Ontologies, Arguments, and Large-Language Models

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Abstract

The explosion of interest in large language models (LLMs) has been accompanied by concerns over the extent to which generated outputs can be trusted, owing to the prevalence of bias, hallucinations, and so forth. Accordingly, there is a growing interest in the use of ontologies and knowledge graphs to make LLMs more trustworthy. This rests on the long history of ontologies and knowledge graphs in constructing human-comprehensible justification for model outputs as well as traceability concerning the impact of evidence on other evidence. Understanding the nature of arguments and argumentation is critical to each, especially when LLM output conflicts with what is expected by users. The central contribution of this article is to extend the Arguments Ontology (ARGO) - an ontology specific to the domain of argumentation and evidence broadly construed - into the space of LLM fact-checking in the interest of promoting justification and traceability research through the use of ARGO-based 'blueprints'.

Keywords

Ontology, Arguments, Semantic Reasoning, Large Language Models

1. Introduction

The explosion of interest in large language models (LLMs) has been accompanied by concerns over the extent to which generated outputs can be trusted, owing largely to the prevalence of hallucinations [1] and bias [2]. Each may be partially addressed by intervention at various points of LLM development, such as by pre-training on vetted data [3] or human-in-the-loop reinforcement [4]. A natural strategy for addressing hallucinations post-inferencing involves **fact-checking**, the process of evaluating whether claims asserted to be true, are indeed true [5]. Traditionally, this process involves identifying asserted claims, relevant evidence or counter-evidence, and delivering a verdict [6]. Work exploring fact-checking [7] with respect to LLMs has focused on the outputs of domain-specific prompts, for example in domains such as climate change [8], disease [9], or Twitter [10], but recent work has sought to expand the scope of this approach [11]. In naive models, claim and evidence pairs are tagged to indicate whether the evidence supports or undermines the claim. More sophisticated models attempt to identify missing evidence for or against claims [5] or to correct claims based on existing evidence [9].

Regardless of the strategies adopted, there is clear reliance on the relationship between claims and evidence, a relationship often characterized in terms of *arguments*. In this respect, fact-checking research for LLMs dovetails with traditional applications of *ontologies* - representational artifacts whose representations are intended to designate some combination of classes and certain relationships among them. Ontologies have proven useful for providing both explicit machine-understandable schemata for

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machine-machine interoperability, and explicit human-understandable schemata [12][13] for *human-machine interoperability* across otherwise disparate vocabularies. Accordingly, ontologies have been recognized as crucial for enhancing LLM accuracy [14][15].

Ontology research intersects well with LLM fact-checking research by providing an avenue for extracting implicit *justification* – human comprehensible arguments in favor of or against model outputs - and facilitating *traceability* – human comprehensible arguments concerning impacts of evidence on other evidence. Little research has been conducted at this intersection. In what follows, we aim to remedy this gap by leveraging an ontology of arguments to highlight how ontologies may support justification and traceability for fact-checking strategies.

2. Adequacy Constraints for Argument Ontologies

2.1. Hallmarks of Arguments

Claims are often asserted in the form of sentences, roughly, the smallest complete syntactic patterns of characters that can be used to convey meaning. For example, “Snow is white” expresses that snow is white. Sentences are not, however, identical to the contents expressed by them: “Schnee ist weiß” expresses the same content as “Snow is white”. Sentences and the content they express may also be used in different ways. The same content might be used to assert that now is white or to ask whether snow is white, the former being an assertion and the latter a question. Additionally, sentences and sentence contents may have different bearers. The sentence you are reading now could be produced on a piece of paper, a billboard, or another computer monitor.

Arguments themselves can be described as collections of sentence contents used to support another sentence content. To illustrate:

1. If Susan leaves work early, she will go home and then to the gym.
2. SUPPOSE Susan leaves work early.
3. Hence, Susan will go home and then to the gym.
4. Hence, Susan will go home.
5. Hence, if Susan leaves work early then Susan will go home.

