

Agentic Architectures in Retrieval-Augmented Generation

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Problem & Motivation

Problem & Motivation



- Classical RAG can still hallucinate when retrieval is weak or incomplete.
- Retrieval is often one-shot; complex questions need **multi-step search**.
- Agentic approaches can **plan, reflect, debate, and adapt retrieval**.

Key idea: dynamic retrieval and multi-agent reasoning can improve grounding and answer quality.

- **Main question:** Do agentic RAG architectures reduce hallucination and improve answer quality vs vanilla RAG?
- Compare **single-agent** vs **multi-agent** and **iterative** vs **one-shot** retrieval.
- Evaluate across **controlled synthetic data** and **realistic benchmarks**.

Agentic RAG Architectures

Recent Papers - At a Glance



These papers illustrate different directions of agentic RAG: modular design, debate, and multimodal reasoning.

- **MA-RAG (2025)** – collaborative multi-agent RAG
(Planner/Step-Definer/Extractor/QA), on-demand agents, no fine-tuning; strong on multi-hop/ambiguous QA.
- **MADAM-RAG (2025)** – multi-agent debate to handle ambiguity, misinformation, and noise; introduces RAMDocs; strong gains on AmbigDocs and FaithEval.
- **HM-RAG (2025)** – hierarchical, multimodal RAG (decompose → parallel retrievers → decision fusion); plug-and-play sources (text/graph/web).
- **Survey: Agentic RAG (2025)** – taxonomy of reflection, planning, tool use, multi-agent collaboration; good figure for “space of methods”.

Agentic RAG Architectures (in this project)



- **vanilla** – single retrieval + answer
- **self_reflective** – answer → critique → refinement
- **query_decomposition** – split the question and aggregate partial answers
- **chain_of_verification** – verify extracted claims and rewrite with evidence
- **active_retrieval** – iterative query rewriting until sufficient context
- **marag** – Researcher → Analyst → Synthesizer
- **madam_rag** – debate + moderator for conflict resolution
- **routing** – choose the best pipeline per question

Note: all architectures share the same retrieval stack.

Implementation

Implementation & Stack



- Python, modular pipeline in `src/`
- LLM providers: OpenAI / Gemini (configurable)
- Retrieval: hybrid dense + lexical, optional reranker
- Metrics: keyword & semantic precision/recall, grounding score, latency, tokens
- Experiment runner: `scripts/run_experiments.py` (YAML-driven)

Synthetic “Future Poland” dataset (controlled)



Purpose: ensure the model **cannot answer from pre-trained knowledge**.

Documents were intentionally crafted with cross-references, subtle contradictions, and multi-hop dependencies.

A generator agent was implemented to create the source files; each file contained deliberate inconsistencies or links to other files, and each document was constrained to a target length.

Files contained information about the future of Poland (2025-2125). Each file contained 1000-2000 words. Topics: e.g. Energy Transformation, Education Reform, AI Expansion.

| Artifact | Description |
|----------------|---|
| raw/*.md | Handwritten knowledge base |
| questions.json | JSON with questions and reference answers |
| chunks.json | Chunked corpus used for retrieval |

Synthetic Dataset Creation Process



- 1 Design themes** (policy timeline + sports domains)
- 2 Write source docs** with cross-references and contradictions
- 3 Create QA pairs** to cover multi-hop, fact-checking, routing stress tests
- 4 Chunking** with overlap + embedding index
- 5 Evaluation pipeline** built for reproducible experiments

Why: ensures that answers are grounded in provided documents, not LLM memory.

Benchmark dataset (external)



Source: [Hugging Face rag-datasets](#)

Converted to local `benchmark_files/*.md` + `benchmark_questions.json`.

Scale: **3,200** Markdown files and **918** questions.

Each file is a single Wikipedia paragraph, covering diverse topics (geography, history, sports, etc.).

This setting is harder for retrieval because the corpus is much larger and thematically broader.

Why benchmark? To test if agentic pipelines generalize beyond synthetic data.

