

Retrieval-Augmented Generation and LLM Agents for Biomimicry Design Solutions

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March 25, 2024

AAAI-MAKE at Stanford University



Introduction

- ▶ **Biomimicry:** practice of designing engineering solutions inspired by biological phenomena.
- ▶ Barriers of Biomimicry:
 - ▶ Finding plausible biological strategies
 - ▶ Extending biological strategies to engineering solutions
- ▶ **Solution:** Streamline literature review process and biological abstraction cycle by developing **BIDARA:** an LLM-based, Bio-Inspired Design And Research Assistant.

Introduction (cntd.)

- ▶ Issues with LLMs:
 - ▶ Incorrect Information
 - ▶ Outdated Information



Unrelated author

Vinet, A., & Henrion, M. (2012). Aerodynamics of the Ariane-5 fairing: from experiments to computations. Journal of Spacecraft and Rockets, 49(2), 227-235.
<https://arc.aiaa.org/doi/abs/10.2514/1.A32117>

Your search - "Aerodynamics of the Ariane-5 fairing: from experiments to computations." - did not match any articles.

Paper does not exist

URL links to unrelated paper

Gravity Recovery and Interior Laboratory Simulations of Static and Temporal Gravity Field

Ryan S. Park, Sami W. Jassar, Eugene G. Falwick, Alan S. Konoplin, Wenshen Lu and Mike M. Watkins
Published Online: 9 Sep 2013 • <https://doi.org/10.2514/1.A32117>



- ▶ Some solutions include COT Prompting, Retrieval-Augmented Generation, LLM Agents.

Experiments

- ▶ **Retrieval-Augmented Generation (RAG):** Accessing data outside an LLM, and then prompting the LLM with that data.
- ▶ **LLM Agent:** LLM is given a list of descriptions of tools to use, and decides which tool to use, following the zero-shot ReAct framework.
- ▶ Experiment Settings:
 - ▶ Zero-Shot Prompting LLM
 - ▶ Few-Shot Prompting LLM with RAG
 - ▶ LLM Agent
 - ▶ LLM Agent with RAG
- ▶ Explore to what extent RAG helps in each setting.

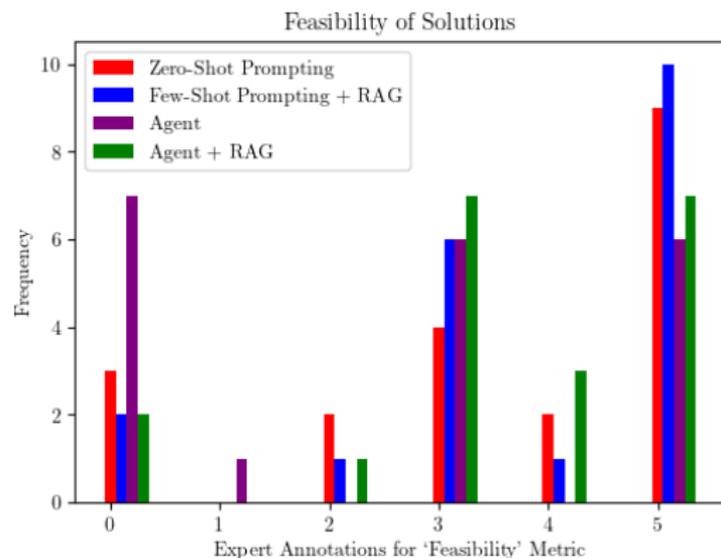
Experiment Modules

- ▶ Prompting:
 - ▶ LLM prompted to generate design solution using the Biomimicry Design Toolbox.
- ▶ LLM Agent:
 - ▶ LLM prompted to generate design solution using the steps from Biomimicry Design Toolbox as tools.
- ▶ RAG:
 - ▶ Uses Semantic Scholar API to retrieve papers.
 - ▶ Title and abstract of top- k papers appended to prompt.
 - ▶ Setting $k = 2$ is max value of k that consistently fits within context window.

Evaluation

- ▶ Human annotators (expert biomimicry practitioners) label a test set.
- ▶ Asked to score solutions in terms of feasibility and novelty on a score of 0-5.

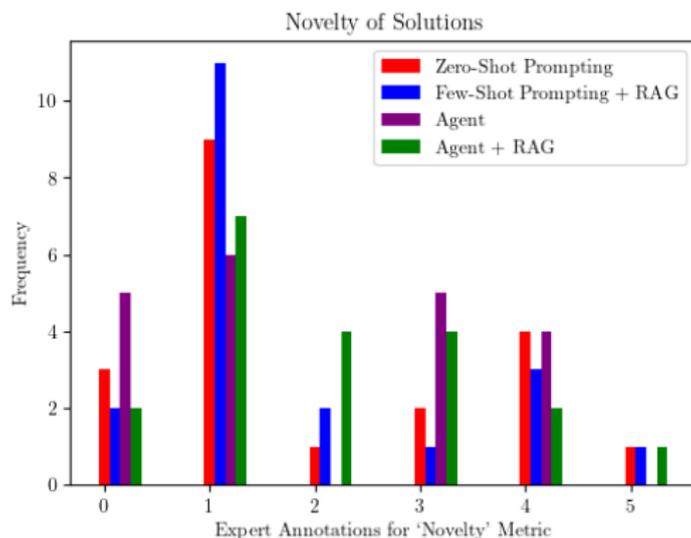
Results



Method	Feasibility
Zero-Shot Prompting	3.45 ± 1.77
Few-Shot Prompting + RAG	3.70 ± 1.58
LLM Agent	2.45 ± 2.06
LLM Agent + RAG	3.50 ± 1.50