Lines 1 and 2 are intended to support 3, which supports 4; lines 2 and 4 support 5. Line 1 is used to assert that the corresponding content is true. Line 2 reflects a supposition that the corresponding content is true in the interest of drawing out consequences. Line 3 follows from 1 and 2; 4 from 5; and 5 from 2 and 4. Arguments, as we see, may be complex, with claims depending on other claims in support of an overall conclusion.

This example also highlights how sentence contents occupy distinct roles in the context of arguments. Lines 1 and 2 are premises of the argument, lines 3 and 4 are sub-conclusions, and line 5 is the main conclusion. Distinguishing roles that sentence contents may play is important for classifying argument types. For example:

1. Ghosts exist.
2. Hence, ghosts exist.

This is a textbook example of a question-begging argument in which the same sentence content plays distinct argument roles. The preceding examples involve sentence contents that may be true or false, but arguments in general need not be so restricted [16]:

1. Hold the door if you want to keep your job!
2. You want to keep your job.
3. Hence, hold the door!

Lines 1 and 3 are expressed by commands, the content of which is not typically taken to be true or false [17][18]. A general ontology of arguments should thus allow for representing arguments containing contents that are neither true nor false.

These brief remarks highlight *hallmarks of arguments*:

* The tripartite relationship among sentences, sentence contents, and bearers
* The supportive roles sentence contents may play in the context of an argument
* Different ways sentence contents may be used as parts of arguments
* The potential complexity of arguments

Any robust ontology characterization of arguments must respect these hallmarks.

2.2. Ontology Best Practices

A well-designed ontology should satisfy certain adequacy constraints that reflect the main goal of ontology development, namely, promoting interoperability of heterogeneous data and information systems [19][20]. Standard adequacy constraints require that ontologies be accurate, adaptable, consistent, and able to provide clear annotations to salient data [21][22]. With respect to *accuracy*, an ontology should accurately represent entities and relationships within its stated scope. For our purposes, this amounts to respecting the preceding hallmarks of arguments. With respect to *adaptability*, an ontology should be designed for reuse by other ontology developers and users. With respect to *clarity*, terms in ontologies should be given unambiguous, clear, labels, synonyms, both formal and natural language definitions, and definition sources, to promote understanding across a variety of potential stakeholders. Ontologies should in addition be logically consistent, both internally and with respect to sister ontologies, as demonstrated, for example, by Web Ontology Language (OWL)-based reasoners [23][24].

These best practices are borne out of years of ontology development by a wide variety of users, and indeed are codified as principles in large ontology development communities, such as the Open Biological and Biomedical (OBO) Foundry [25] and the Industrial Ontologies Foundry (IOF) [26]. To encourage best practices, further principles for ontology design have emerged from these communities, such as having ontologies within their respective communities extend from a single top-level ontology: Basic Formal Ontology (BFO) [27][28]. BFO - an ISO/IEC 21838:2 top-level ontology standard [29] - contains high-level general terms such as **object** and **process**. Extending from a common top-level ontology promotes interoperability by ensuring that no matter how far ontologies extend into specific domains, relating for example to **electrons**, **tables**, **whales**, they will nevertheless share a common top-level language and logical framework for definitions. Relevant for our purposes here: extending from BFO promotes explainability and traceability, as all extended ontology terms will be accompanied by definitions [30] following the scheme: *A is a B that Cs*, where "A" is a subclass of "B" and differentiated from other subclasses of B by virtue of satisfying "C" [20]. For example, an **agent** is a **material entity** capable of performing a **planned act**. Altogether, these observations suggest the following constraints should be respected for an ontology of arguments, the ontology should:

* Extend from a top-level ontology, such as BFO. [*Adaptability*]
* Contain clear labels, annotations, and in particular, definitions following the "A is a B that Cs" scheme. [*Clarity*]
* Be represented in OWL2 and verified for logical consistency using associated reasoners. [**Consistency**]
* Distinguish sentences, sentence contents and their uses, the roles of sentence contents in arguments, bearers of sentences and contents, and simple from complex arguments. [*Accuracy*]

In the next section, we examine existing ontologies of arguments or evidence, noting where they fall short of one or more adequacy constraints.

