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Published in: HHAI 2024

DOI:
10.3233/FAIA240219

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Document Version
Publisher's PDF, also known as Version of record

Publication date: 2024

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

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Download date: 01-08-2024
Hypothesis Updating by Combining Knowledge Graphs and Argumentation

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Abstract. This project explores the applicability of computational argumentation and knowledge graph methods for the validation and updating of scientific hypotheses. Starting from a game setting example, we suggest that such framework could be extended to the scientific discovery domain as a long-term plan.

Keywords. Computational Argumentation, Hypothesis Representation, Hypothesis Evolution, Scientific Knowledge Graphs

1. Introduction

Motivation: developing scientific assistants. In recent years, there has been an extremely fast increase in the volume of scientific publication: for example, science and engineering publications increased from about 2 millions in 2010 to 3.3 millions in 2022 [1]. As a consequence, delving into the amount of literature can often feel an intractable task. In this sense, it feels natural to explore the possibilities for the creation of scientific assistants able to help with sifting through the literature and validating/evolving the hypothesis proposed by the researcher. Following the recent rise of Large Language Models (LLMs), various attempts of assistants have been studied [2,3] but, despite their clear potentialities, they share some of the common explainability pitfalls of deep learning approaches (hallucinations, bias and retrieval of non existent sources are often mentioned as possible concerns [4]).

Example Scenario. Consider a scenario where a team of researchers is trying to develop new treatments for asthma. Starting from the findings of paper A, they consider studying the introduction D-vitamin in the therapy as paper A links it to reduced symptoms severity and control. They then input the research question and the related literature supporting the idea to an assistant. The assistant consults a paper [5] in its knowledge base, where a systematic review on diabetes and D-vitamin correlation is performed, with milder conclusions. The agent suggests lack of strong evidence for a positive interaction. An assistant could help the researchers to further develop or revisit their hypothesis: in

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This work is partially supported by the Hybrid Intelligence programme (https://www.hybrid-intelligence-centre.nl/), funded by a 10 year Zwaartekracht grant from the Dutch Ministry of Education, Culture and Science.
this simple scenario, the system could 'argue' against the original hypothesis, while the researchers would be given the option of providing additional supporting literature or updating their hypothesis after the attack, iterating the process until they are satisfied with the new revised hypothesis.

Towards an hybrid intelligence solution. Various stakeholders [6,7] have pushed for a shift of the publishing paradigm towards a more standardized and machine-readable approaches, as more and more research effort is put into the creation of annotated databases of scientific research. In this context, new opportunities and challenges appear, among which the possibility of automatically validating a given novel hypothesis against the machine-readable resources encoded in the form of Scientific Knowledge Graphs (SKG).

While SKGs provide structured knowledge for a scientific assistant, they might not be enough to foster the development of Hybrid Intelligence [8] systems, where humans and agents are intended to enhance each others’ capabilities toward achieving a shared common goal in an explainable, collaborative, responsible setting. Computational argumentation could then represent an inherently explainable approach to bridge the gap: considering that the scientific discourse is argumentative by nature, one could thus imagine a scientific assistant that opens a dialogue with the researcher, highlighting the possible weaknesses (attacks) and strengths (support) of the proposed hypotheses and helping their validation and revision via an iterative process.

2. Related work

This section will provide an overview of existing literature on the two more technical aspects of this project: machine readable research and computational argumentation. Due to space limitations, we will leave a detailed discussion on how to integrate those techniques into hybrid intelligence systems for further work, as we expect it to require an in-depth exploration.

Machine-readable research: datasets and models. In the scope of providing machine readable scientific knowledge, Knowledge Graphs have been employed [9]. Many SKGs are already available, but they are usually limited to a single area of expertise: to mention a few examples, mentioned in [10], Papers with Code2 for machine learning, MetaLab3 for cognitive sciences and coda4 for social sciences.

There also exist attempts to provide a systematic collection of research works from different domains, populating graph data model from annotated papers: the Open Research Knowledge Graphs (ORKG) [10] aims to collect an extensive amount of papers from different areas, and present them in accordance with FAIR (Findability, Accessibility, Interoperability, Reusability) guidelines [11]. PubGraph [12] is a large scale knowledge graph, which maps the metadata of the OpenAlex [13] to Wikidata [14] properties, further integrated with data from the Semantic Scholar Academic Graph (S2AG) [15], and it additionally provides large-scale benchmarks for knowledge graph completion tasks. OpenAIRE [16] is an European project that aims to provide a Graph Data Model to 'foster, support and monitor Open Science scholarly communication in Europe'; be-

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2 https://paperswithcode.com/about
3 https://langcog.github.io/metalab/
4 https://cooperationdatabank.org/about-coda/
Beyond the model, an actual research graph is provided, with a focus on Open Science and highlighting links between scientific resources and findings.

