Handling Heterogeneous Disagreements Through Abstract Argumentation (Extended Abstract)

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Abstract. Agents disagree in many situations and in many ways on their beliefs, preferences and goals. Abstract argumentation frameworks are a formal model to handle disagreement, which is represented as a conflict relation between a set of arguments. To solve the conflict and identify justified arguments, a single argumentation semantics is applied at a global level, under the assumption that the involved conflicts are essentially homogeneous. In the talk I will argue that disagreements are in general heterogeneous and thus should be treated in different ways according both to their nature and to the specific agents features. Accordingly, a general model of abstract argumentation will be discussed, able to handle heterogeneous disagreements by means of multiple argumentation semantics at a local level.

Keywords: Abstract argumentation · Heterogeneous disagreement · Multiple semantics

1 Background in Abstract Argumentation

Formal argumentation can be considered as a model concerned with how assertions are proposed, discussed and resolved in the context of disagreement [5]. The idea is that reasoning is defeasible and corresponds to a process of production and evaluation of *arguments*, each representing a reason to support (or oppose) a given statement. In general, arguments may be in conflict since the validity of an argument can be disputed by other arguments, which may support an opposite conclusion or attack one of its premises or the validity of an inferential step. As a result, the acceptability of a claim does not only depend on the arguments supporting it, but also on the presence of counterarguments, which in turn can be attacked by counterarguments and so on.

The argumentation model has been proved general and flexible enough to accommodate various kinds of disagreement. In multi-agent systems, such disagreement arises in many situations and in many ways on agents beliefs, preferences and goals, both during their individual reasoning activity (e.g. to revise beliefs in front of perceptual information [7] or to deliberate among a set of possible actions [10]) and in their mutual interaction (as e.g. in negotiation [1]).

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While arguments can have different internal structures giving rise to a variety of argumentation approaches (e.g. [11,13,18]), in order to evaluate the status of arguments their structure may be abstracted away and the attacks between them can be represented simply as a binary relation. This corresponds to the model of *abstract argumentation frameworks* [8], specifically devoted to conflict management, where arguments are the nodes of a directed graph $AF = (Ar, att)$ whose edges correspond to their conflict relation: we say that argument a attacks argument b if $(a, b) \in att$. To solve the conflict and identify justified arguments, various *argumentation semantics* have been devised that can be introduced by means of the notion of *extension*, intuitively representing a set of arguments that can survive the conflict together. Given an $AF = (Ar, att)$, an argumentation semantics $\mathcal{S}$ associates to AF a set of extensions, i.e. subsets of Ar, denoted as $\mathcal{E}_{\mathcal{S}}(AF)$. An argument is then skeptically justified if it belongs to all extensions, while it is credulously justified if it belongs to at least one of them.

Specific argumentation semantics differ in the definition of extension adopted. Most of them are based on the notion of admissibility: a set of arguments $\mathcal{A}rgs$ is *admissible* if it is conflict-free, i.e. $\neg\exists a, b \in \mathcal{A}rgs : a$ attacks b, and able to *defend* all of its elements, i.e. for any argument b which attacks an argument $a \in \mathcal{A}rgs$, there is an argument $c \in \mathcal{A}rgs$ such that c attacks b. Intuitively, admissible sets feature a sort of internal coherence and are able to provide a counterargument to any opposite argument that may be advanced. A further requirement for extensions is *completeness*, i.e. one should not abstain about an argument which is defended: a *complete extension* is an admissible set including all arguments it defends. Most argumentation semantics then identify their extensions among complete extensions, by introducing additional conditions on them. In particular[1]:

- *Grounded semantics* (**GR**) identifies as its unique extension the least (w.r.t. $\subseteq$) complete extension;
- *Stable semantics* (**ST**) identifies as its extensions the complete extensions each of them able to attack all arguments outside it;
- *Preferred semantics* (**PR**) identifies as its extensions the maximal (w.r.t. $\subseteq$) complete extensions;
- *Ideal semantics* (**ID**) identifies as its unique extension the maximal set (w.r.t. $\subseteq$) which is admissible and contained in all preferred extensions [9].