2.3. Literature Review

Of the ontologies dealing with argumentation and evidence we reviewed, none adequately reflect the hallmarks of arguments and none satisfy all of the preceding criteria for ontology development. A common issue is the conflation of arguments and evidence. For example, the Legal Knowledge Interchange Format (LKIF) Core Ontology [31] views arguments 'as reasons expressed through a medium', thereby overlooking how sentence contents may serve as parts of complex arguments to support other contents in multiple ways, in addition to serving as 'reasons'. The Argument Interchange Format (AIF) does not make such a conflation, [32] but instead conflates sentence contents with what the contents are about [33]. The Argument Model Ontology (AMO) distinguishes claims, evidence, warrant, rebuttals, and so on, but does not distinguish the contents of sentences composing arguments from the roles played by such contents within an argument [34][35]. The Semantic Science Integrated Ontology (SIO) provides a treatment of arguments, validity, soundness, and so forth, but defines the contents of sentences as "expressing something true or false", ignoring the fact that arguments may involve sentence contents that are neither [36]. Most of the preceding do not adopt a top-level ontology, though there are argument ontologies that do, such as the OBO Foundry Evidence Ontology (EO) [37]. Though EO imports BFO as a top-level, it creates a sibling hierarchy alongside the main hierarchy of BFO, despite the fact that terms such as **evidence** are defined to fall under BFO's root class **entity**. Additionally, the scope of EO is restricted to the biological domain. Related, while the Explanation Ontology (EXO) adopts a top-level ontology, namely SIO, it inherits the serious issues exhibited by that import [38]. The lack of any existing ontology that respects our adequacy constraints motivated the development of the Arguments Ontology (ARGO), which we discuss in what follows.

3. ARGO

ARGO is a small ontology designed to satisfy the above adequacy constraints. ARGO extends from BFO, leveraging resources from other BFO-conformant ontologies such as the Information Artifact Ontology (IAO) [33], an extension of BFO designed to represent information and information bearers.

ARGO not only distinguishes sentences and sentence content, it also provides a more general class under which instances of the former will fall. The ARGO class **expression** consists of patterns of character shapes in a language, such as the string of characters comprising this clause. **Sentence** is a subclass of **expression**, instances of which must be usable on their own to express content. For example, "Happy" is not a sentence, while "Sam is happy" is. Both are distinct from the class **sentence content**. The **sentence** "Susan is happy" expresses the **sentence content** that Susan is happy, which is plausibly what the sentence is about.

Sentence contents are a subclass of the IAO class **information content entity**, roughly, copyable patterns that are about things, such as the content of a book or the information encoded in a docx file on a hard drive. **Information content entities** allow us to distinguish sentence contents from bearers, as the same **information content entity** may be copied across multiple bearers. For example, the content of a given PDF may exist across distinct laptops. Similarly, a **sentence content** may have identical instances across bearers. Two observant friends of Susan, for instance, may both believe Susan is happy, each expressing this by uttering "Susan is happy".

A given **sentence content** may serve as a conclusion in one argument and premise in another. Premises are linked to conclusions insofar as they are offered as support for conclusions. This link between premises and a conclusion may be plausibly understood as an action — a passing from some collection of **sentence contents** to another **sentence content** because one believes the latter is justified, supported, or entailed by the former. We reflect this link between premises and conclusion with a class **act of inferring**. A **premise** is a **sentence content** that stands in a particular relation to an argument as a result of being the input of an **act of inferring**; a **conclusion** is a **sentence content** that stands in a particular relation to an argument as a result of being the output of an **act of inferring**. The relations 'has input' and 'has output' are reused from the Common Core Ontologies [39].

Premises are often *affirmed* in arguments; **suppositions** are always *accepted.* To suppose that a **sentence content** is true, is often done for the sake of some further inferential goal, for example hypothetical deliberation, indirect reasoning, *reductio ad absurdam*, and so on. We capture these distinctions in terms of differing acts, namely, an **act of affirming** in which an agent believes a **sentence content** is true based on evidence, and an **act of accepting** in which an agent entertains a **sentence content** as true independent of evidence. Outputs in each case can, moreover, be inputs to **acts of inferring**. To illustrate:

1. If Susan leaves work early, she will go home and then to the gym.
2. SUPPOSE Susan leaves work early.
3. Hence, Susan will go home and then to the gym.
4. Hence, Susan will go home.
5. Hence, if Susan leaves work early then Susan will go home.

