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On the Input/Output behavior of argumentation frameworks

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ABSTRACT

This paper tackles the fundamental questions arising when looking at argumentation frameworks as interacting components, characterized by an Input/Output behavior, rather than as isolated monolithical entities. This modeling stance arises naturally in some application contexts, like multi-agent systems, but, more importantly, has a crucial impact on several general application-independent issues, like argumentation dynamics, argument summarization and explanation, incremental computation, and inter-formalism translation. Pursuing this research direction, the paper introduces a general modeling approach and provides a comprehensive set of theoretical results putting the intuitive notion of Input/Output behavior of argumentation frameworks on a solid formal ground. This is achieved by combining three main ingredients. First, several novel notions are introduced at the representation level, notably those of *argumentation framework with input*, of *argumentation multipole*, and of *replacement* of multipoles within a traditional argumentation framework. Second, several relevant features of argumentation semantics are identified and formally characterized. In particular, the *canonical local function* provides an input-aware semantics characterization and a suite of *decomposability* properties are introduced, concerning the correspondences between semantics outcomes at global and local level. The third ingredient glues the former ones, as it consists of the investigation of some semantics-dependent properties of the newly introduced entities, namely **S**-*equivalence* of multipoles, **S**-*legitimacy* and **S**-*safeness* of replacements, and *transparency* of a semantics with respect to replacements. Altogether they provide the basis and draw the limits of sound interchangeability of multipoles within traditional frameworks. The paper develops an extensive analysis of all the concepts listed above, covering seven well-known literature semantics and taking into account various, more or less constrained, ways of partitioning an argumentation framework. Diverse examples, taken from the literature, are used to illustrate the application of the results obtained and, finally, an extensive discussion of the related literature is provided.

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1. Introduction

This paper deals with modularity in abstract argumentation. The "Merriam-Webster Learner's Dictionary" defines *modular* as "having parts that can be connected or combined in different ways" while the "Free Dictionary online" remarks that modularity is intended "for easy assembly and repair or flexible arrangement and use". As such, modularity is a highly desirable property, often enforced by design, in any kind of either material (like the popular Lego toys) or immaterial (like programs developed according to the object-oriented paradigm) artifacts, including knowledge representation and reasoning formalisms.

Roughly speaking, modularity involves two main properties, namely *separability* and *interchangeability* of modules. As to the former, it has to be possible to describe and analyze the global behavior of an artifact in terms of the combination of the local behaviors of the modules composing it. Each local behavior can be characterized individually in a way which is independent of the internal details of the other modules (and, in a sense, of the module itself) and captures only the connections and mutual interactions between the module and the other ones. To put it in other words, each module can be described as a black-box whose Input/Output behavior fully determines its role in the global behavior of any artifact it is plugged in. As to the latter, the interest in replacing a module with another one is very common and arises from a large variety of motivations, either at the operational or design level. Interchangeability of two modules requires first of all that they are compatible as far as the connections with the rest of the artifact are concerned, i.e. that the interfaces they expose are such that wherever one of the modules can be "plugged in", the other can too. Besides this *plug-level* interchangeability, it is of great interest to characterize the *behavior-level* interchangeability of modules, namely to identify the situations where internally different modules can be freely interchanged without affecting the global behavior of the artifact they belong to, since their Input/Output behavior is equivalent in this respect.

While the formalism of abstract argumentation frameworks [25] and the relevant argumentation semantics (see [3] for a survey) do not appear to have been designed with modularity in mind, investigating their relevant properties is an important research topic which, after having been somehow overlooked, is attracting increasing attention in recent years. An argumentation framework is basically a directed graph representing the conflicts between a set of arguments (the nodes of the graph) and an argumentation semantics can be regarded as a method to answer (typically in a non-univocal way, i.e. producing a set of alternative answers) the "justification question": "Which is the justification status of arguments given the conflict?"

Referring to a representative set of semantics proposed in the literature, (namely admissible, complete, grounded, preferred, stable, semi-stable and ideal semantics) this paper provides a systematic and comprehensive assessment of modularity in abstract argumentation, by identifying and analyzing in this context the formal counterparts of the general notions of separability and interchangeability described above.

Given a partition of an argumentation framework into *partial* (or *local*) interacting subframeworks, analyzing separability consists in addressing the following issues:

- Is it possible to define a local counterpart of the notion of semantics? i.e. Is there a method to produce local answers to the justification question, taking into account the interactions with other subframeworks?
- Can the set of justification answers prescribed by the (global) semantics be obtained by properly combining (in a bottom-up fashion) the sets of local answers produced in the subframeworks by its local counterpart?
- symmetrically, Can the sets of local answers be obtained (in a top-down fashion) as projections onto the subframeworks of the global answers?

As to the first issue, we introduce the notion of *local function* for a subframework[1] and show that under very mild requirements, satisfied by all semantics considered in this paper, it is possible (and easy) to identify the *canonical local function* for a global semantics. As to the second and third issues, we introduce the formal notions of top-down and bottom-up decomposability, which, jointly, correspond to the notion of (full) decomposability of an argumentation semantics.

Strong as it may seem, full decomposability with respect to every arbitrary partition of every argumentation framework is not unattainable. Indeed, we show that it is satisfied by some of the semantics considered in this paper, while some others are able to achieve at least top-down decomposability and the remaining ones lack all decomposability properties.

As arbitrary partitions correspond to a completely free (if not anarchical) notion of modularity, we also consider a "tidier" style of partitioning, involving the graph-theoretical notion of *strongly connected components*. It turns out that, restricting the set of partitions this way, helps some, but not all, semantics to recover full decomposability.

Turning to interchangeability, we deal with both its plug-level and behavior-level aspects. As to the plug-level, borrowing some terminology from circuit theory, we introduce the notion of *argumentation multipole* as a generic replaceable argumentation component, namely a partial framework interacting through an input and output relation with an external set of invariant arguments.

Plug-level compatibility of two multipoles is a very relaxed notion, since it is only required that two multipoles refer to the same set of external arguments. This is motivated by the fact that imposing a tighter correspondence between Input/

[1] Technically, a subframework is captured by the formal notion of *argumentation framework with input* provided in Definition 11.

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