Meta-level Argumentation with Argument Schemes

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Abstract. Arguments in real-world decision making, for example in medical or engineering domains, are often based on patterns of informal argumentation, called argument schemes. In order to improve automated tool support of decision making in such domains, a formal model of argument schemes appears necessary. To address this need, we represent each argument scheme as a defeasible rule in the meta-language, so each application of an argument scheme results in a meta-level argument, and we deal with critical questions via meta-level counter-arguments. In order to understand the interactions between the object-level and meta-level arguments, we introduce bimodal graphs. The utility of the framework is demonstrated by a use case characteristic of the requirements of our partner in the aviation industry.

1 Introduction

Complex decision making processes such as engineering design are driven by argumentation between their participants. Human argumentation often involves common patterns of informal reasoning, called argument schemes. An argument scheme is, for example, the Appeal to Expert Opinion, in which one refers to a statement by a technical expert about a particular problem. Decision making processes, whether or not they involve argumentation, are supported by automated tools. The utility of such tools grows with the accuracy of their internal representation of the world. Since argument schemes are a fundamental part of complex decision making processes, they need to be formalised in software tools. Such a formalisation will greatly improve the support that automated tools may provide to engineering and other processes. In this paper we propose a formalisation of argument schemes via meta-level argumentation.

Our framework comprises three ingredients: Structured argumentation, meta-level argumentation, and bimodal graphs. Structured argumentation allows one to create arguments from defeasible rules. Meta-level argumentation has been proposed to reason about arguments [11, 4, 18], describing the properties of arguments and attacks. We present a meta-language for structured argumentation in which argument schemes are expressed. Arguments both on the meta- and on the object-level are given a graph-based interpretation using bimodal graphs.

The rest of this paper is organised as follows. After a brief summary of related work (Section 2), a brief overview of Dung's framework for abstract argumentation is given in Section 3. In Section 4 we present the framework for structured argumentation upon which the subsequent work is based. Abstract (graph-based) argumentation is extended in Section 5, where Bimodal Graphs are introduced as an interpretation of meta-level argumentation. Section 6 describes the meta-language used in our framework for structured argumentation. In Section 7, we use meta-ASPIC to extend structured argumentation with argument schemes. The paper concludes with some considerations on the usefulness of our model in practice, in particular for our use case partner (Section 8).

2 Related Work

This paper is based upon three different approaches: Abstract argumentation, meta-level argumentation and structured argumentation.

Abstract argumentation [8] provides a graph-based interpretation of argument graphs. Bipolar argumentation [6, 12, 7] is an extension of Dung's abstract argumentation framework, adding a "supports"-relation as a second relation over arguments. Dung's original framework considered this relationship only implicitly, using the concept of defence for the defeaters of an argument's defeaters. Supporting arguments allow additional extension semantics. For example, sets of arguments are considered safe if none of their members depend on (are supported by) an argument outside the extension, which results in a stronger notion of internal coherence than just being conflict-free. Whilst bipolar argumentation is appealing as it offers a range of possibilities for defining the "supports"-relation, there is no formalisation of meta-level arguments, and supports for attacks (i.e. each attack by an argument A on argument B is justified by an argument C) cannot be defined.

Meta-argumentation is concerned with using arguments to reason about arguments, rather than using arguments to reason about a domain. Earlier work on meta-level argumentation [11] has shown how several extensions to abstract argumentation can be modeled using meta-level constructs in a "pure" abstract argumentation system as defined by Dung [8]. This is achieved by translating each of these additions, such as attacks on attacks, or preferences, into a constellation of several arguments that are only connected by the "attacks" relation. The extensions of the extended abstract argumentation systems are shown to conincide with those of the resulting argument graph. However, this approach to meta-level argumentation does not provide a systematic way of instantiating abstract arguments. The examples in [11] suggest that there is a need for a systematic approach which uses structured arguments to unify the various proposals for abstract argumentation.

Argument schemes are patterns of informal reasoning often employed in discussions between humans [17]. Argument schemes simplify the argumentation process considerably, since they remove the need for making explicit every detail of an argument, as initial results from our use cases in the aerospace industry have shown. Previous research has been concerned with the representation of argument schemes in a formal setting [3, 2, 1], in particular for the legal domain [13, 9, 19]. However, these proposals not do provide meta-level argumentation as a means of reasoning about arguments. In this paper we argue that meta-level argumentation offers some benefits to formalise a range of argument schemes that involve arguments for decision making.

However, to represent argument schemes in structured argumentation, there is a eed to develop the meta-level aspects of structural argumentation. We draw upon previous work on a hierarchy of meta-argumentats [18], on a logical formisation of argument schemes [10] and recently argument schemes as a component of social interaction [15]. Furthermore, to understand the interactions of arguments and meta-level arguments, we propose Bimodal Argument Graphs.

3 Dung's Framework

Interactions between arguments can be characterised by argument graphs. This approach was first explored by Dung [8] whose definitions we will briefly recall.