Here, 1 is affirmed while 2 is accepted. Lines 3 and 4 are sub-conclusions and line 5 is the main conclusion; line 3 is inferred based on a combination of an affirmed line and an accepted line, which suggests it is itself accepted. Accordingly, 4 is accepted as it is based on the accepted 3, while 5 is best described in terms of an agent affirming the connection between what is supposed and a consequence of it.

Premises may also be *prescribed* in arguments, through an **act of prescribing**, as illustrated by line 2 in the following:

1. Attack now only if the weather is fine!
2. Attack now!
3. Hence, the weather is fine.

Putting aside whether this is a *persuasive* argument, line 2 is plausibly a **premise** in the overall argument, but certainly not one that is believed to be true. In conformance with our adequacy constraints, we maintain that prescriptive **sentence contents** may be the inputs or outputs of **acts of inferring**, and so operate as premises or conclusions in arguments.

Interestingly, **suppositions** are not plausibly understood as being *prescribed.* To suppose one "Attack now!" is to entertain a **sentence content** of the sort 'whomever is directed to attack now, attacks now' as true. This stems from supposition always being made for the sake of some further inferential goal. We thus say that **suppositions** are always *accepted.* In the interests of space, we focus on **acts of affirming** and **acts of accepting** in the remainder.

We are now able to characterize **arguments** as ordered collections of **sentence contents** involving **premises**, **suppositions**, and a single **conclusion**. There are, of course, sub-conclusions in arguments, and they provide the means by which to describe complex arguments. A **sub-conclusion** is a **sentence content** that is: (1) An affirmed, prescribed or accepted input in an **act of inferring** in an **argument**; (2) An affirmed, prescribed, or accepted output in an **act of inferring** in an **argument** distinct from the argument of (1); (3) Both **arguments** of (1) and (2) are parts of the **argument** to which the **sentence content** stands in the 'subconclusion in' relation. **Arguments** that involve **sub-conclusions** are **complex arguments**.

There are many different purposes one might have in constructing an argument. The paradigm case involves arguing, where an individual provides an argument with the intent of convincing others that the conclusion of the argument is true. We characterize this process as an **act of arguing**. One can argue successfully or unsuccessfully, but one cannot argue without intending to convince one's audience of some conclusion; even when arguing against a given conclusion, you are still arguing in favor of *some* conclusion. Of course, one may have no intention to convince others of some conclusion; one may be creating an argument for the purpose of interpretation or to anticipate what an opponent might say during a debate. In such cases, one is not arguing; rather, one is merely creating arguments, which we characterize as a process of **act of argument creation**. An **act of arguing** may have an **act of argument creation** as process part, if in the process of arguing one creates an argument. Creating an argument involves a series of steps, at least one of which is an **act of inferring**. In **Figure 1** we

