Exploiting Artificial Intelligence for the Discovery and Modeling of Knowledge Patterns from Tropes in Scientific Texts

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Abstract. In order to effectively convey concepts, scientific literature often derails or suspends the normal referentiality of language through figurative expressions. It is not surprising, then, that science itself is rooted in metaphor and analogy for creating meaning. However, most knowledge extraction and natural language processing (NLP) solutions have tended to be merely based on prior quantifications of topics or lower level linguistic features such as word frequency or occurrences of parts of speech and other grammatical constructions. This work aims at bridging this gap through the exploitation of Artificial Intelligence (AI) for the discovery and modeling of knowledge patterns (KPs) in scientific texts. The hybridization of natural language processing and semantic technologies will foster the formalization and extraction of KPs from text used in a non-literal sense and abstractive form. Specifically, this work will: (i) detect and model tropes, such as metaphor, simile, metonymy; (ii) explore the relationship between them and other structural elements of the text; (iii) analyze the effect that their usage has on readers (sentiment analysis and mining); (iv) analyze their diachronic evolution; (v) identify and formalize invariances into knowledge patterns and populate a Knowledge Graph based on this metamodel. The resulting insights and techniques will benefit the scientific community, foster a practice-based understanding of science and advance knowledge representation and extraction techniques from texts, even in different fields from the scientific one.

Keywords: Tropes · Knowledge Patterns · Science of science · Scholarly articles.

1 Introduction

Combining the concepts of science and rhetoric can sound oxymoronic. Nevertheless, is it is a matter of fact that even the most objective-aspiring written artifact may leverage tropes. For example, metaphors or analogies may convey complex notions or harmonize knowledge effectively. When R. Hooke coined the term "cell" to denote the object he was observing under his microscope, it was because it reminded him of the small rooms occupied by monks in monasteries. The language of science is so trope-based that, according to philosopher T. Kuhn [23], even theory change must be expected to be accompanied by a change in metaphors and in the corresponding parts of the network of language similarities through which terms attach to nature. A clear example of this paradigm shift can best be seen in the history of the atom, first represented by Democritus with a spherical analogy that has been discarded by E. Rutherford in the nineteenth century in favor of a planetary model, bearing consequences on the interpretation of the atom's characteristics.

As an increasing number of scientific literature datasets are open access, more and more attention has gravitated towards their linguistic and structural analysis. However, research in this field has often relied on the quantification of lower level linguistic features such as entities, word frequency or occurrences of parts of speech and other grammatical constructions.

This research fits within the scope of Science of Science and Philosophy of Science in Practice, and explores the relationship between rhetoric and science by leveraging available open access academic datasets. Through the adoption of the so far unexplored Science of Science approach in such a frame of reference, it is indeed possible to exploit Artificial Intelligence for the discovery and modeling of KPs from semantic figures of speech in scientific texts. The unveiling of both universal and domain-specific patterns forms the foundation for the formalization of abstract schemata to organize scholarly knowledge into Knowledge Patterns. KPs are structures that in different research areas are "used to organize our knowledge, as well as for interpreting, processing or anticipating information" [32, 33]. In this context, despite the concepts of "frame" and "framing" having been used in a range of different fields, inevitable differences between different fields aside, a "frame" as defined by [13, 30] can be related to a KP. They can be both conceived as "primitives"[32], portions of background knowledge that connect language analysis with concepts and knowledge. Thus, in order to take into account the contextual and perceptual power of tropes, a frame-based methodology is considered crucial for this research.

The Knowledge Graph that is meant to emerge from the extraction of KPs thanks to the hybridization of natural language processing and semantic technologies would be the first to allow users to read and explore scholarly literature through an ontological structure oriented towards the collection of rhetorical expressions and their contextualization.

Apart from the possibility for the formal framework to serve as input to a learning model to automatically detect figures of speech in scientific texts, this project has the outcome of discovering and modelling applicable KPs to study their communicative purposes and cognitive reception.

2 State of the Art

Despite the surfacing of the Science of Science discipline [49], and despite the field of automatic identification and interpretation of rhetorical figures dating back to 1964 [4], very little scientific effort has focused on the tropes' presence and function within scientific literature corpora, especially for what concerns the ontological representation of these phenomena.