Definition 1 (Argument Graph and Extensions). *A tuple* $(\mathcal{A}, \mathcal{R})$ *is an* argument graph *iff* $\mathcal{A}$ *is a set and* $\mathcal{R} \subseteq \mathcal{A} \times \mathcal{A}$ *is relation over* $\mathcal{A}$*, the "attacks"-relation.*

Let $\mathcal{G} = (\mathcal{A}, \mathcal{R})$ *be an argument graph and let* $S \subseteq \mathcal{A}$*.*

1. S *is* conflict-free *iff there exist no* $A_1, A_2 \in S$ *such that* $(A_1, A_2) \in \mathcal{R}$*.*
2. *Let* $A \in S$*.* S defends A *iff for every* $(B, A) \in \mathcal{R}$*, there exists a* $C \in S$ *such that* $(C, B) \in \mathcal{R}$*.*
3. S *is an* admissible set *iff* S *is conflict free and defends all of its elements* $A \in S$*.*
4. S *is a* preferred extension *iff* S *admissible and* S *is maximal with respect to* $\subseteq$*.*
5. *Let* $\mathcal{F}$ *be a function of subsets of* $\mathcal{A}$ *such that* $\mathcal{F}(S) = \{A \mid S \text{ defends } A\}$*. Let* E *be the least fixed point of* $\mathcal{F}$*.* E *is the* grounded extension *of* $\mathcal{G}$*.*
6. *Let* $\mathcal{G} = (\mathcal{A}, \mathcal{R})$ *be an argument graph and let* $x \in \{\mathsf{grounded}, \mathsf{preferred}\}$*. Then,* $\Sigma_x(\mathcal{G}) = \{\mathcal{E} \subseteq \mathcal{A} \mid \mathcal{E} \text{ is a } x\text{-extension of } \mathcal{G}\}$*.*

See Fig. 1 for an example of an argument graph.

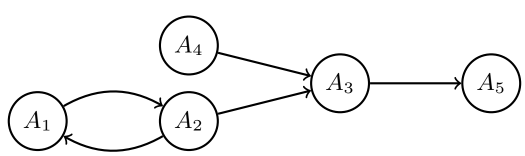


Fig. 1. An argument graph. There are two preferred extensions $\{A_1, A_4, A_5\}$ and $\{A_2, A_4, A_5\}$ and a grounded extension $\{A_4, A_5\}$. Some conflict-free sets are $\{A_1, A_3\}$, $\emptyset$, and $\{A_2, A_4\}$. The set $\{A_1, A_4, A_5\}$ defends A_1, A_4 and A_5. $\{A_1, A_2\}$ defends A_1 and A_2. $\{A_1, A_4, A_5\}$ is an admissible set and a preferred extension. The least fixed point of $\mathcal{F}$ is $\{A_4, A_5\}$.

4 Structured Argumentation

In this section we present a framework for structured argumentation that instantiates abstract argument graphs. It is a subset of ASPIC+ [14].

We only model a subset of the original ASPIC+ definitions, in order to increase the clarity of our presentation. For example, our framework does not consider an ordering of the logical language, nor does it divide the knowledge base into premises, axioms, assumptions and issues. However, the missing aspects of ASPIC+ may be added easily using the same method. Our framework uses only defeasible rules, thus avoiding some of the potential issues with strict rules in ASPIC+ [5].

Definition 2 (Logical Language). *Let $\mathcal{L}$ be a set of positive and negative literals. $\mathcal{L}$ is a* logical language *iff there is a function $\bar{\cdot} : \mathcal{L} \to 2^{\mathcal{L}}$ such that $\bar{\cdot}(x) = \{\neg x\}$ where $\neg x$ is the literal with the opposite polarity of x.*

Example 1. Let $\mathbb{A} = \{\mathtt{a}, \ldots, \mathtt{z}\}$ be a set of characters. The language $\mathcal{L}_{\mathbb{A}}$ is defined as $\mathcal{L}_{\mathbb{A}} = \mathbb{A} \cup \overline{\mathbb{A}}$ where $\overline{\mathbb{A}} = \{\neg x \mid x \in \mathbb{A}\}$ and for all $x \in \mathbb{A}$, $\overline{x} = \{\neg x\}$ and for all $\neg x \in \overline{\mathbb{A}}$, $\overline{\neg x} = \{x\}$.

If $\mathcal{L}$ is a logical language then $\bar{\cdot}$ is called a *contrariness function* of $\mathcal{L}$.

Definition 3 (Defeasible Rule). *Let $\mathcal{L}$ be a logical language and let $\varphi_1, \ldots, \varphi_n$, $\varphi \in \mathcal{L}$ with $n \geq 1$. Then, $\varphi_1, \ldots, \varphi_n \Rightarrow \varphi$ is a* defeasible rule *over $\mathcal{L}$.*

Example 2. A defeasible rule over $\mathcal{L}_{\mathbb{A}}$ is $\mathtt{a}, \mathtt{c}, \neg\mathtt{k} \Rightarrow \neg\mathtt{d}$.

The letter $\mathcal{D}$ is used to denote sets of defeasible rules. Rules can be assigned a name in order to refer to them in arguments, using a naming function n. We now have the ingredients of an argumentation system.

Definition 4 (Argumentation System). *An argumentation system $AS = (\mathcal{L}, \bar{\cdot}, \mathcal{D}, n)$ is an* argumentation system *iff*

1. *$\mathcal{L}$ is a logical language*
2. *$\bar{\cdot}$ is a contrariness function of $\mathcal{L}$*
3. *$\mathcal{D}$ is a set of defeasible rules over $\mathcal{L}$*
4. *$n : \mathcal{D} \to \mathcal{L}$ assigns names to defeasible rules.*

A knowledge base contains some elements of the logical language. These are the premises of arguments.

Definition 5 (Knowledge Base). *Let $\mathcal{L}$ be a logical language. A set $\mathcal{K}$ is a* knowledge base *iff $\mathcal{K} \subseteq \mathcal{L}$.*

Arguments are built by applying the defeasible rules in an argumentation system to a knowledge base. We write arguments as a sequence in square brackets: $[s]$. An argument is either a fact from the knowledge base or it is composed by applying a defeasible rule to several arguments. We will write $[q; s; r]$ to indicate that q and s are arguments and r is a defeasible rule.

Definition 6 (Argument). *Let* $AS = (\mathcal{L}, \bar{\cdot}, \mathcal{D}, n)$ *be an argumentation system, let* $\mathcal{K} \subseteq \mathcal{L}$.

