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Guest Editorial: Argumentation in Multi-Agent Systems

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1. Introduction

The theory of argumentation [52] is a rich, interdisciplinary area of research lying across philosophy, communication studies, linguistics, and psychology. Its techniques and results have found a wide range of applications in both theoretical and practical branches of artificial intelligence and computer science [9, 45]. These applications range from specifying semantics for logic programs [13], to natural language text generation [14], to supporting legal reasoning [7], to decision-support for multi-party human decision-making [22] and conflict resolution [51].

In recent years, argumentation theory has been gaining increasing interest in the multi-agent systems (MAS) research community. On one hand, argumentation-based techniques can be used to specify *autonomous agent reasoning*, such as belief revision and decision-making under uncertainty and non-standard preference policies. On the other hand, argumentation can also be used as a vehicle for facilitating *multi-agent interaction*, because argumentation naturally provides tools for designing, implementing and analysing sophisticated forms of interaction among rational agents. Argumentation has made solid contributions to the theory and practice of multi-agent dialogues.

In this introduction to the special issue, I first briefly introduce some key notions in argumentation theory. I then outline two major applications of argumentation in MAS, namely in autonomous agent reasoning (Section 3) and multi-agent communication (Section 4). Throughout the discussion, I introduce the four papers in this special issue, which are revised and expanded versions of papers selected from the proceedings of the First International Workshop on Argumentation in Multi-Agent Systems (ArgMAS), which was held in New York during July 2004 in conjunction with the International Conference on Autonomous Agents and Multiagent Systems (AAMAS).

2. What is argumentation good for?

According to a recent authoritative reference on argumentation theory, argumentation can be defined as follows:

> *Argumentation is a verbal and social activity of reason aimed at increasing (or decreasing) the acceptability of a controversial standpoint for the listener or reader, by putting forward a constellation of propositions intended to justify (or refute) the standpoint before a rational judge.* ([52], page 5)

Let us decompose the elements of this definition that are most relevant to our discussion. First, the ultimate goal of argumentation is to resolve a "*controversial*" standpoint; controversial in the sense that it is subject to both "*justification*" or "*refutation*" depending on the information available. This distinguishes argumentation from the classical deductive reasoning viewpoint, in which proofs for propositions cannot be contested. Moreover, the nature of the "*standpoint*" can vary. While the classical study of argumentation has focused mainly on propositional standpoints—i.e. things that are believed or known—there is no reason why the standpoint is confined to be propositional. A standpoint can, in principle, range from a proposition to believe, to a goal to try to achieve, to a value to try to promote. That is, argumentation can be used for theoretical reasoning (about what to believe) as well as practical reasoning (about what to do).

Secondly, argumentation is an "*activity of reason*", emphasising that a particular process is to be followed in order to influence the acceptability of the controversial standpoint. This activity and the propositions put forward are to be evaluated by a "*rational judge*": a system that defines the reasonableness of these propositions according to some criteria. An important objective of argumentation theory is to identify such system of criteria.

In summary, argumentation can be seen as the principled interaction of different, potentially conflicting arguments, for the sake of arriving at a consistent conclusion. Perhaps the most crucial aspect of argumentation is the interaction between arguments. Argumentation can give us means for allowing an agent to reconcile conflicting information within itself, for reconciling its informational state with new perceptions from the environment, and for reconciling conflicting information between multiple agents through communication. It is for these reasons that argumentation has begun to receive great interest in the multi-agent systems community. In particular, argumentation lends itself naturally to two main sorts of problems encountered in MAS:

- *Forming and revising beliefs and decisions:* Argumentation provides means for forming beliefs and decisions on the basis of incomplete, conflicting or uncertain information. This is because argumentation provides a systematic means for resolving conflicts among different arguments and arriving at consistent, well-supported standpoints;
- *Rational interaction:* Argumentation provides means for structuring dialogue between participants that have potentially conflicting viewpoints. In particular, argumentation provides a framework for ensuring that interaction respects certain principles (e.g. consistency of each participant's statements).

In the next sections, I shall discuss these applications in more detail and refer to some relevant literature.

3. Argumentation for autonomous agent reasoning

Argumentation is a process of reasoning. Hence, an autonomous agent could weigh arguments for and against different stances in order to arrive at a well-supported stance. In this section, I discuss two main applications of argumentation to autonomous agent reasoning.