In the following, **GR** and **ID** will be called unique-status semantics, while stable and preferred semantics will be called multiple-status semantics. Intuitively, **GR** corresponds to the most skeptical semantics among those based on complete extensions, as it justifies the smallest possible set of arguments. Conversely, **ST** and **PR** are able to justify more arguments by exploiting multiple extensions. In particular, **ST** is more committed than **PR**, by adopting a definition of extension where any argument is either in the extension or is attacked by it, while **PR** adopts a weaker definition which, differently from **ST**, always guarantee

[1] The reader is referred to [3] for an introduction to argumentation semantics also including additional proposals.

the existence of extensions [8]. **ID** can be considered a unique-status semantics which is more committed than **GR**, as it always justifies a (sometimes strict) superset of the grounded extension, but also more skeptical than **PR**, as it adds the requirement of admissibility to the set of skeptically justified arguments according to **PR**.

Whereas in the brief introduction above I have used the term *skepticism* informally to characterize argumentation semantics, in [4] several partial orders have been defined to provide a formal counterpart to the tendency of making more or less committed choices about argument justification. Here I need to recall the following relations, with reference to two argumentation semantics $\mathcal{S}_1$ and $\mathcal{S}_2$:

- $\mathcal{S}_1 \preceq^S_{\cap+} \mathcal{S}_2$ iff for any AF where both $\mathcal{S}_1$ and $\mathcal{S}_2$ identify a non empty set of extensions, $\forall E_2 \in \mathcal{E}_{\mathcal{S}_2}(AF)\ \exists E_1 \in \mathcal{E}_{\mathcal{S}_1}(AF) : E_1 \subseteq E_2$.
- $\mathcal{S}_1 \preceq^S_{\cup+} \mathcal{S}_2$ iff for any AF where both $\mathcal{S}_1$ and $\mathcal{S}_2$ identify a non empty set of extensions, $\forall E_1 \in \mathcal{E}_{\mathcal{S}_1}(AF)\ \exists E_2 \in \mathcal{E}_{\mathcal{S}_2}(AF) : E_1 \subseteq E_2$.

Intuitively, $\mathcal{S}_1 \preceq^S_{\cap+} \mathcal{S}_2$ indicates that $\mathcal{S}_1$ is more skeptical w.r.t. $\mathcal{S}_2$ according to a skeptical viewpoint on argument justification, since every extension in $\mathcal{E}_{\mathcal{S}_2}(AF)$ has a more skeptical counterpart in $\mathcal{E}_{\mathcal{S}_1}(AF)$, while $\mathcal{E}_{\mathcal{S}_1}(AF)$ can include additional unrelated extensions (that can only lead to less committed choices on argument justification). Dually, $\mathcal{S}_1 \preceq^S_{\cup+} \mathcal{S}_2$ indicates that $\mathcal{S}_1$ is more skeptical w.r.t. $\mathcal{S}_2$ according to a credulous viewpoint on argument justification.

Referring to the argumentation semantics introduced above, it turns out that $\mathbf{GR} \prec^S_{\cap+} \mathbf{ID} \prec^S_{\cap+} \mathbf{PR} \prec^S_{\cap+} \mathbf{ST}$ and $\mathbf{GR} \prec^S_{\cup+} \mathbf{ID} \prec^S_{\cup+} \mathbf{ST} \prec^S_{\cup+} \mathbf{PR}$ (where $\mathcal{S}_1 \prec^S_{\cap+} \mathcal{S}_2$ denotes that $\mathcal{S}_1 \preceq^S_{\cap+} \mathcal{S}_2$ and $\mathcal{S}_2 \not\preceq^S_{\cap+} \mathcal{S}_1$, and similarly for $\prec^S_{\cup+}$).