1. *Every* $\varphi \in \mathcal{K}$ *is an* argument $[\varphi]$ *with* $Conc([\varphi]) = \varphi$
2. *If* $A_1, \ldots, A_n$ *are arguments and there exists a rule* $r \in \mathcal{D}$ *such that* $r = Conc(A_1), \ldots, Conc(A_n) \Rightarrow \varphi$, *then* $A = [A_1; \ldots; A_n; r]$ *is an* argument *with* $Conc(A) = \varphi$

Example 3. In the examples, we will omit the square brackets around arguments if there is no ambiguity. Let $\mathcal{L}_{\mathbb{A}}$ be defined as above and let $\mathcal{D} = \{\mathtt{a}, \neg\mathtt{k} \Rightarrow \neg\mathtt{d}\}$. Let $\mathcal{K} = \{\mathtt{a}, \neg\mathtt{k}, \mathtt{d}\}$. Possible arguments are $[\mathtt{a}]$, $[\neg\mathtt{k}]$ and $[\mathtt{a}; \neg\mathtt{k}; \mathtt{a}, \neg\mathtt{k} \Rightarrow \neg\mathtt{d}]$ and $[\mathtt{d}]$

Definition 7 (Sub-argument). *Let* A, B *be two arguments.* A *is a* subargument *of* B, *short* $A \sqsubseteq B$, *iff* $B = A$ *or* $B = [A_1; \ldots; A_n; r]$ *and* $\exists i \leq n$ *such that* $A \sqsubseteq A_i$.

The auxiliary function *Rules* is defined on arguments and gives information about the rules used in an argument.

Definition 8 (Rules). *Let* A *be an argument. The function Rules returns the rules used in* A *and is defined as* $Rules([\varphi]) = \emptyset$ *and* $Rules([A_1; \ldots; A_n; r]) = \{r\} \cup Rules(A_1) \cup \ldots \cup Rules(A_n)$.

If the premises or conclusions of two arguments are contrary, then they attack each other. There are two kinds of attack: Undercuts resulting from attacks on defeasible rules, and rebuttals from attacks on conclusions.[3]

Definition 9 (Attack). *Let* $AS = (\mathcal{L}, \bar{\cdot}, \mathcal{D}, n)$ *be an argumentation system, let* $\mathcal{K} \subseteq \mathcal{L}$ *be a knowledge base and let* A, B *be arguments.* A attacks B *iff*

1. *There exists a rule* $r \in \mathcal{D}$ *such that* $Conc(A) \in \overline{n(r)}$ *and* $r \in Rules(B)$ (undercut) *or*
2. *There exists an argument* $B' \in Sub(B)$ *such that* $Conc(A) \in \overline{Conc(B')}$ (rebuttal)

Example 4. Let $A_1 = [\mathtt{a}; \neg\mathtt{k}; \mathtt{a}, \neg\mathtt{k} \Rightarrow \neg\mathtt{d}]$ and $A_2 = [\mathtt{d}]$ be arguments. A_1 rebuts A_2 and A_2 rebuts A_1.

Now that attacks have been defined, an argument graph can be obtained by constructing all arguments and their attacks.

Definition 10 (Argument Graph from Structured Argumentation). *Let* $AS = (\mathcal{L}, \bar{\cdot}, \mathcal{D}, n)$ *be an argumentation system and let* $\mathcal{K} \subseteq \mathcal{L}$ *be a knowledge base. Tthe* argument graph *of* AS *is defined as* $(\mathcal{A}, \mathcal{R})$ *with* $\mathcal{A} = \{A \mid A \text{ is an argument in } (AS, \mathcal{K})\}$ *and* $\mathcal{R} = \{(A, B) \mid A, B \text{ are arguments in } (AS, \mathcal{K}) \text{ and } A \text{ attacks } B\}$.

[3] ASPIC+ defines a third kind of attack, the undermining, from attacks on premises. In our case underminings would be a subset of rebuttals since every premise is an argument for itself.

Example 5. Let $AS = (\mathcal{L}, \bar{\cdot}, \mathcal{D}, n)$ be an argumentation system and let $\mathcal{K} \subseteq \mathcal{L}$ be a knowledge base with $\mathcal{D} = \{\neg\mathtt{k} \Rightarrow \neg\mathtt{d}\}$ and $\mathcal{K} = \{\mathtt{a}, \neg\mathtt{k}, \mathtt{d}\}$. The argument graph of $(AS, \mathcal{K})$ is $(\mathcal{A}, \mathcal{R})$ and it is defined as $\mathcal{A} = \{[\mathtt{a}], [\neg\mathtt{k}], A_1, A_2\}$ with A_1, A_2 as in Ex. 4 and a set of attacks $\mathcal{R} = \{(A_1, A_2), (A_2, A_1)\}$.

5 Bimodal Graphs

Bimodal graphs capture arguments both on the object-level and on the meta-level. Every object-level argument and every object-level attack is supported by at least one meta-level argument. Meta-level arguments can only attack meta-level arguments, and object-level arguments can only attack object-level arguments. A bimodal graph therefore has two components, one argument graph for the meta-level and another argument graph for the object-level, alongside a "supports"-relation that originates in the meta-level and targets attacks and arguments on the object-level.