Early research in metaphor processing performed supervised classification with hand-engineered lexical, syntactic and psycholinguistic features [47, 21, 48, 45, 6]. Alternative approaches are corpus-based [5], perform metaphor detection from distributional properties of words [42] or, more recently, work by training deep neural models [38, 16, 17, 28, 9], even with a knowledge graph-based approach [34]. Various methods of metaphor processing have also focused on the role the trope plays in communication, especially political discourse [37, 7]. Other than metaphor, machine-learning based detection of semantic rhetorical figures in text and their annotation has been mainly explored for metonymy [12, 20, 26, 29, 40], simile [27], and personification [39].

Among the thesauri dedicated to metaphors only, the largest and most common is the VU Amsterdam Metaphor Corpus (VUA) [43]. But, according to [44], existing corpora tend to prevent the analysis from identifying different types of metaphors: the VUA has a high percentage of conventional metaphors, making it difficult to capture novel ones.

For what concerns tropes interpretation, MetaNet, as developed by [10], is the reference structured repository of conceptual metaphors, each of which is often aligned to linguistic frames available in FrameNet. In [15], the authors based on MetaNet the development of the Amnestic Forgery Ontology and contributed to automated metaphor interpretation by enriching knowledge extraction pipelines. In this context, KPs are crucial in facilitating ontological reuse and clarifying formal models as sets of modular theories rather than mere formalizations of axioms.

To the best of our knowledge, most studies that involve broad semantic representation of rhetorical figures such as [18, 31] have been developed independently of the rhetorical tradition and frame theory. They tend to be solely based on reasoning approaches using, for example, the Semantic Web Rule Language[1] (SWRL). Other than that, it is necessary to link these models to frameworks of documents representation and scholarly practices. Possible solutions in this direction are the SPAR ontologies [35], the Scholarly Ontology (SO) [36] and the Ontology of Rhetorical Figures in German, which includes an exhaustive representation of tropes [24].

Hence, according to our analysis, it is possible to conclude that a Science-of-Science quantitative model of semantic figures of speech needs to be paired with a formal model of reference to take into account the multi-layered nature of meaning conveyance, and that such a framework has not been built yet for scholarly texts.

3 Problem Statement and Contributions

This research relies on three hypotheses:

[1] https://www.w3.org/Submission/SWRL/

- **H1**: tropes can be found in science discourse and formalized in Knowledge Patterns (KPs);
- **H2**: a knowledge graph (KG) can be costructed by using identified KPs as schema;
- **H3**: KPs can be used as interpretive lenses over the scientific literature by querying the KG.

The proposed approach allows a user to navigate different ways of meaning-making both synchronously, i.e., how and where a metaphor is used in a specific moment in time, and diachronically, i.e. the evolution of the use of a specific metaphor in time, and exploit the data for a number of research endeavors.

The problem raises a number of research questions that will guide the project:

RQ1: How to exploit Artificial Intelligence for the discovery and modeling of KPs from semantic figures of speech in scientific texts?

RQ2: What is the perceptual content and cognitive impact of the reception of tropes in scientific academic texts?

RQ3: How can we formalize the relationship between tropes and other structural elements of the text?

RQ4: What does the diachronic evolution in the use of semantic figures of speech can tell us about cultural context, author's intention, forms of meaning conveyance in general?

RQ5: What do invariances in KPs tell us about tropes' understanding and use in scientific texts, and how can they be further exploited in Artificial Intelligence?

The research will contribute as follows:

- Reuse and implementation of semantic rhetorical figures datasets, such as the VUA [43], UniMet[22], the University of Córdoba Metonymy Database [1];
- Implementation of state-of-the-art methods for tropes identification and joint emotion detection;
- Development of the Tropes Ontology basing on outlined KPs (tropes schemata representation, addressing philosophical and cognitive theories). Such an ontology will be modularized and networked following the NeON [46] and eXtreme Design methodologies [3];
- Elaboration and publication of the Semantic Rhetorical Figures Knowledge Graph;
- Definition of the method and evaluation system.

4 Research Methodology and Approach

The main aim of this work is to design and implement a Knowledge Graph starting from the drafting of knowledge patterns emerged from invariances in scientific scholarly texts. In this section, methodology and approach are elaborated for each research question.