Other options relate top-down approaches, defining generic models to represent scientific claims, their provenance and their evolution. For example, nanopublications [17] define a minimal model to encode independent scientific publications into Knowledge Graphs and reference them; a nanopublication consists of an assertion, its provenance and its related publication info (metadata), which could offer an initial bridging tool for available data (SKGs) and novel hypotheses. Similarly, the DISK framework [18] defines a model to keep track of hypothesis revision and updating in the context of automated discovery. It is specifically integrated as an open source framework for scientific knowledge discovery, and as we aim to focus on hypothesis updating, it could provide insights and functionality for tracking the evolution during the interaction.

Computational Argumentation. Computational argumentation stems from non-monotonic logic and defeasible reasoning and it is generally concerned with the acceptability of sets of statements and arguments that might be incompatible, or alternatively provide support, to each other.

A large number of modern argumentation frameworks is originated from the introduction of Abstract Argumentation Frameworks (AFs) [19]. In this seminal work, the author ‘abstracts’ from the content of the arguments per se and focuses on analyzing the relations between arguments. Specifically, only attacks are considered, and intuitively an argument can be accepted if either it has no attackers, or if additional arguments are (recursively) accepted such that they attack all the original argument’s attackers.

[19] also introduces various semantics defining ‘rational’ ways to justify acceptability of sets of arguments. As an example, the grounded extension includes the arguments that can be accepted without disagreement (i.e. representing the ‘common ground’ in a debate), while an admissible extension is a set of arguments where each element is admissible, possibly different from the grounded counterpart as multiple admissible extensions could exist, contrasting with each other (e.g. given arguments A and B attacking each other, both the single element sets \{A\} and \{B\} are admissible, while only the empty set \{\} is grounded).

Bipolar Argumentation Frameworks [20], and Quantitative Bipolar Argumentation Frameworks (QBAF) [21] further extend AFs by respectively introducing the support relations and a quantitative weighting to attacks and supports. In QBAFs, semantics change from value-based, where arguments are accepted or rejected, to quantitative: each argument initially starts with a given strength, and semantics defines how such values are updated depending on attackers and supporters.

An alternative approach to include quantitative information in AFs is proposed by [22] with Weighted Argumentation Frameworks (WAF), which are value-based and extend original AFs by defining the concept of an inconsistency budget, where attacks can be disregarded until their combined strength reaches a given threshold.

In the context of this project, we expect to not only consider the relations among arguments, but the content of the argument themselves, and how (scientific) hypotheses can be mapped into argument structures. The work by Toulmin [23] could be seen as a promising starting point to the aspects of hypotheses representation. He proposes a standardized high-level model of arguments, which at its core defines the concepts of claim, data (evidence) and warrant (the explanation that links data and claim). The model and its extensions could be adapted to represent and compare scientific claims.
Alternatively, Argumentation Schemes [24] (AS) also define templates of arguments, often following a structure similar to *modus ponens*. Argumentation Schemes try to provide a compendium of common argument patterns, together with a list of *critical questions*, which if true could be used as defeaters. They could thus provide a model for the discourse on scientific hypotheses verification: finding an appropriate AS for mapping the claims, the critical questions could be used to guide the search in the knowledge base for possible attacks. Argument schemes are also formalized in the Argument Web [25], which is based on the Argument Interchange Format (AIF) [26]. These tools aim to provide a standardized, shareable and interoperable ecosystem of various computational argumentation resources and approaches in the context of the Semantic Web [27].

3. Research Questions and Challenges

The wider research question we aim to tackle with this proposal is *to what extent a combination of scientific knowledge graphs and argumentation frameworks can provide assistive functionalities for hypothesis verification and updating.* Specifically, we propose the following sub-questions as steps towards the core one:

- **Can we re-utilize existing formalization and models for representing scientific knowledge and hypotheses?**
  In the context of FAIR science, it is fundamental to consider reusability of models and thus preference should be given to extending what resources already exist and are consolidated. As a consequence, we aim to adapt and extend existing models and verify if they are sufficient to capture the information needed to compare scientific claims.

- **Which argumentation framework already exist that can provide updating functionality for hypotheses?**
  Multiple argumentation frameworks have been proposed in the literature, often with different expressivity and use-cases. We plan to investigate which of the available formalization options can be used for the described research problem, and which trade-offs between their complexity and expressivity are involved in the task of comparing hypotheses.