2 Handling Heterogeneous Disagreements: Introduction and Motivation

While various argumentation semantics have appeared in the literature, with the exception of [17] no proposal has been made to mix different semantics in the same argumentation framework. However, there are several motivations for this.

From a general point of view, it has to be noted that no semantics has prevailed over the others, rather different proposals are meant to satisfy specific properties and/or fulfill some desired behavior in problematic examples [3,6]. It is then likely that which semantics to adopt should depend on the application context. For the same reason, it is reasonable to make it possible to apply specific semantics in different parts of the same argumentation framework, reflecting the heterogeneous nature of the corresponding conflicts.

In this respect, different semantic treatments have been advocated in the literature, either directly or indirectly. In the context of single agents, one reason for this concerns the nature of arguments involved in conflicts. In particular, a distinction has been advocated in [16] between epistemic and practical reasoning, i.e. reasoning over beliefs vs reasoning about what to do (where the latter concerns goals, desires and intentions). While in the first case conflicts between arguments arise mainly from uncertainty and incompleteness of information, in the second case distinct goals may conflict since they cannot all be fulfilled due resource limitations. As a consequence, in [16] grounded semantics is proposed to deal with epistemic arguments, on the grounds that truth is at stake and a skeptical approach ensures that only well established arguments can be justified. The idea is that in case of indecision it is better to do further investigations (e.g. acquiring additional information) to solve the conflicts, rather than making an arbitrary choice between conflicting arguments. On the other hand, a very credulous approach is advocated for practical arguments, i.e. selecting a preferred extension at random, in order to always enforce a choice over equally preferable alternatives.

Focusing on epistemic reasoning, it can be noted that to achieve a skeptical behavior there are several alternatives to grounded semantics. In this respect, a paradigmatic example is a modification of the so-called "Nixon Diamond", where two conflicting arguments support the same conclusion that Nixon is politically extreme. In particular, one of the arguments is based the premise that Nixon is a Quaker, implying that he is presumably a dove thus politically extreme, while the other argument yields the same conclusion based on the premise that he is Republican, thus presumably a hawk. To get the shared conclusion as justified, we have to adopt a multiple-status semantics (such as preferred semantics) and justify all those propositions that appear as conclusions of at least an argument in any preferred extension. These include the so-called "floating conclusions" which turn out to be justified even if not supported by any skeptically justified argument.

On the other hand, John Horty in [12] provides some examples where this solution appears as counterintuitive, i.e. there are cases where the conflict arising between extensions seems to undermine the assumption, underlying multiple-status semantics, that one of them is correct. In these cases, rather than considering multiple extensions it seems more appropriate to doubt about them and adopt a single-status approach such as the grounded semantics. A rebuttal to this conclusion is provided in [15], where the problematic examples in [12] are modelled by adding extra-information in such a way that the intuitive results can still be obtained with the approach based on multiple extensions. I note however that the corresponding modelling is relatively complex, thus depending on the audience an equivalent formalization based on multiple semantics may be more intuitive.

In general, the choice of the appropriate semantics seems to depend on practical considerations. Besides those outline above, the cost of evaluation errors may play a role in this choice [12], i.e. more skeptical semantics should be adopted for the more critical arguments in this respect. Moreover, since different semantics feature different computational complexities, most complex ones may be devoted to most relevant arguments w.r.t. the focus of attention towards a specific issue [17].

Finally, considering multi-agent systems it may well be the case that different agents feature different reasoning attitudes, being e.g. more confident or thoughtful [14]. In the context of argumentation-based reasoning, different attitudes correspond to the adoption of semantics featuring different degrees of skepticism. In this respect, multiple semantics play a role both to model the interaction among individual agents, and when an agent represents the reasoning of another agent and selects a corresponding semantics based e.g. on its estimated sincerity and competence [17].