Experimental Setup



- Configured through YAML (`configs/experiment.yaml`)
- Runs each architecture for each question
- Asynchronous execution with checkpoints

Metrics:

| Metric | Meaning |
|-----------------------------|--|
| Keyword precision/recall@k | lexical overlap with retrieved chunks |
| Semantic precision/recall@k | embedding similarity to answer |
| Grounding score | token overlap between answer and context |
| Latency / Tokens | efficiency & cost proxy |

Results

Results - Future Poland

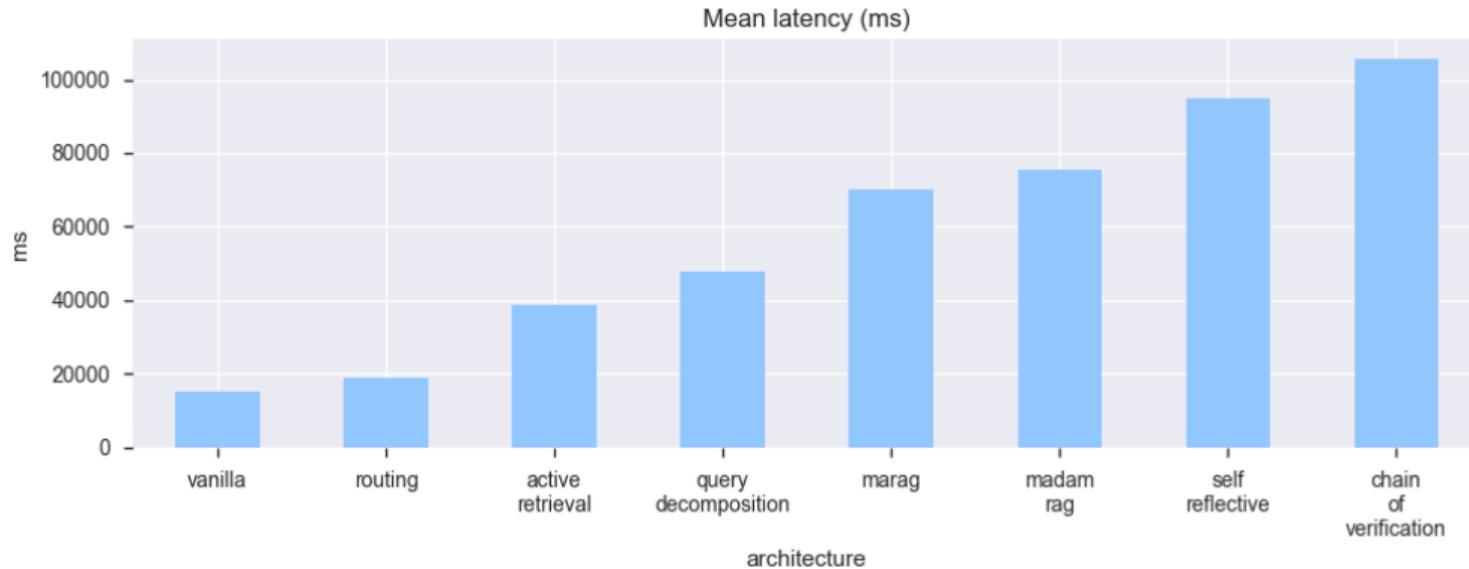


Figure 1: Future Poland: Latency

Results - Future Poland

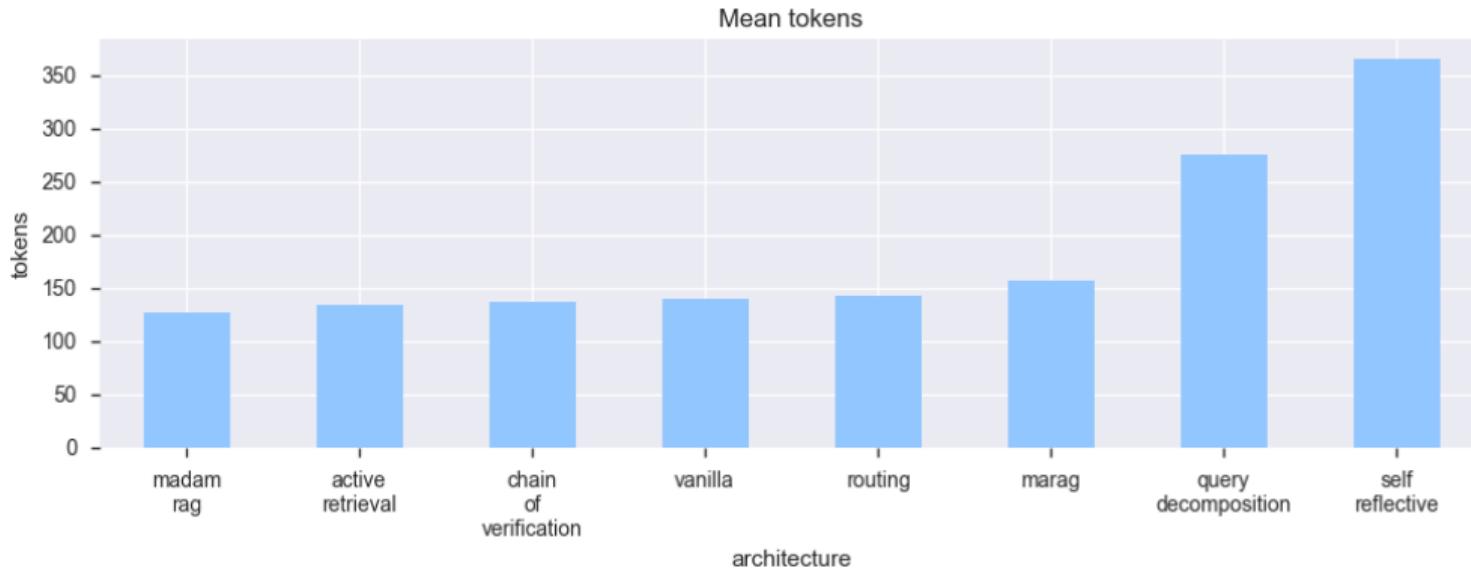


Figure 2: Future Poland: Mean Tokens

Results - Future Poland

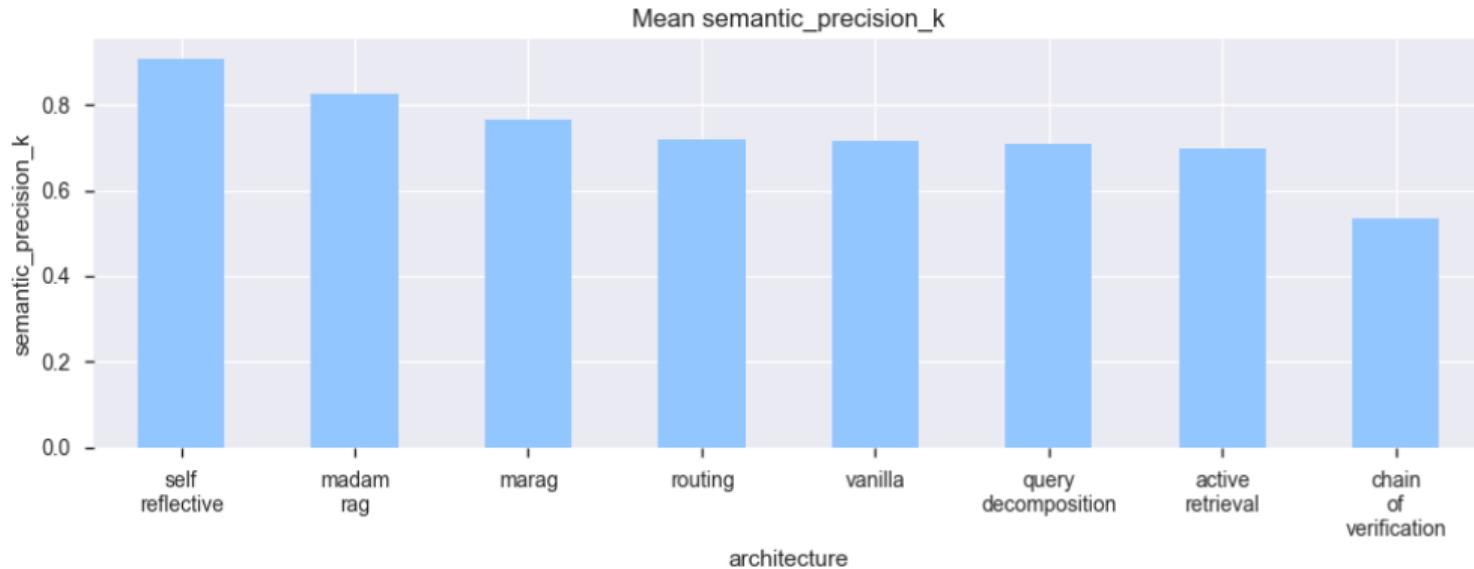


Figure 3: Future Poland: Mean Tokens

Results - Future Poland

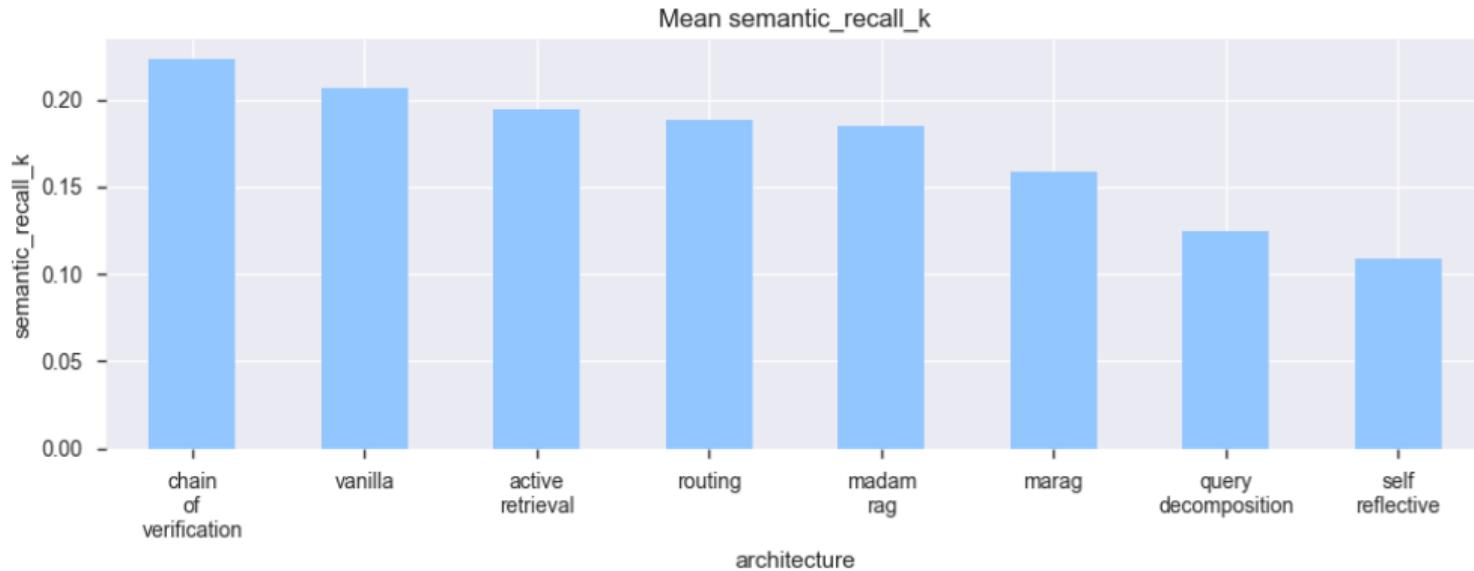


Figure 4: Future Poland: Mean Tokens

Results - Future Poland



Comparison by precision, recall, and grounding score: the number of times each agent was best across these metrics was counted.

| architecture | best_count |
|-----------------------|------------|
| self_reflective | 23 |
| marag | 19 |
| active_retrieval | 14 |
| routing | 13 |
| vanilla | 10 |
| chain_of_verification | 8 |
| madam_rag | 7 |
| query_decomposition | 6 |

Results - Future Poland

A ranking was also computed for each question, and `np.log(s).sum` was calculated, where `s` is the rank position for that question.