3.1. Argumentation for belief revision

One of the main challenges in specifying autonomous agents is the maintenance and updating of its beliefs in a dynamic environment. An agent may receive perceptual information that is inconsistent with its view of the world, in which case the agent needs to update its beliefs in order to maintain consistency. The major challenge of nonmonotonic reasoning formalisms [8] is to specify efficient ways to update beliefs. At the normative level, the AGM paradigm [21] specifies the rationality postulates that must be satisfied by an idealistic process of belief revision. On the operational level, formalisms for mechanising nonmonotonic reasoning include Truth Maintenance Systems (TMS) [12], default logic [46] and circumscription [35].

Argumentation provides an alternative way to mechanise nonmonotonic reasoning. Argument-based frameworks view the problem of nonmonotonic reasoning as a process in which arguments for and against certain conclusions are constructed and compared. Nonmonotonicity arises from the fact that new premises may enable the construction of new arguments to support new beliefs, or stronger counterarguments against existing beliefs. Various argument-based frameworks for nonmonotonic reasoning have been proposed in the last 20 or so years, e.g. [15, 17, 30, 31, 38, 41, 50].[1]

While the above-mentioned frameworks have developed into a solid and mature sub-field of AI, their incorporation into *situated* autonomous agent reasoning remains an opportunity to be pursued. In order to do so, an adequate representation of the environment is needed, and a mechanism for integrating perceptual information into the belief-update mechanism is also required. Moreover, situated agents are required to update their beliefs in a timely fashion in order to take appropriate action accordingly. The first paper in this issue

> "*Argumentation and the Dynamics of Warranted Beliefs in Changing Environments*" by Marcela Capobianco, Carlos I. Chesñevar and Guillermo R. Simari

presents a framework for argumentation-based belief revision for agents situated in an environment. They do so by extending an existing framework for belief revision—based on defeasible logic programs(DeLP) [19]—to enable the agent to handle perceptions. The resulting framework is called *Observation-based Defeasible Logic Programs* (ODeLP). In particular, they focus on improving the efficiency of belief-update by introducing *dialectical trees*, which are a data structures that store precompiled knowledge about potential conflicts among arguments.

3.2. *Argumentation for deliberation and means-ends reasoning*

An autonomous agent does not only maintain a mental picture of its environment. The agent is faced with two additional tasks: the task of *deliberation* in which it decides what state of the world it wishes to achieve—namely its goal—and the task of *means-ends reasoning* in which it forms a plan to achieve this goal. Argumentation is also potentially useful for tackling both these challenges.

Recently, argumentation has been used as a means for choosing among a set of conflicting desires [1] and goals [2]. Another argument-based framework for deliberation has been presented by Kakas and Moraitis [28]. In this approach, arguments and preferences among them are used in order to generate goals based on a changing context.

Fox and Parsons [18] provide an argumentation framework for qualitative reasoning about the expected value of possible actions, in a spirit that parallels classical decision-theoretic reasoning about the expected utility of actions [25]. In their framework, an argument system is used to arrive at a stance on beliefs, while another argument system identifies the *outcomes* of possible actions. Together, arguments over beliefs and the results of actions can be combined to create arguments about the *expected value* of possible actions.

Argumentation has also been used in planning. One of the earliest works on argument-based planning is perhaps John Pollock's use of the notion of defeat among plans [39]. Recently, argument-based approaches have also been used for generating plans [2, 27, 49]. However, such frameworks currently generate relatively simple plans in comparison with algorithms found in the mainstream planning literature [20]. One important question worth exploring is whether argumentation will offer real advances over existing planning algorithms.

4. Argumentation for agent communication

An inherent, almost defining, characteristic of multi-agent systems is that agents need to communicate in order to achieve their individual or collective aims. Argumentation theory has been an inspiration for studying and formalising various aspects of agent communication.

4.1. *Understanding and specifying dialogue protocols*

Argumentation theory has been a major inspiration for exploring different *types* of dialogues in MAS. Argumentation theorists Douglas Walton and Erik Krabbe describe a typology of main atomic dialogue types based on their preconditions (in terms of participants' beliefs) and the outcome that participants seek from the dialogue [55]. Following are the main dialogue types, each with an informal explanation of its preconditions and goals:[2]

1. *Information Seeking:* One participant seeks an answer to some question from another participant. The first participant believes that the second may have such answer.
2. *Persuasion:* Two (or more) participants have conflicting beliefs. One participants seeks to change another participant's belief.
3. *Inquiry:* A number of participants collaborate to reach an answer to some open question—that is, a question for which no one participant knows the answer.
4. *Deliberation:* A number of participants seek to decide on a course of action.
5. *Negotiation:* A number of participants, with conflicting interests and a need to cooperate, attempt to reach agreement over the division of some scarce resources.