3 Multiple Argumentation Semantics: A Basic Requirement and Preliminary Results

Based on the above considerations, given an argumentation framework $AF = (Ar, att)$ it makes sense to consider a partition $\mathcal{P} = \{P_1, \ldots, P_n\}$ of Ar where each element P_i is associated to a specific semantics[2] $S(P_i)$. The question is then how to properly introduce a definition of extension arising from the application of different semantics at a local level.

To this purpose, we may first consider the limit case where all the elements of the partition are associated to the same semantics $\mathcal{S}$: in this case, a sensible requirement[3], that we call *uniform semantics equivalence*, is that the novel definition should return the same extensions as $\mathcal{S}$ applied to the whole argumentation framework. This limit case is strongly related to the notion of *semantics decomposability* which has been extensively investigated in [2]. Intuitively, a semantics $\mathcal{S}$ is fully decomposable if, given a partition of an argumentation framework into a set of sub-frameworks, the outcomes produced by $\mathcal{S}$ can be obtained as a combination of the outcomes produced by a local counterpart of $\mathcal{S}$ applied separately on each sub-framework, and vice versa.

To simplify the formal treatment, it is convenient to adopt a labelling-based counterpart of semantics definitions [3] where an extension E is replaced by a corresponding *labelling*, i.e. a total function that associates to each argument a label in $\{\texttt{in}, \texttt{out}, \texttt{undec}\}$, such that an argument a is labelled `in` iff $a \in E$; it is labelled `out` iff $\exists\ b \in E$ such that b attacks a; it is labelled `undec` if neither of the above conditions holds. Thus, a semantics $\mathcal{S}$ returns for any AF a set of labellings $\mathcal{L}_{\mathcal{S}}(AF)$ instead of a set of extensions. Given a set of arguments Ar, we denote as $\mathfrak{L}_{Ar}$ the set including all possible labellings of Ar.

In order to formally describe the interactions between the sub-frameworks induced by the arbitrary partition, we exploit the notion of *argumentation framework with input*, namely a tuple $(AF_L, \mathcal{I}, \mathcal{L}ab_{\mathcal{I}}, att_{\mathcal{I}})$, including an argumentation framework $AF_L = \langle Ar, att \rangle$, a set of arguments $\mathcal{I}$ such that $\mathcal{I} \cap Ar = \emptyset$ (playing the role of *input* arguments, i.e. affecting AF_L from the outside), a labelling $\mathcal{L}ab_{\mathcal{I}} \in \mathfrak{L}_{\mathcal{I}}$ (i.e. a labelling assigned to $\mathcal{I}$, to be taken into account in the local semantics evaluation inside AF_L) and a relation $att_{\mathcal{I}} \subseteq \mathcal{I} \times Ar$ (i.e. the attack relation from input arguments to Ar). The local semantics evaluation for the arguments of AF_L is then expressed by a *local function* F, which assigns to any

[2] This has been first proposed in [17] and called sorting.

[3] Focusing on extension-based semantics, this has been called *Uniform Case Extension Equivalence* in [17].

argumentation framework with input a (possibly empty) set of labellings, i.e. $F(AF_L, \mathcal{I}, \mathcal{L}ab_{\mathcal{I}}, att_{\mathcal{I}}) \in 2^{\mathfrak{L}_{Ar}}$, where $\mathfrak{L}_{Ar}$ is the set of all labellings of AF_L.