Definition 11 (Bimodal Argument Graph). *A* bimodal argument graph *is a tuple* $(\mathcal{A}_O, \mathcal{A}_M, \mathcal{S}_A, \mathcal{S}_R, \mathcal{R}_O, \mathcal{R}_M)$ *with*

1. $\mathcal{A}_O, \mathcal{A}_M$ *are sets such that* $\mathcal{A}_O \cap \mathcal{A}_M = \emptyset$*, object- and meta-level arguments*
2. $\mathcal{R}_O \subseteq \mathcal{A}_O \times \mathcal{A}_O$*, for object-level attacks*
3. $\mathcal{R}_M \subseteq \mathcal{A}_M \times \mathcal{A}_M$*, for meta-level attacks*
4. $\mathcal{S}_A \subseteq \mathcal{A}_M \times \mathcal{A}_O$*, meta-level arguments supporting object-arguments*
5. $\mathcal{S}_R \subseteq \mathcal{A}_M \times \mathcal{A}_O \times \mathcal{A}_O$*, meta-level arguments supporting object-level attacks*
6. *For all* $A \in \mathcal{A}_O$ *there exists a* $B \in \mathcal{A}_M$ *such that* $(A, B) \in \mathcal{S}_A$
7. *For all* $(A_1, A_2) \in \mathcal{R}_O$ *there exists a* $B \in \mathcal{A}_M$ *such that* $(B, A_1, A_2) \in \mathcal{S}_R$

The object-level argument graph is $(\mathcal{A}_O, \mathcal{R}_O)$, and the meta-level argument graph is $(\mathcal{A}_M, \mathcal{R}_M)$. These two components are connected by the "supports"-relations $\mathcal{S}_R$ and $\mathcal{S}_A$. This support is the only structural interaction between meta- and object-level. Definition 11 Cond. 6 ensures that every object-level argument is supported by at least one meta-level argument, and Def. 11 Cond. 7 ensures that every object-level attack is supported by at least one meta-level argument.

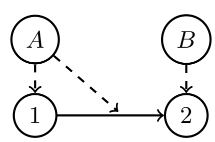


Fig. 2. Bimodal graph for the object-level graph $(\{1, 2\}, \{(1, 2)\})$. The support relation is indicated by the dashed arrows. There are two meta-level arguments ($\mathcal{A}_M = \{A, B\}$), two object-arguments $\mathcal{A}_O = \{1, 2\}$ with no meta-attacks $\mathcal{R}_M = \emptyset$ and a single object-level attack $\mathcal{R}_O = \{(1, 2)\}$. A supports 1 and the attack of 1 on 2. B supports 2.

Every extension of the meta-level induces a subgraph ("perspective") of the object-level graph with potentially many object-level extensions, as defined next.

Definition 12 (Perspective). *Let $\mathcal{G} = (\mathcal{A}_O, \mathcal{A}_M, \mathcal{S}_A, \mathcal{S}_R, \mathcal{R}_O, \mathcal{R}_M)$ be a bimodal argument graph and let $x \in \{\mathsf{grounded}, \mathsf{preferred}\}$. An x-*perspective of $\mathcal{G}$ *is a tuple $(\mathcal{A}'_O, \mathcal{R}'_O)$ if there exists an extension $\mathcal{E} \in \Sigma_x(\mathcal{A}_M, \mathcal{R}_M)$ with*

1. $\mathcal{A}'_O = \{A \mid \exists B \in \mathcal{E}$ *such that* $(B, A) \in \mathcal{S}_A\}$
2. $\mathcal{R}'_O = \{(A_1, A_2) \mid \exists B \in \mathcal{E}$ *such that* $(B, A_1, A_2) \in \mathcal{S}_R\}$

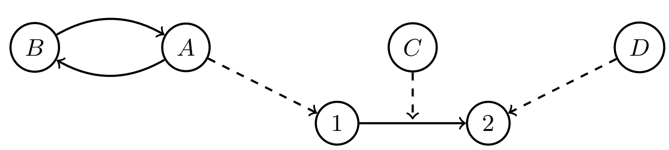
The function $P_x(\mathcal{G})$ returns all x-perspectives of a bimodal argument graph $\mathcal{G}$. For all object-level arguments B, if the meta-level argument for B has no attackers, then B is in every extension.

Proposition 1. *Let $\mathcal{G} = (\mathcal{A}_O, \mathcal{A}_M, \mathcal{S}_A, \mathcal{S}_R, \mathcal{R}_O, \mathcal{R}_M)$ be a bimodal argument graph and let $(A, B) \in \mathcal{S}_A$ such that $\nexists C \in \mathcal{A}_M$ such that $(C, A) \in \mathcal{R}_M$. Then, the object-level argument B is in every perspective of $\mathcal{G}$.*

Since meta-level arguments reason about object-level arguments, an object-argument may be present (acceptable) in one perspective and missing from another perspective. If there is no conflict on the meta-level, the bimodal argument graph simply yields the same results as the object-level graph on its own.

Definition 13 (Controversial Graph). *Let $\mathcal{G} = (\mathcal{A}_O, \mathcal{A}_M, \mathcal{S}_A, \mathcal{S}_R, \mathcal{R}_O, \mathcal{R}_M)$ be a bimodal argument graph. $\mathcal{G}$ is* controversial *iff $\mathcal{R}_M \neq \emptyset$. $\mathcal{G}$ is* uncontroversial *iff $\mathcal{G}$ is not controversial.*

Example 6. The graph shown in Fig. 6 has a disputed argument, (1). For the grounded meta-extension $\{C, D\}$, there is a unique perspective $(\{2\}, \emptyset)$. The two preferred meta-extensions $\mathcal{E}_1 = \{A, C, D\}$ and $\mathcal{E}_2 = \{B, C, D\}$ induce two perspectives $(\{1, 2\}, \{(1, 2)\})$ and $(\{2\}, \emptyset)$ (coinciding with the grounded perspective).



The simplest uncontroversial bimodal graph only has one meta-level argument which supports all object-level arguments and their attacks.