In the formal specification of different types of dialogues, two main argumentation-theoretic concepts were adopted by the MAS community: *dialogue-games*, and *argument schemes*. I shall briefly discuss each below.

4.1.1. Dialogue games. One of the most formally precise ways of studying different types of dialogues is through *dialogue-games*. Dialogue-games are interactions between two or more players, where each player makes a *move* by making some utterance in a common communication language, and according to some pre-defined rules. Dialogue-games have their roots in the philosophy of argumentation [6] and were used as a tool for analysing fallacious arguments [23]. Such games have been used by Walton and Krabbe themselves to study fallacies in persuasion dialogues.

Recently, dialogue-games have become influential in AI and MAS, mainly as a means for specifying protocols [32]. A *dialogue-game protocol* is defined in terms of a set of locutions, as well as different types of rules: *commencement rules*, *combination rules*, *commitment rules* and *termination rules* [33]. Commencement and termination rules specify when a dialogue commences and how it terminates. Commitment rules specify how the contents of commitment stores change as a result of different locutions. Finally, combination rules specify the legal sequences of dialogue moves.

In AI and MAS, formal dialogue-game protocols have been presented for different atomic dialogue types in the typology of Walton and Krabbe described above. These include persuasion dialogues [4], inquiry dialogues [26], negotiation [34, 48], and deliberation [24]. Other types of dialogues based on combinations of such atomic dialogues have also been proposed, including team formation dialogues [10], dialogues for reaching collective intentions [11], and dialogues for interest-based negotiation [43]. The second paper in this issue:

> "*A Dialogue Game Protocol for Multi-Agent Argument Over Proposals for Action*" by Katie Atkinson, Trevor Bench-Capon and Peter McBurney

presents a dialogue-game protocol for persuasion over action. The protocol enables two agents to propose, attack and defend an action or course of actions (or inaction).

Dialogue-game protocols offer a number of advantages. First, they offer an intuitive approach to defining protocols and naturally lend themselves to argumentation-theoretic analysis, e.g. of dialogue embedding, commitments and fallacies. Secondly, it has been argued that dialogue-games offer a good compromise between the strict

rule-governed nature of economic auction mechanisms [56] and the greater expressiveness of generic agent communication languages such as FIPA-ACL [16] (see [33]).

4.1.2. Argumentation schemes. Another main inspiration from argumentation theory in MAS is the notion of an *argumentation scheme* [54]. These are schemes that capture stereotypical (deductive or non-deductive) patterns of reasoning found in everyday discourse. For example, Walton specifies 25 argumentation schemes for common types of presumptive reasoning. The most useful aspect of argumentation schemes is that they each have an associated set of *critical questions*. These critical questions help identify various arguments that can be presented in relation to a claim based on the given scheme. Hence, while a scheme can be used to establish a "stance," the set of critical questions help build communication structures about that stance.

Argumentation schemes offer a number of useful features to MAS communication. Their structure helps reduce the computational cost of argument generation, since only certain types of propositions need to be established. This very feature also reduces the cost of evaluating arguments.

A few attempts have been made to utilise the power of argumentation schemes in AI, mainly in constructing argumentation schemes for legal reasoning [40, 53]. In MAS, the paper by Atkinson et al. in this issue (see above) uses an argumentation scheme for proposing actions to structure their dialogue-game protocol. In a similar fashion, Karunatillake et al. [29] present an argument scheme for reasoning about social influences and use it to construct a protocol for negotiation in the presence of social influences. In this issue, the paper

> "*Towards a Formal and Implemented Model of Argumentation Schemes in Agent Communication*" by Chris Reed and Doug Walton

presents a formalised and implemented framework for specifying argumentation schemes. The framework enables the specification of argumentation schemes using the XML-based *argument markup language* (AML). The work reported in this paper provides an important step towards the practical use of argumentation schemes in MAS.

4.2. Integrating communication with autonomous reasoning

We have seen that argumentation can serve both as a framework for implementing autonomous agent reasoning (e.g. about beliefs and actions) and as a means to structure communication among agents. As a result, argumentation can naturally provide a means for integrating communication with reasoning in a unified framework.