A semantics $\mathcal{S}$ is *fully decomposable* iff there is a local function F such that for every argumentation framework $AF = \langle Ar, att \rangle$ and every partition $\mathcal{P} = \{P_1, \ldots, P_n\}$ of Ar it holds that $\mathcal{L}_{\mathcal{S}}(AF) = \mathcal{U}(\mathcal{P}, AF, F)$ with $\mathcal{U}(\mathcal{P}, AF, F) \triangleq \{\mathcal{L}ab_{P_1} \cup \ldots \cup \mathcal{L}ab_{P_n} \mid \mathcal{L}ab_{P_i} \in F(AF{\downarrow_{P_i}}, {P_i}^{\mathrm{inp}}, (\bigcup_{j=1 \ldots n, j \neq i} \mathcal{L}ab_{P_j}){\downarrow_{{P_i}^{\mathrm{inp}}}}, {P_i}^R)\}$, where $AF{\downarrow_{P_i}} = (P_i, att \cap (P_i \times P_i))$ is the restriction of AF to P_i, ${P_i}^{\mathrm{inp}} = \{a \notin P_i \mid \exists b \in P_i : (a,b) \in att)\}$ includes the external arguments attacking P_i, $(\bigcup_{j=1 \ldots n, j \neq i} \mathcal{L}ab_{P_j}){\downarrow_{{P_i}^{\mathrm{inp}}}}$ is the labelling externally assigned[4] to ${P_i}^{\mathrm{inp}}$, and ${P_i}^R = att \cap ({P_i}^{\mathrm{inp}} \times P_i)$ is the attack relation from ${P_i}^{\mathrm{inp}}$ to P_i.

It is proven in [2] that, under some mild conditions, if a semantics $\mathcal{S}$ is fully decomposable then the local function used to compute the local labellings is unique, and corresponds to the so called *canonical local function* $F_{\mathcal{S}}$. The latter can be identified by applying $\mathcal{S}$, for any argumentation framework with input, to a corresponding *standard argumentation framework* where the input labelling is enforced through the addition of arguments attacking `out`-labelled arguments and self-attacks for all `undec`-labelled arguments.

We can then generalize the above definition to the case of multiple semantics. Considering an $AF = (Ar, att)$ and a partition $\mathcal{P} = \{P_1, \ldots, P_n\}$ of Ar with associated semantics $S(P_i)$, one is led to define the resulting labellings as $\{\mathcal{L}ab_{P_1} \cup \ldots \cup \mathcal{L}ab_{P_n} \mid \mathcal{L}ab_{P_i} \in F_{S(P_i)}(AF{\downarrow_{P_i}}, {P_i}^{\mathrm{inp}}, (\bigcup_{j=1 \ldots n, j \neq i} \mathcal{L}ab_{P_j}){\downarrow_{{P_i}^{\mathrm{inp}}}}, {P_i}^R)\}$. It is then easy to see that the basic requirement of uniform semantics equivalence w.r.t. a semantics $\mathcal{S}$ coincides with the property of full decomposability of $\mathcal{S}$.

Table 1 reports some results from [2] concerning the decomposability properties of argumentation semantics, also including **CO** that denotes the semantics identifying as its labellings all complete labellings. In the table, top-down decomposability holds iff for any AF and any partition $\mathcal{P}$, $\mathcal{L}_{\mathcal{S}}(AF) \subseteq \mathcal{U}(\mathcal{P}, AF, F_{\mathcal{S}})$, while bottom-up decomposability holds iff $\mathcal{L}_{\mathcal{S}}(AF) \supseteq \mathcal{U}(\mathcal{P}, AF, F_{\mathcal{S}})$. Top-down and bottom-up decomposability can be viewed as two partial decomposability properties, indicating that the combination of the labellings locally computed by $F_{\mathcal{S}}$ on the partition is complete and correct w.r.t. the globally computed labellings, respectively. Table 1 also reports the decomposability properties restricting the allowed partitions so that every element is the union of some strongly connected components (SCCs). From the perspective of mixing semantics, we can summarize these results as follows:

- admissibility and completeness are preserved by the definition introduced above: due to full decomposability of **CO**, mixing semantics based on complete labellings (such as those considered in this paper) always yields a set of complete labellings;

[4] More precisely, given a labelling $\mathcal{L}$ and a set of arguments $\mathcal{A}rgs$, $\mathcal{L}{\downarrow_{\mathcal{A}rgs}} \equiv \mathcal{L} \cap (\mathcal{A}rgs \times \{\mathtt{in}, \mathtt{out}, \mathtt{undec}\})$.

