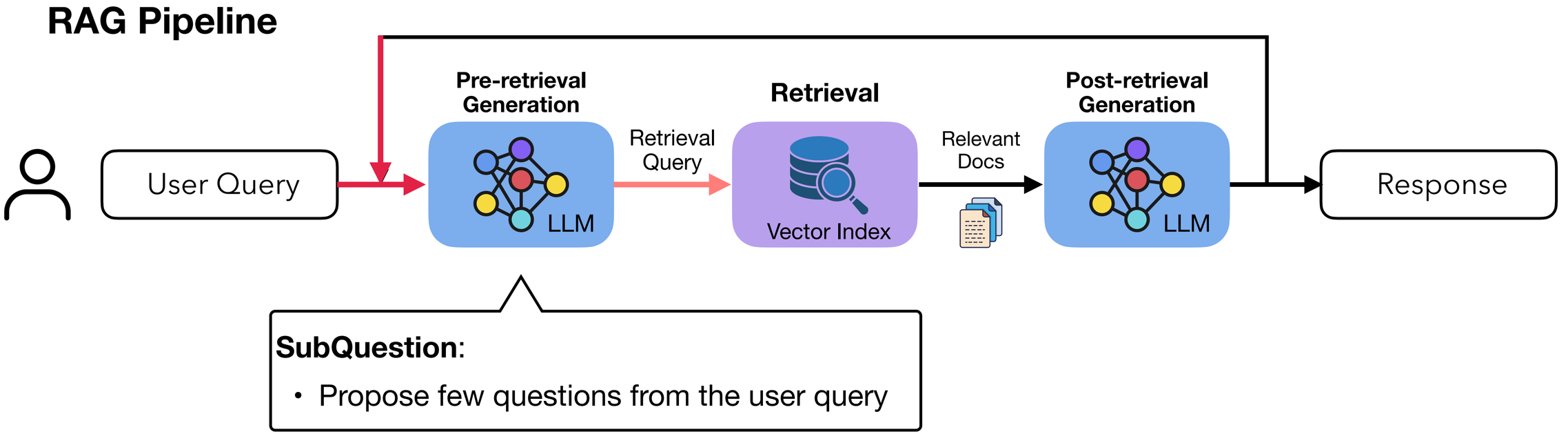
Appendix

Insight: Query Correlation Between Stages



Precise Zero-Shot Dense Retrieval without Relevance Labels, ACL 2023

Insight: Query Correlation Between Stages



https://docs.llamaindex.ai/en/stable/examples/query_engine/sub_question_query_engine/