The log reduces the impact of extreme low ranks, and the sum yields a single aggregate score across all questions.



| architecture | place_product_logsum |
|-----------------------|----------------------|
| marag | 106.188469 |
| self_reflective | 110.169673 |
| active_retrieval | 121.567201 |
| vanilla | 122.350255 |
| routing | 127.495255 |
| madam_rag | 147.584518 |
| query_decomposition | 156.248498 |
| chain_of_verification | 161.094112 |

Results - Future Poland



Average rank (lower is better) was computed per question type for each architecture.
Cells with **1.0** mark the best result for a given question type.

| architecture | abstractive sum- mary | aggregation reason- ing | causal reason- ing | comparative reason- ing | conflict resolu- tion | counter- factual | multi- hop factual | temporal reason- ing | vanilla factual |
|--------------|-----------------------------|-------------------------------|--------------------------|-------------------------------|-----------------------------|---------------------|--------------------------|----------------------------|--------------------|
| AR | 4.0 | 5.0 | 5.0 | 5.0 | 3.0 | 2.0 | 6.0 | 4.0 | 2.0 |
| CoV | 7.0 | 8.0 | 6.0 | 7.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| MADAM | 8.0 | 5.0 | 7.0 | 3.0 | 7.0 | 4.0 | 5.0 | 5.0 | 7.0 |
| MARAG | 1.0 | 2.0 | 1.0 | 1.0 | 2.0 | 5.0 | 1.0 | 1.0 | 3.0 |
| QD | 6.0 | 5.0 | 8.0 | 8.0 | 4.0 | 7.0 | 7.0 | 5.0 | 6.0 |
| Routing | 2.0 | 4.0 | 4.0 | 2.0 | 5.0 | 5.0 | 4.0 | 5.0 | 1.0 |
| SR | 5.0 | 1.0 | 3.0 | 4.0 | 1.0 | 1.0 | 2.0 | 2.0 | 5.0 |
| Vanilla | 3.0 | 2.0 | 2.0 | 6.0 | 5.0 | 3.0 | 3.0 | 3.0 | 4.0 |

Results - Benchmark



The benchmark questions were generally simpler (e.g. "What is the largest religious group in Canada?"), and despite a larger number of chunks being searched, responses were produced faster and at lower cost; precision was lower while recall was higher, which indicates broader retrieval coverage with more noise.

Results - Benchmark

Lower values indicate better overall ranking (log-sum of per-question ranks); `vanilla` and `self_reflective` were the strongest on this benchmark.



| architecture | place_product_logsum |
|------------------------------------|----------------------|
| <code>vanilla</code> | 17.945994 |
| <code>self_reflective</code> | 18.505610 |
| <code>active_retrieval</code> | 20.649590 |
| <code>marag</code> | 20.852531 |
| <code>routing</code> | 24.918288 |
| <code>madam_rag</code> | 30.666406 |
| <code>chain_of_verification</code> | 31.793606 |
| <code>query_decomposition</code> | 36.884528 |

Conclusions & Future Work

- Agentic gains are strongest when the corpus is hard (conflicts, multi-hop); for simple facts, vanilla can be best.
- Self_reflective and marag deliver the highest grounding on the synthetic set, so critique/structure improves evidence anchoring.
- On the benchmark, iterative strategies don't consistently beat vanilla — diminishing returns are visible.
- Agentic cost is higher and less predictable, so routing and iteration caps are crucial for budget stability.
- There is room to improve routing (better difficulty classification, retrieval profile selection, dynamic limits).
- Chain_of_verification underperforms relative to other architectures and isn't a quality leader; its use should be limited to cases that specifically need claim verification.

- RAG performance on large datasets was difficult to evaluate reliably, and no single metric was found to be sufficient.
- Benchmark questions were often simple, which limited the stress on advanced agent behavior.
- Cost and latency increased sharply for deeper multi-agent pipelines.

Future Work



- Larger and more diverse synthetic datasets should be created.
- Stronger automatic evaluation (e.g., RAGAS, factuality) should be explored.
- Smarter routing should be refined to balance quality and token cost.

Thank you for your attention

Questions

References

- MA-RAG (2025): collaborative multi-agent RAG (Planner/Step-Definer/Extractor/QA), on-demand agents, no fine-tuning; wins on multi-hop and ambiguous QA. <https://arxiv.org/abs/2505.20096>
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<https://arxiv.org/abs/2504.12330>
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<https://arxiv.org/abs/2501.09136>
- RAG datasets: Hugging Face rag-datasets hub.
<https://huggingface.co/rag-datasets>

References