Proposition 2. *Let $\mathcal{G} = (\mathcal{A}_O, \mathcal{A}_M, \mathcal{S}_A, \mathcal{S}_R, \mathcal{R}_O, \mathcal{R}_M)$ be an uncontroversial bimodal graph. Then, $P_{\mathsf{grounded}}(\mathcal{G}) = P_{\mathsf{preferred}}(\mathcal{G}) = \{(\mathcal{A}_O, \mathcal{R}_O)\}$.*

The following result shows that multiple argument graphs can be combined in a single bimodal graph in a way that each one of the original graphs is represented by an admissible perspective of the combination.

Theorem 1. *Let $\mathcal{G}_O$ be an argument graph. For every nonempty set of subgraphs $\mathcal{G}^* \subseteq Subgraphs(\mathcal{G}_O)$, there exists a bimodal graph $\mathcal{G}_B$ such that $P_{\mathsf{admissible}}(\mathcal{G}_B) = \mathcal{G}^*$ and $ObjectGraph(\mathcal{G}_B) = \mathcal{G}_O$.*

If the graphs in $\mathcal{G}^*$ represent a range of argument graphs and it is uncertain what the actual argument graph looks like (unlike a classical abstract argumentation system, where the graph is defined with certainty and the question is which arguments to accept). The number of admissible perspectives (ie the number of admissible extensions of the meta-graph) can then be interpreted as a indicator of the uncertainty inherent in $\mathcal{G}^*$, the original set of graphs.

Another interpretation of Theorem 1 is that of merging multiple sets of knowledge. If the graphs in $\mathcal{G}^*$ represent knowledge bases – perhaps parts of the same global graph – then creating the bimodal graph $\mathcal{G}_B$ is a merge operation that leaves the original sources intact.

6 Meta-ASPIC

Meta-ASPIC uses the language and reasoning of structured argumentation to capture meta-level argumentation. In terms of the meta-level argument hierarchy presented by Wooldridge [18], meta-ASPIC is located on level Δ_2, the first meta-tier. Arguments in meta-ASPIC can refer to object-level arguments (ie to arguments on Δ_1), but not vice versa. Self-reference is therefore not an issue. It is, however, possible to argue about attacks on the object-level and about the applicability of rules, the "constituents" of arguments. Such an argumentative model of structured argumentation is useful when the original definitions need to be extended, for example to incorporate argument schemes (Section 7), preferences, or attacks on attacks.

Before we introduce meta-ASPIC, we will describe the language and notation used in the definitions. The language $\mathcal{L}_m$ of meta-ASPIC is that of grounded predicates $p(t_1, \ldots, t_n)$ applied to terms t_i. A term is either an object-level symbol or a grounded predicate. The rules of meta-ASPIC will be grounded using elements of an object-level knowledge base $\mathcal{K}_O$ and a set of object-level rules $\mathcal{D}_O$. $\mathcal{K}_{\mathtt{m}}$ consists of defeasible object-level rules ($\mathtt{Rule}(a_1, \ldots, a_n \Rightarrow a)$) and facts $\mathtt{Fact}(a)$.

Example 7. $\mathtt{Rule}(\mathtt{a} \Rightarrow \mathtt{b})$ is a predicate where $\mathtt{a} \Rightarrow \mathtt{b}$ is a defeasible rule.

The definition of a structured argument (Def. 6) is captured on the meta-level by creating a set of rules for object-level facts ($\mathcal{D}_k$) and another set of meta-level rules ($\mathcal{D}_d$). The first set contains exactly one grounded predicate for each of the rules and facts in $\mathcal{K}_O$, as defined next. The predicate $\mathtt{Arg}(A, C)$ plays a central role as it denotes an argument A with conclusion C.

Definition 14 (Standard meta-system). *Let $AS_O = (\mathcal{L}_O, \bar{\cdot}_O, \mathcal{D}_O, n_O)$ be an argumentation system (Def. 4) and let $\mathcal{K}_O$ be a knowledge base. Let $\mathcal{G} = (\mathcal{A}, \mathcal{R})$ be the argument graph (Def. 10) of $(AS_O, \mathcal{K}_O)$. Let $\lceil \cdot \rceil$ denote the function that maps defeasible rules to their textual representation.*

The standard meta-system *of* $(AS_O, \mathcal{K}_O)$*,* $AS_{\mathtt{m}} = (\mathcal{L}_{\mathtt{m}}, \bar{\cdot}_{\mathtt{m}}, \mathcal{D}_{\mathtt{m}}, n_{\mathtt{m}})$ *with knowledge base* $\mathcal{K}_{\mathtt{m}}$ *where* $\mathcal{D}_{\mathtt{m}} = D_k \cup D_d \cup D_{att}$ *is defined as*

$$
\begin{aligned}
\mathcal{K}_{\mathtt{m}} &= \{\mathtt{Fact}(\varphi) \mid \varphi \in \mathcal{K}_O\} \cup \{\mathtt{Rule}(r) \mid r \in \mathcal{D}_O\} \\
D_k &= \{\mathtt{Fact}(\varphi) \Rightarrow \mathtt{Arg}([\varphi], \varphi) \mid [\varphi] \in \mathcal{A}\} \\
D_d &= \{\mathtt{Arg}(A_1, \varphi_1), \ldots, \mathtt{Arg}(A_n, \varphi_n), \mathtt{Rule}(r) \Rightarrow \mathtt{Arg}([A_1; \ldots; A_n; r], \varphi) \mid \\
&\quad \exists B = [A_1; \ldots; A_n; r](B \in \mathcal{A} \wedge \forall 1 \leq i \leq n. \varphi_i = Conc(A_i)\} \\
D_{att} &= \{\mathtt{Arg}(A_1, c_1), \mathtt{Arg}(A_2, c_2) \Rightarrow \mathtt{Attacks}(A_1, A_2) \mid \\
&\quad (A_1, A_2) \in \mathcal{R} \wedge Conc(A_1) = c_1 \wedge Conc(A_2) = c_2\} \\
\mathcal{L}_{\mathtt{m}} &= \{Q \mid Q \textit{ is a grounded predicate in } \mathcal{D}_{\mathtt{m}}\} \cup \{\lceil r \rceil \mid r \in \mathcal{D}_O\} \\
n_{\mathtt{m}} &= \lceil \cdot \rceil, \bar{\cdot}_{\mathtt{m}} = \emptyset
\end{aligned}
$$

Object-level arguments, object-level attacks and the "sub-argument"-relation over object-level arguments are represented in the standard meta-system as the following result shows.