- **Are the semantics related to such frameworks suited to verify and update hypotheses from SKGs?**
  Each argumentation framework offers different types of semantics for the acceptability of arguments. While the more common concept of grounded and admissible semantics can already represent valuable evaluation tools, it might be the case that more on-point semantics need to be suggested for formalising the condition for accepting a proposed hypothesis and its justifications.

- **How can a scientific assistant support researchers by aligning with the principles of Hybrid Intelligence?**
  Aiming to achieve an hybrid setting, a scientific assistant should be designed to enhance and support the capabilities of the human users. Being able to sustain an argumentative dialogue could be a first requirement, but we also plan to explore what other collaborative techniques could foster positive interaction.
4. Approach and evaluation

Figure 1 provides a high level visualization of the pipeline we intend to implement. Chosen an appropriate scenario, we will create and populate a dataset in the shape of a knowledge graph (0), which we will use to generate arguments to test the hypotheses. In the pipeline we propose, the user’s hypotheses (1) will be mapped into a common representation (2): initially, as we intend to try to reuse and adapt available resources, we plan to study the possibility of using Toulmin’s model and nanopublications for such representation. The represented hypothesis and the information contained in the KG will then be aligned (3), and arguments in support or contrasting the hypothesis will be identified, thus creating an argumentation graph. In the initial phase, we will employ simple techniques tailored on the toy ontology akin to pattern matching. As argument schemes have already been widely treated in the literature, the first iteration of the pipeline development will could then finding schemes that can map relevant reasoning strategies and match them to the information available in the graph. In the future, we also expect to shift towards more complex techniques as we tackle the scientific assistant topic, possibly using machine learning-based methods like graph embeddings or graph neural networks. We intend to study the applicability of increasing complex argumentation frameworks for validating the hypotheses against the available knowledge base (4), ideally QBAFs or WAFs would represent the most expressive options as they allow quantitative information, but in the first phases we will first test the potentiality of simpler frameworks as AFs, which could nonetheless provide baseline functions in detecting faulty hypotheses.

The results of the argumentation will be an ‘argumented hypothesis’, containing some criticism or some additional suggestions for strengthening the claim. Iteratively, the user will be able to provide a refined version of the hypothesis, possibly answering to the attacks, until a satisfying result is reached. Ideally, the system will also keep track of the various updates, for which we initially intend to adapt the DISK framework.

We plan to develop the project incrementally, starting from a controlled ‘toy’ context and later applying the results to the more generic scientific assistant area. At various steps of the iteration, we plan to evaluate our results via user studies. Additionally, performance and ease-of-use might be further evaluated by comparison with deep-learning based (scientific) assistant models.
5. Current results and Conclusion

Current results. The context of choice for the toy setting is the social deduction board game 'Avalon', in which players constantly create hypotheses regarding the hidden roles of other players given shared evidence. There are multiple reasons for which we chose the game as a starting point. First, its nature reflects a core part of the problem at hand: as a social deduction game, players are required to formulate hypotheses about the hidden role of other players by using imperfect and limited evidence. Second, the search space is restricted by the ruleset, creating a more controlled use-case, which can be more easily analyzed compared to directly tackling the task of scientific knowledge discovery. Third, a large corpus of open data is available from the online platform ProAvalon\(^5\) which will allow us to directly approach the development of a prototype, bypassing the need to develop experiments and data collection for the initial phase.

In the next steps we plan to develop a 'proof-of-concept' system. While we have full control over the Avalon dataset, scientific resources contained in SKGs often vary in representation and completeness of information. This will require us to explore ways of mapping such variety of representation into the chosen argument models, overhead we can temporarily ignore in Avalon where the arguments can be hand-crafted from game knowledge.

At present, we built a Knowledge Graph based on the Avalon dataset for which we designed and populated an owl ontology. It currently contains 19 classes and 17 properties, and maps data from the online matches and from the rules of the game, which we will employ for the argumentation process. It has a total of 2700 axioms from the mapping of the first 10 game entries of the dataset, but it can be easily extended to a larger scale once the rest of the pipeline is developed.

As following steps, we aim to analyze which argumentation schemes can be used to map common reasoning patterns in the game, and try to represent role hypotheses and their justifications via such schemes, verifying and updating using critical questions.

For the user-based evaluation, the administrators of the ProAvalon platform have shown interest in possibly allowing the integration of bots as available game options, which could provide preliminary results regarding the applicability of the framework.

Conclusion. In this work, we presented a doctoral research proposal for combining knowledge graph and computational argumentation technologies for hypothesis validation and updating. After reviewing the main resources that we intend to employ for the project, we described the proposed pipeline and presented the current results of the project.

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\(^5\)https://proavalon.com/statistics


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