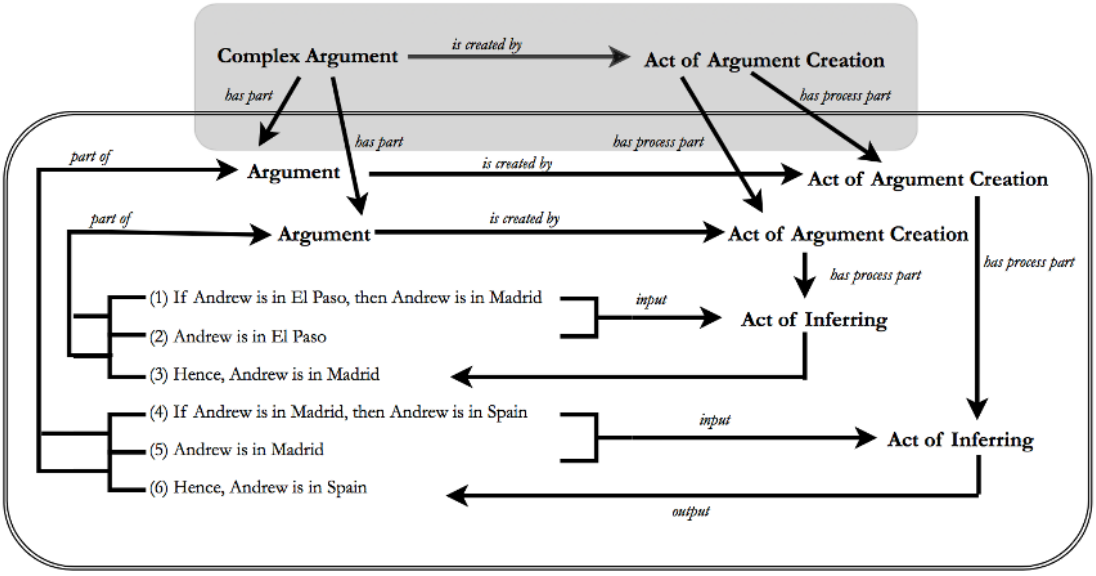

Figure 1: Complex Argument

have a **complex argument** that is created by an **act of argument creation** which has two proper **act of argument creation** parts, each of which has an **act of inferring** part, respectively. The **sentence contents** exhibited by lines 1 and 2 exhibit inputs to an **act of inferring**, just as lines 4 and 5 are inputs to another such act. Each has as its output a corresponding **sentence content** that is a part of some **argument**, which in turn is a proper part of the overall **complex argument**. Importantly, 3 and 5 exhibit the same **sentence content** used differently across two simple arguments that make up a complex argument. These observations reflect our position that any **complex argument** is an **argument** with at least one **argument** as proper part.

In anticipation of applying our results to fact-checking strategies, we now turn to relationships between **sentence contents** in distinct **arguments**. For example, argument A may be a counter-argument to argument B if B has a conclusion that contradicts the conclusion of argument A. It is however more often the case that counterarguments undermine, but do not contradict, some part of another argument. For example, argument C may have some counterargument D if the conclusion of D undermines the justification of one or more premises of C. To capture such generality, ARGO adopts an 'opposes' relation, which holds between **sentence contents** across **arguments**. Sub-relations of opposes include: negates, contradicts, and undermines. Similarly, a 'supports' relation is introduced to illustrate potentially favorable evidence. These are, of course, coarse-grained and a fuller treatment will introduce degrees of support and opposition. Even so, the resources described here suffice for applying ARGO to fact-checking.

4. Explainable, Traceable, LLMs

Having illustrated design features of ARGO and demonstrated how this ontology satisfies our adequacy constraints, we return to the topic of research at the intersection of ontologies, LLMs, and fact-checking. As discussed, fact-checking typically involves tagging pairs of claims and evidence, noting when the latter supports or undermines the former. Claims and evidence are, however, best understood in their appropriate context, i.e. with respect to relevant supporting or opposing arguments. While situating claims and evidence in their appropriate argument context can be, admittedly, a monumental task, ARGO can be leveraged to provide structure to such chaos.