RQ1: For automatic tropes' detection, the first step consists in being aware of the state of the art, as it may not be necessary to invent a new approach but rather to further enhance or even combine already existing methods. Indeed, there are a few directions that can be taken for automatic tropes' detection, but none of them has been tested on an academic articles corpus. Therefore, a comparative study has to be first carried on in order to see which model achieves the best performance. The selection of a specific corpus should also be done carefully. For instance, even available open-access articles may not all be structured correctly or even contain useful information. For this purpose, We propose to take into consideration different corpora in order to get a sample as complete as possible. After having built a consistent and well-balanced corpus across different element of interest, different algorithms for metaphor, analogy and metonymy detection are trained and tested on it. The output for the classification will be then manually checked for potential problems and inconsistencies.

RQ2: This step will require the implementation of state-of-the-art methods for joint modeling of tropes and emotion detection. The output for the classification will be once again manually checked.

RQ3: On the basis of the automatic identification, with the aid of statistical measures and after a survey of existing ontologies on rhetorical figures, cognitive theories of tropes and documents representation, patterns are found to be represented from a semantic point of view. A crucial role in this phase will be represented by the Amnestic Forgery ontology outlined in [15], which inherits the Framester schema to enrich analysis on tropes' conceptual frames. In this way, it is possible to design and implement the framework that populates the KG with real data.

RQ4: The emerging KG will be time-aware as input data has temporal features. The analysis and representation of diachronic development of science communication will help researchers in understanding the correlation between argumentative discourse, rhetorical figures and framing power of theories.

RQ5: Other than contributing to the general field of Science of Science through both synchronic and diachronic analysis, the implementation of the above functions may result in new application fields. Apart from the possibility for the formal framework to serve as input to a learning model to automatically detect figures of speech in scientific texts, the project will also discover and model applicable KPs to study their communicative purposes and cognitive reception. The automatic detection of tropes in scientific texts and their organization in a knowledge graph that takes into account all these intertwined elements could benefit a wide range of applications, including the identification of authorial fingerprints, and the improvement of recommendation systems. The knowledge graph resulting from this work would also be a reusable tool to navigate figures of speech that exist in other types of texts and investigate many related tasks like multimodal representation of tropes, moral value detection, hate speech detection, political discourse analysis, and would eventually help in the field of automatic text generation for different use cases (educational tools, chatbots).

5 Evaluation Plan

In the evaluation method of the algorithms assessing automatic tropes detection, I aim to use well-known evaluation metrics: true positive, true negative, false positive, false negative, precision, recall and accuracy. For what concerns the KG, a first evaluation is focused on assessing its cognitive soundness and requires the involvement of humans in the loop. Then, the evaluation of the KG itself will be performed iteratively thanks to suggestions by domain experts. I will employ standard evaluation metrics along with the three principles explained in [8, 14, 25]: usability, logical consistency, user evaluation and requirements coverage and an additional survey post testing session related to querying results obtained from scholars interested in the field. The ontology development will reuse Ontology Design Patterns, whose employment will be evaluated according to the experiments and guidelines in [2]. To make results reproducible, all the code will be made publicly available with an open license.

6 Conclusions

This work contributes to the Science of Science field, as it aims to find patterns in the use of tropes in scientific texts, understand how theories are made and develop over time, and base on these invariances to develop a KG to be populated with automatically identified real data. One challenge that immediately emerges is the non heterogeneity of the disciplines' products of communication. Furthermore, while some tropes may be cross-lingual, the analysis will for the moment take in consideration only English texts, an aspect that inevitably has modelling repercussions. To confront these issues, a wider dataset, as well as continuous confrontation with both scholars of different fields to understand their ways of working and state-of-the-art algorithms will be taken into account.

Acknowledgements This work was supported by the PhD scholarship "Discovery, Formalisation and Re-use of Knowledge Patterns and Graphs for the Science of Science", funded by the Italian National Research Council, Institute for Cognitive Sciences and Technologies (ISTC-CNR) through the WHOW project (EU CEF programme - grant agreement no. INEA/CEF/ICT/A2019/2063229). The author is grateful to her supervising professors Prof. Aldo Gangemi and Prof. Andrea Giovanni Nuzzolese for helpful suggestions, advices and comments.

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