– only stable semantics is fully decomposable with arbitrary partitions, thus the uniform semantics equivalence is not satisfied in the general case;
– on the other hand, full decomposability is recovered for all semantics besides **ID** if partitions based on SCCs are considered.

It should be noted that the partitions based on SCCs include the case where an argumentation framework is partitioned in two sets, i.e. a set without attacks from external arguments and the remainder of the framework. This is the case e.g. of the approach recalled in the previous section integrating epistemic and practical reasoning. Actually, in [16] epistemic arguments identify an unattacked set, since they can attack the practical ones but not vice versa.

Table 1. Decomposability properties of argumentation semantics.

	CO	ST	GR	PR	ID
Full decomposability	Yes	Yes	No	No	No
Top-down decomposability	Yes	Yes	Yes	Yes	No
Bottom-up decomposability	Yes	Yes	No	No	No
Full decomposability w.r.t. SCC	Yes	Yes	Yes	Yes	No
Top-down decomposability w.r.t. SCC	Yes	Yes	Yes	Yes	No
Bottom-up decomposability w.r.t. SCC	Yes	Yes	Yes	Yes	No

Finally, on the basis of top-down decomposability of **GR** and **PR**, it can be proved that uniform semantics equivalence is recovered for **GR** and **PR** by adding to $\mathcal{U}(\mathcal{P}, AF, F_{\mathcal{S}})$ a minimality and maximality condition, respectively. More specifically, let us denote with $\sqsubseteq$ the commitment relation between labellings such that $\mathcal{L}_1 \sqsubseteq \mathcal{L}_2$ iff $\texttt{in}(\mathcal{L}_1) \subseteq \texttt{in}(\mathcal{L}_2)$ and $\texttt{out}(\mathcal{L}_1) \subseteq \texttt{out}(\mathcal{L}_2)$, where $\texttt{in}(\mathcal{L})$ and $\texttt{out}(\mathcal{L})$ denote the arguments labelled `in` and `out` by $\mathcal{L}$, respectively. Then, for grounded semantics it holds that $\mathcal{L}_{\mathbf{GR}}(AF) = \min_{\sqsubseteq} \mathcal{U}(\mathcal{P}, AF, F_{\mathcal{S}})$, and for preferred semantics it holds that $\mathcal{L}_{\mathbf{PR}}(AF) = \max_{\sqsubseteq} \mathcal{U}(\mathcal{P}, AF, F_{\mathcal{S}})$.

4 Discussion and Open Issues

The results of the previous section show that, under some restrictions on the allowed partitions, the local semantics computation proposed in [2] can be extended to multiple semantics. This raises several research issues, both from the perspective of adopting such schema and along the direction of revising it.

As to the first perspective, an interesting issue is to identify further restrictions on the partitions that guarantee uniform semantics equivalence, possibly considering also ideal semantics. Moreover, it would be interesting to formally characterize the labellings obtained by mixing semantics w.r.t. the skepticism relations. In particular, one may expect the resulting semantics to feature a somewhat intermediate level of skepticism w.r.t. individual semantics, and the level of skepticism to monotonically depend on that of individual semantics. As to the last point, replacing a semantics associated to a sub-framework e.g. with a more skeptical one should correspondingly result in a more skeptical semantics.

As to the revision of the proposed computation schema, a starting point may be the minimization/maximization of labellings, which as shown above yields uniform semantics equivalence for **GR** and **PR** in the general case. However, it is not really clear how this can be applied in case of multiple semantics. Another option would be to modify the "interface" between sub-frameworks by increasing the amount of information exchanged between them (currently including only the labels assigned to external attackers). This would require a significant revision of the proposed computation schema, paving the way for significant further research.

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