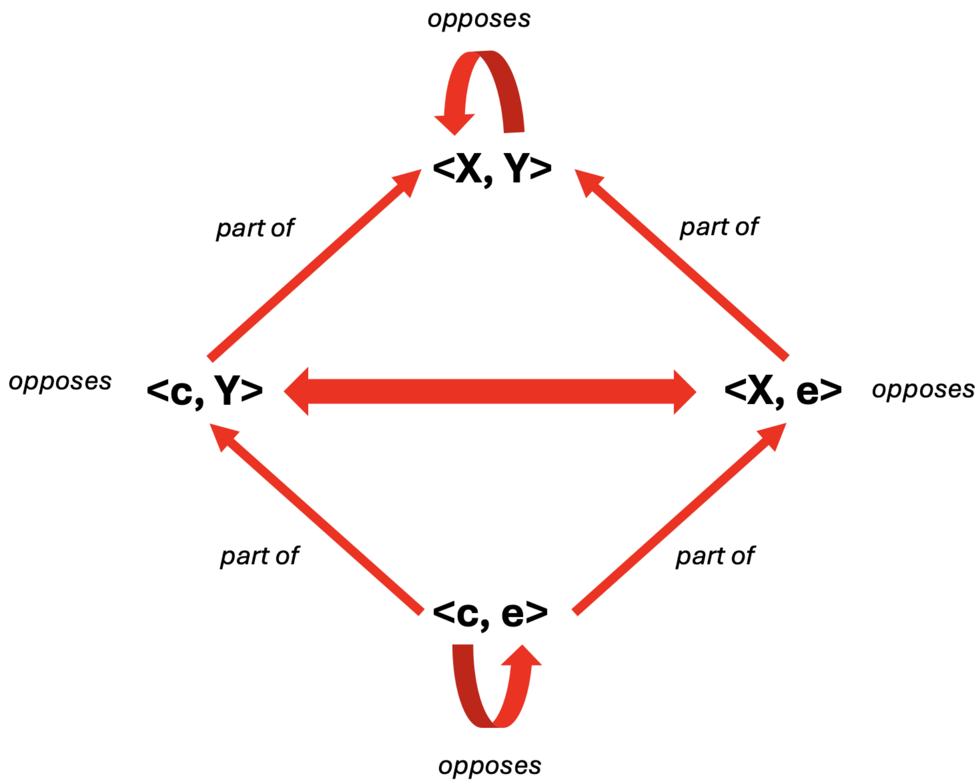

Figure 2: ARGO Blueprint Relationships

Suppose we have the following claim-evidence pair: <*c*,*e*> where *c* is assumed to be part of argument *X* and *e* part of argument *Y*. This results in four pairs - <*c*,*e*>, <*c*,*Y*>, <*X*,*e*>, <*X*,*Y*>, some of which are connected as parts, some of which are connected by 'opposes', 'negates', 'supports', and so on. **Figure 2** illustrates, fixing on 'opposes'. The pair <*c*,*e*> is part of <*c*,*Y*> since *e* is part of *Y*. Similarly for <*c*,*e*> and <*X*,*e*>. Pairs <*c*,*Y*> and <*X*,*e*> share overlapping parts, namely, *c* and *e*, while both are part of <*X*,*Y*>. If we assume <*c*,*e*> is tagged with 'opposes', we have a method for filtering relevant from irrelevant arguments. Note that if *e* opposes *c*, then *Y* should oppose *c*. Indeed, if *Y* does not oppose *c*, then at a minimum *Y* does not support *e* opposing *c*. For example, suppose "Tom is at the grocery store" is opposed by "Tom is at home". Suppose the latter is part of the argument:

1. If Tom lives in the grocery store then he is at home.
2. Tom lives in the grocery store.
3. Hence, Tom is at home.

This argument does not oppose "Tom is at the grocery store" because line 2 of the argument does not support "Tom is at home" opposing "Tom is at the grocery store".[1] This is, in broad strokes, the ARGO-Blueprint strategy which facilitates expanding the scope of fact-checking beyond tagging claim and evidence pairs to include arguments relevant to a given tagging.

Because ARGO is represented in the Web Ontology Language (OWL), our ontological representations are machine-readable and supported by automated reasoners such as Hermit [23], targeted information extraction using SPARQL, and schema validation using SHACL. ARGO can support quality control checks for fact-checking in the presence of such tools. For example, if it is asserted that *e* opposes *c*, then a well-designed ontology aimed at filtering relevant arguments should support the inferences: *Y* opposes *c*, *e* opposes *X*, and *Y* opposes *X*. Such a filtering strategy seems plausible working top-down

[1] We leave for another time when *Y* opposes *c* but does *not* support *e*, a topic that is relevant to research on expanding evidence [5] and claim correction [9].

as well. If Y opposes X, then some part of X is opposed by Y - namely, c - and some part of Y opposes X - namely, e. Hence, e opposes c. What goes for 'opposes' should hold - modulo where appropriate - for 'negates', 'supports', and so on.

As illustrated, ARGO-blueprints can be used to promote the identification and extraction of justifications both for and against claims, and to provide the sort of traceability that is needed to evaluate the impact evidence has on other evidence. In this respect, we envision that, as we work to improve the trustworthiness of LLMs, ARGO-Blueprints will provide a path towards more encompassing, more complete, fact-checking results.

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