To illustrate the above point, consider the following popular example by Parsons et al. [36]. The example concerns two home-improvement agents—agent A_1 trying to hang a painting, and another A_2 trying to hang a mirror. A_1 possesses a screw, a screw driver and a hammer, but needs a nail in addition to the hammer to hang the painting. On the other hand, A_2 possesses a nail, and believes that to hang the mirror, it needs a hammer in addition to the nail. Now, consider the following dialogue (described here in natural language) between the two agents:

A1: *Can you please give me a nail?*
A2: *Sorry, I need it for hanging a mirror.*
A1: *But you can use a screw and a screw driver to hang the mirror! And if you ask me, I can provide you with these.*
A2: *Really? I guess in that case, I do not need the nail. Here you go.*
A1: *Thanks.*

At first, A_2 was not willing to give away the nail because it needed it to achieve its goal. But after finding out the reason for rejection, A_1 managed to persuade A_2 to give away the nail by providing an alternative plan for achieving the latter's goal.

We can use this example to highlight how argumentation-based techniques can provide a comprehensive set of features required for communication. Let us consider these in detail.

1. *Reasoning and Planning:* Argumentation can be used by each agent to form its beliefs about the environment, and to generate plans for achieving their goals. For example, agent A_2 can use argument-based deliberation to arrive at the goal to acquire a nail.
2. *Generating Utterances:* Argumentation can be used to generate arguments for utterances and arguments. For example, after A_1 requests a nail from A_2, the latter builds an argument against giving away the nail by stating that it needs the nail to achieve one of its own goals (namely, hanging the mirror). This information can be used again by A_2 to generate a counter-argument for why A_2 does not need the nail.
3. *Evaluating incoming communication:* Argumentation-based belief revision can be used to evaluate incoming communication. For example, when A_2 received the argument from A_1, it had to evaluate that argument to make sure it is sensible. A_2 would not have accepted A_1's argument if the former did not believe the latter actually possesses a screw and screw driver.
4. *Communication Structuring:* The whole dialogue can be structured through argumentation-based protocols, based on dialogue-games, which may themselves be based on certain argumentation schemes for reasoning about resources and plans.

Indeed, the above example, described in a theoretical framework by Parsons et al. [36], has been fully implemented using an argumentation framework based on abductive logic programming [48]. Other attempts to integrate reasoning and communication within a unified argumentation framework have also been made [5, 43, 47]. A review of these frameworks and others can be found in Rahwan et al. [44].

A particularly important issue on the boundary between communication and internal reasoning is the specification of *argumentation dialogue strategies*. A strategy in an argumentation dialogue specifies what utterances to make in order to bring about some desired outcome (e.g. to persuade the counterpart to perform a particular action). While work on argument evaluation and generation has received much attention, the strategic use of arguments has received little attention in the literature. Recently, the effects of a specific set of agent *attitudes* on dialogue outcomes have been studied [3, 37]. For example, a *confident* agent is happy to assert statements for

which it has an argument, but a more *careful* agent makes assertions only after going through its whole knowledge base and making sure it has no arguments against it. When it comes to more complex dialogue strategies, however, only informal methodologies have been proposed [43, Chapter 5]. In this special issue, the paper

> "*Modular Representation of Agent Interaction Rules through Argumentation*" by Antonis Kakas, Nicolas Maudet and Pavlos Moraitis

provides a formal approach to modelling dialogue strategies themselves as logical theories. In particular, the authors distinguish two theories: a theory that enable agents to generate utterances that conform with the agreed-upon interaction protocol, and another theory that describes the agent's attitudes and strategies. The decision of what to utter at a particular stage in the dialogue is then based on reasoning using both these theories. As such, the paper represents an important step towards a formal realisation of complex argumentation dialogue strategies.

5. Concluding remarks

Argumentation theory has been concerned with the study of rational human reasoning and dialogue for millennia. It is therefore an ideal resource for techniques, results and intuitions for problems in multi-agent reasoning and communication. This special issue has resulted from the first workshop specialised on argumentation in MAS and consolidates some of the main themes that have been developed over the last few years. I hope that the issue serves as a good introduction to the state-of-the-art in this emerging field and inspires more researchers to contribute to it.

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Notes

1. For comprehensive surveys on argument-based approaches to nonmonotonic reasoning, see [9, 42].
2. It is notable that Walton and Krabbe do not claim that this set is comprehensive. Moreover, we omit 'eristic' dialogues, since they are of little interest to us.

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