Proposition 3. *Let* $AS = (\mathcal{L}, \bar{\cdot}, \mathcal{D}, n)$ *be an argumentation system, let* $\mathcal{K}$ *be a knowledge base and let* $AS_{\mathtt{m}}$ *be the standard meta-system of* AS *with knowledge base* $\mathcal{K}_{\mathtt{m}}$*. Let* $(\mathcal{A}, \mathcal{R})$ *be the argument graph of* $(AS, \mathcal{K})$ *and let* $(\mathcal{A}_{\mathtt{m}}, \mathcal{R}_{\mathtt{m}})$ *be the argument graph of* $(AS_{\mathtt{m}}, \mathcal{K}_{\mathtt{m}})$*. Then,*

1. $\forall A \in \mathcal{A}, \exists A_m \in \mathcal{A}_{\mathtt{m}}$ *such that* $Conc(A_m) = \mathtt{Arg}(A, Conc(A))$
2. $\forall (A, B) \in \mathcal{R}, \exists A_m \in \mathcal{A}_{\mathtt{m}}$ *such that* $Conc(A_m) = \mathtt{Att}(A, B)$
3. $\forall A, B \in \mathcal{A}$ *. If* $A \sqsubseteq B$ *then* $\exists A_m, B_m \in \mathcal{A}_{\mathtt{m}}$ *such that* $A_m \sqsubseteq B_m$*,* $Conc(A_m) = \mathtt{Arg}(A, Conc(A))$ *and* $Conc(B_m) = \mathtt{Arg}(B, Conc(B))$

A meta-ASPIC system is a structured argumentation system that contains knowledge of an argumentation system in the form of meta-predicates.

Definition 15 (meta-ASPIC). *Let* $AS' = (\mathcal{L}', \bar{\cdot}', \mathcal{D}', n')$ *be an argumentation system (Def. 4) and let* $\mathcal{K}'$ *be a knowledge base.* $(AS', \mathcal{K}')$ *is a* meta-ASPIC system *iff there exists an argumentation system* AS_O *with knowledge base* $\mathcal{K}_O \neq \emptyset$ *such that* $AS_{\mathtt{m}} = (\mathcal{L}_{\mathtt{m}}, \bar{\cdot}_{\mathtt{m}}, \mathcal{D}_{\mathtt{m}}, n_{\mathtt{m}})$ *is the standard meta-system (Def. 14) of* $(AS_O, \mathcal{K}_O)$ *such that* $\mathcal{L}_{\mathtt{m}} \subseteq \mathcal{L}'$*,* $\bar{\cdot}_{\mathtt{m}} \subseteq \bar{\cdot}'$*,* $\mathcal{D}_{\mathtt{m}} \subseteq \mathcal{D}'$*, and* $n_{\mathtt{m}} \subseteq n'$*.*

Example 8. Let $AS, \mathcal{K}$ be an object-level argumentation system and knowledge base as in Ex. 5. The rules to represent facts in the corresponding standard meta system are $D_k = \{\mathtt{Fact(a)} \Rightarrow \mathtt{Arg([a], a)}, \mathtt{Fact(\neg k)} \Rightarrow \mathtt{Arg([\neg k], \neg k)}, \ldots\}$. The single defeasible rule results in $\{\mathtt{Arg([a], a)}, \mathtt{Arg([\neg k], \neg k)}, \mathtt{Rule(a, \neg k \Rightarrow \neg d)}$ $\Rightarrow \mathtt{Arg([a; \neg k; a, \neg k \Rightarrow \neg d], \neg d)}\} = D_d$

The definitions of meta-ASPIC ensure that the resulting arguments conform with bimodal argument graphs. A meta-ASPIC system can thus be transformed into a bimodal argument graph which can be used to evaluate arguments using extension semantics, such as those of Dung [8]. In Def. 16, we separate meta-level arguments from those on the object-level, by classifying them according to their conclusions. Essentially, arguments whose conclusion is $\mathtt{Arg}(X, Y)$ act as meta-support for an object-level argument X with conclusion Y. Attacks are determined likewise, using the predicate $\mathtt{Attacks}(X_1, X_2)$.

Definition 16 (Bimodal Graph from meta-ASPIC). *Let AS be a meta-ASPIC system with knowledge base* $\mathcal{K}$ *and let* $(\mathcal{A}, \mathcal{R})$ *be the argument graph of* $(AS, \mathcal{K})$ *(Def. 10). Let* $\mathcal{G}_{meta} = (\mathcal{A}_O, \mathcal{A}_M, \mathcal{S}_A, \mathcal{S}_R, \mathcal{R}_O, \mathcal{R}_M)$ *be a bimodal argument graph.* $\mathcal{G}_{meta}$ *is the* bimodal graph of $(AS, \mathcal{K})$ *iff*

1. $\mathcal{A}_O = \{X \mid \exists A \in \mathcal{A}.\exists Y.Conc(A) = \texttt{Arg}(X, Y)\}$
2. $\mathcal{A}_M = \mathcal{A}$
3. $\mathcal{S}_A = \{(A, X) \mid \exists A \in \mathcal{A}.\exists Y.Conc(A) = \texttt{Arg}(X, Y)\}$
4. $\mathcal{S}_R = \{(A, X, Y) \mid \exists A \in \mathcal{A}.Conc(A) = \texttt{Attacks}(X, Y)\}$
5. $\mathcal{R}_O = \{(X, Y) \mid \exists A \in \mathcal{A}.Conc(A) = \texttt{Attacks}(X, Y)\}$
6. $\mathcal{R}_M = \mathcal{R}$

A standard meta-system contains one meta-level argument for each object-level argument and for each object-level attack. The bimodal graph of a standard meta-system does not have any attacks on the meta-level.