Table: Feasibility scores for different methods.

Results (cntd.)



Method	Novelty
Zero-Shot Prompting	1.90 ± 1.55
Few-Shot Prompting + RAG	1.75 ± 1.41
LLM Agent	1.85 ± 1.53
LLM Agent + RAG	2.00 ± 1.34

Table: Novelty scores for different methods.

Main Takeaways

- ▶ Integrating RAG increases feasibility of design solution in all settings, but the novelty of the design solution varies.
- ▶ Design solutions generated with RAG are less likely to be unrelated to the design question.
- ▶ Prompting methods have higher feasibility and novelty scores than the LLM agent counterparts in most cases.
- ▶ Few-Shot Prompting LLM with RAG is the most appropriate setting.

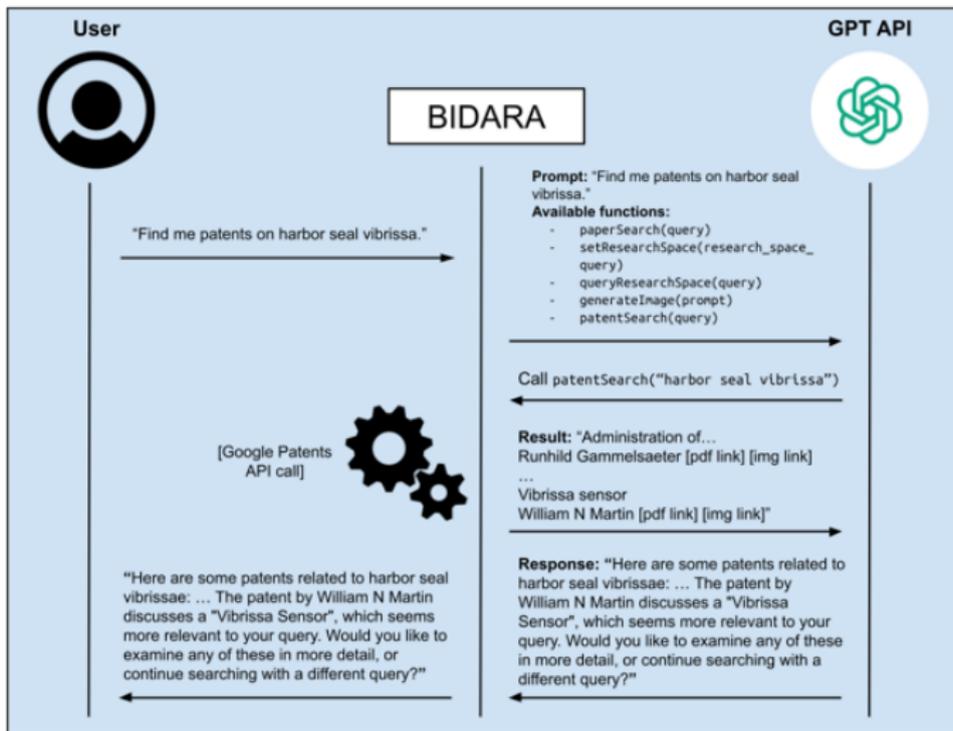
Directions and Motivations

- ▶ Expert interviews were conducted asking for feedback and potential improvements.
- ▶ **Liked:** Detailed and structured answers, citations, ease of chatting
- ▶ **Improvements:** Fact-based generation, links, visuals

Recent Work

- ▶ Function-calling framework added to address expert suggestions, provide expanded capability.
- ▶ Functions include:
 - ▶ `paperSearch()`
 - ▶ `setResearchSpace()`, `queryResearchSpace()`
 - ▶ `generateImage()`
 - ▶ `patentSearch()`
- ▶ Initial testing shows functions are called with a very high degree of accuracy, paper Q&A responses also align with papers in research space.

Function-calling System Diagram



Conclusion

- ▶ First work integrating RAG within LLM-generated biomimetic design solutions.
- ▶ BIDARA uses RAG and ReAct frameworks to reduce hallucinations.
- ▶ Few-Shot Prompting + RAG was the most feasible method with Agent + RAG being the most novel (via expert blind ratings).
- ▶ Function-calling adds more avenues for RAG and interactive tools for users.