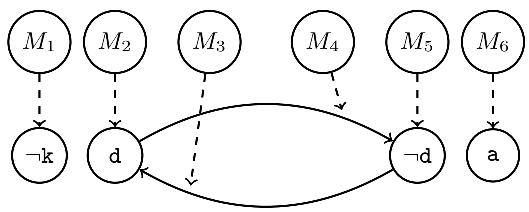


Fig. 3. A bimodal argument graph reflecting Ex. 8. The M_i are meta-level arguments, e.g. $M_1 = [\texttt{Fact}(\neg\texttt{k}); \texttt{Fact}(\neg\texttt{k}) \Rightarrow \texttt{Arg}(\neg\texttt{k}, \neg\texttt{k})]$ and $M_4 = [\texttt{Arg}(A_2, \texttt{d}); \texttt{Arg}(A_5, \neg\texttt{d}); \texttt{Arg}(A_2, \texttt{d}); \texttt{Arg}(A_5, \neg\texttt{d}) \Rightarrow \texttt{Attacks}(A_2, A_5)]$ where A_i is the object-level argument of M_i.

Proposition 4. *Let* $AT = (AS, \mathcal{K})$ *be a standard meta-system with knowledge base* $\mathcal{K}$ *and let* $\mathcal{B} = (\mathcal{A}_O, \mathcal{A}_M, \mathcal{S}_A, \mathcal{S}_R, \mathcal{R}_O, \mathcal{R}_M)$ *be its bimodal graph (Def. 16). Then,* $\mathcal{B}$ *is uncontroversial.*

Meta-ASPIC as presented so far provides a baseline for argument schemes, as we explain in the next section.

7 Argument Schemes

Argument schemes are patterns of informal reasoning [17]. An argument scheme consists of a set of conditions and a conclusion. If the conditions are met, then the conclusion holds. Each argument scheme is associated with set of critical questions. Each critical question identifies possible attacks on arguments derived from argument schemes, by pointing out either a condition that must hold for an argument scheme to be applied, or an exception that renders an argument scheme invalid for a specific instance.

The classification of informal arguments by argument schemes helps to identify similar kinds of argumentation. Argument schemes can also be used to identify weaknesses in argumentation, by making explicit the underlying assumptions of an argument and by providing a list of typical attacks on arguments from argument schemes, in the form of critical questions.

Throughout this section, we develop the notion of argument schemes based on a use case from our industry partner. This use case is presented in the examples, starting with Ex. 9.

Example 9. Several engineers are designing a rib that is part of a wing. They are currently trying to decide on a material (`Mat`). While in reality there is a choice of a large number of alloys and composites, we assume here that the principal decision is only that of aluminium (`Al`) or composite materials (`Comp`). The choice will be represented as `Mat(Comp)` or `Mat(Al)`.

The two options are mutually exclusive. This constitutes the first argument scheme used in this example: Argument from Alternative. This alternative is expressed by the fact `Alter(Mat(Comp), Mat(Al))`. Since aluminium and composites cannot both be chosen at the same time, choosing one means excluding the other. The argument scheme is represented as

$$\begin{array}{l}\texttt{Arg}(A_1, \texttt{Mat}(\texttt{Comp})), \texttt{Arg}(A_2, \texttt{Mat}(\texttt{Al})), \texttt{Alter}(\texttt{Mat}(\texttt{Comp}), \texttt{Mat}(\texttt{Al})) \\ \Rightarrow \texttt{Attacks}(A_1, A_2)\end{array} \qquad (MR_1)$$

And an analogous rule MR_2 with the conclusion $\texttt{Attacks}(A_2, A_1)$. We use labels MR_i for defeasible rules which result in meta-level arguments. It is important to note that, even though MR_1 and MR_2 seem to be based on the logical axiom *tertium non datur*, it behaves differently, because the assumption that a third option does not exist can be attacked (and indeed there are more than two possible materials for the component).

Having established the external constraints of the solution, we now turn to the actual debate about the materials. Engineer `E` is recognised by her peers as an expert on metallurgy (abbreviated `Mly`) and suggests to use aluminium.

$$\begin{array}{l}\texttt{Expert}(\texttt{E}, \texttt{Mly}), \texttt{Domain}(\texttt{Mat}, \texttt{Mly}), \texttt{Asserts}(\texttt{E}, \texttt{Mat}(\texttt{Al})) \\ \Rightarrow \texttt{Arg}(\texttt{Mat}(\texttt{Al}), \texttt{Mat}(\texttt{Al}))\end{array} \qquad (MR_3)$$

In reality, arguments from expert opinion usually do not just state a conclusion without backing it up with further evidence. Instead, expert arguments summarise the expert's reasoning as well as the conclusion [16]. For example, `E` might recommend aluminium based on her experience with similar designs. Due to the limited space we omit these details here.

It turns out that the knowledge of `E`, the expert, may be outdated because `E` has not published any work on metallurgy recently (`NoPub(E, Mly)`). This opens the argument from expert opinion to an attack on one of its premises (conditions):

$$\texttt{NoPub}(\texttt{E}, \texttt{Mly}) \Rightarrow \neg\texttt{Expert}(\texttt{E}, \texttt{Mly}) \qquad (MR_4)$$

This attack is an example of a common pattern. Every argument scheme is associated with a list of "Critical Questions", questions which point to potential weaknesses of the argument. Some critical questions, such as the one expressed in MR_4, target the conditions of an argument scheme. Another type of critical questions is aimed at exceptions to the applicability of a scheme.

Another common pattern of argumentation is to argue from (positive or negative) consequences. In our example, heavy components increase the fuel consumption of airplanes. Minimising weight is therefore very important in aerospace design. The relatively high weight of aluminium is a reason to avoid it. This argument scheme is known as Argument from Negative Consequences (bringing about A will result in C, C is negative, therefore A should not be brought about).

$$\texttt{BadCons}(\texttt{Mat}(\texttt{Al})) \Rightarrow \texttt{Arg}(\texttt{BadCons}, \neg\texttt{Mat}(\texttt{Al})) \quad (MR_5)$$

Conversely, using composites will have positive consequences, since it is lighter.

$$\texttt{GoodCons}(\texttt{Mat}(\texttt{Comp})) \Rightarrow \texttt{Arg}(\texttt{GoodCons}, \texttt{Mat}(\texttt{Comp})) \quad (MR_6)$$

With the meta-level rules MR_1 to MR_6, several arguments from argument schemes can be formed. The bimodal graph of this example is shown below. Since the meta-level extensions conincide, there is only one perspective which results in the acceptance O_C and $O_{\overline{Al}}$ on the object-level.

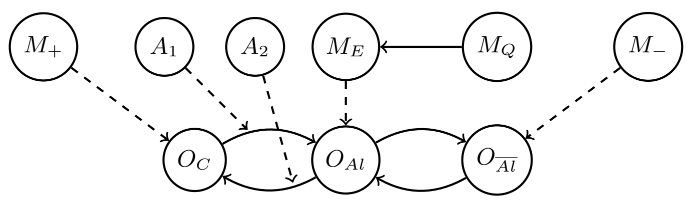


Fig. 4. Bimodal graph of Ex. 9. The arguments are $M_+ = [\texttt{GoodCons}(\texttt{Mat}(\texttt{Comp})); MR_6]$ (Arg. from Positive Consequences), $A_1 = [\texttt{Alter}(\texttt{Mat}(\texttt{Comp}), \texttt{Mat}(\texttt{Al})); MR_+]$ (Arg. from Alternative), $M_E = [\texttt{Expert}(\texttt{E}, \texttt{Mly}), \texttt{Domain}(\texttt{D}, \texttt{Mly}), \texttt{Asserts}(\texttt{E}, \texttt{Mat}(\texttt{Al})); MR_3]$ (Arg. from Expert Opinion), $M_Q = [\texttt{NoPub}; MR_4]$ and $M_- = [\texttt{BadCons}(\texttt{Mat}(\texttt{Al})); MR_5]$

Argument schemes affect the object-level arguments and object-level attacks. They can therefore be defined using the appropriate predicates of meta-ASPIC.

Definition 17 (Argument Scheme). *Let $\varphi_1, \ldots, \varphi_n \Rightarrow \varphi$ be defeasible rule. $\varphi_1, \ldots, \varphi_n \Rightarrow \varphi$ is an* argument scheme *iff $\varphi \in \{\texttt{Arg}(A, X), \texttt{Attacks}(A_1, A_2)\}$ for any arguments A, A_1, A_2.*

Critical questions are defined similarly. Definition 18 ensures that arguments from argument schemes can be attacked by arguments whose last rule is a critical question.

Definition 18 (Critical Question). *Let $r = \varphi_1, \ldots, \varphi_n \Rightarrow \varphi$ be an argument scheme and let $c = \psi_1, \ldots, \psi_n \Rightarrow \psi$ be a defeasible rule. c is a* critical question *for r iff $\psi \in \overline{\varphi_n}$ (Condition) or $\psi \in \overline{n(r)}$ (Exception)*

This section demonstrated how the language of meta-ASPIC may be used to model the use of argument schemes as meta-level arguments. The case study illustrates the advantages of modeling argument schemes using meta-argumentation for both arguments and attacks on the object-level.

8 Discussion

We presented an approach to meta-level argumentation with argument schemes based on three lines of work: Structured argumentation, meta-level argumentation and bimodal graphs. The framework for structured argumentation is a lightweight model that allows one to express object-level and meta-level arguments. The interactions of arguments are evaluated using bimodal argument graphs. We developed a set of argument schemes based on a case study from the aerospace industry.

The version of meta-ASPIC presented in this paper only uses a subset of the original ASPIC+ system. However, we formally prove elsewhere that the full meta-ASPIC gives exactly the same results as ASPIC+. Argumentation systems that already use ASPIC+ can thus easily be transformed into using meta-ASPIC to gain extensibility as demonstrated for example in Section 7.

Our model of argument schemes builds upon a recent by Sklar *et al.* [15] in two ways. Firstly, the argument schemes we consider include not only social argumentation patterns (authority, *ad hominem*, etc.) but also factual patterns determined by context (Argument from Alternative in Ex. 9 and Argument from Analogy), which are employed frequently in engineering. Secondly, the meta-argumentation system presented above handles arguments about attacks (object-level argument A attacks object-level argument B), whereas in the approach by Sklar *et al.*, such argument schemes can only change the status of arguments (object-level argument A is defeated because of an *ad hominem* attack on the meta-level).

There are two avenues for future work. The first one is to extend the theoretical foundation of bimodal graphs, in particular to explore their relation to abstract argumentation in a similar fashion to [11], in order to deepen the understanding of argument schemes. The second direction is to implement the framework in order to measure its performance and usefulness, particularly regarding the case study.

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