An Argumentation-based Semantics for Agent Communication Languages

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Abstract. In recent years, the importance of defining a standard framework for agent communication language (ACL) has been widely recognized. However, classical proposals (*mentalistic semantics* and *social semantics*) fail to meet the objectives of verifiability and flexibility required in complex interactions involving heterogenous agents possibly designed by different programmers. In this paper we propose an ACL which allows *heterogenous* agents to engage *flexibly* in the different kinds of dialogues identified by Walton and Krabbe in [14]. To this end, we propose a two-layered semantics which includes a commitment level and a reasoning level based on argumentation.
Key words: Agent Communication Languages, Argumentation, Commitment, Protocol.

1 INTRODUCTION

When building multi-agent systems, we take for granted the fact that the agents which make up the system will need to communicate and to engage in the different types of dialogues dentified by Walton and Krabbe in [14], using a communication language (ACL).
The definition of an ACL from the syntactic point of view (the different *illocutionary acts* or *speech acts* or *performatives* that agents can perform during a dialogue) poses no problems. The situation is different when semantics is taken into account. Any communication language must have a well-defined semantics: given that agents in a multi-agent system may be independently designed by different programmers, a clear understanding of semantics is essential.
Although a number of agent communication languages have been developed, obtaining a suitable formal semantics for ACLs remains one of the greatest challenges of multi-agent theory. Moreover, the investigation of formal argumentation for dialogue modelling is not new, but there is still no satisfying approach for the integration with a reliable ACL semantics. Our aim is to define an ACL whose semantics prevents the shortcomings of the existing approaches while keeping their benefits. The new semantics is a novel combination of an agent-internal argumentation-based reasoning level and an agent-external commitment level within a single two-level framework.

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1. **The reasoning level:** It is concerned with the reasoning part of the agent. It is based on argumentation theory and depends broadly on the nature of the agent. This is internal to the agent.
2. **The commitment level:** It is concerned with the different commitments brought about. This is of course external to the agent.

2 A SYSTEM OF ARGUMENTATION

In this section we briefly introduce the argumentation system which forms the backbone of our approach. We start with a possibly inconsistent knowledge base Σ with no deductive closure. We assume Σ contains formulas of a propositional language $\mathcal{L}$. $\vdash$ stands for classical inference and $\equiv$ for logical equivalence.

Definition 1 *An* argument *is a pair* (H, h) *where* h *is a formula of* $\mathcal{L}$ *and* H *a subset of* Σ *such that i)* H *is consistent, ii)* $H \vdash h$ *and iii)* H *is minimal, so no subset of* H *satisfying both i) and ii) exists.* H *is called the* support *of the argument and* h *is its* conclusion.

In general, since Σ is inconsistent, arguments in $\mathcal{A}(\Sigma)$, the set of all arguments which can be made from Σ, will conflict, and we make this idea precise with the notion of undercutting:

Definition 2 *Let* (H_1, h_1) *and* (H_2, h_2) *be two arguments of* $\mathcal{A}(\Sigma)$. (H_1, h_1) undercuts (H_2, h_2) *iff* $\exists h \in H_2$ *such that* $h \equiv \neg h_1$. *In other words, an argument is undercut iff there exists an argument for the negation of an element of its support.*

To capture the fact that some facts are more strongly believed (or desired, or intended, depending on the nature of the facts) we assume that any set of facts has a preference order over it which derives from the stratification of the knowledge base Σ into non-overlapping sets $\Sigma_1, \ldots, \Sigma_n$ such that facts in Σ_i are all equally preferred and are more preferred than those in Σ_j where $j > i$. The preference level of a nonempty subset H of Σ, $level(H)$, is the number of the highest numbered layer which has a member in H.

Definition 3 *Let* (H_1, h_1) *and* (H_2, h_2) *be two arguments in* $\mathcal{A}(\Sigma)$. (H_1, h_1) *is* preferred *to* (H_2, h_2) *according to Pref iff* $level(H_1) \leq level(H_2)$.

We can now define the argumentation system we will use:

Definition 4 *An* argumentation system *(AS) is a triple* $\langle \mathcal{A}(\Sigma), Undercut, Pref \rangle$ *such that* $\mathcal{A}(\Sigma)$ *is a set of the arguments built from* Σ, $Undercut \subseteq \mathcal{A}(\Sigma) \times \mathcal{A}(\Sigma)$, *and Pref is* *a (partial or complete) preordering on $\mathcal{A}(\Sigma) \times \mathcal{A}(\Sigma)$. $\gg^{Pref}$ stands for the strict pre-order associated with Pref.*

The preference order makes it possible to distinguish different types of relation between arguments:

Definition 5 *Let A, B be two arguments of $\mathcal{A}(\Sigma)$.*

- *B* strongly undercuts *A iff B undercuts A and it is not the case that $A \gg^{Pref} B$.*
- *If B undercuts A then A* defends itself *against B iff $A \gg^{Pref} B$.*
- *A set of arguments $\mathcal{S}$* defends *A if there is some argument in $\mathcal{S}$ which strongly undercuts every argument B where B undercuts A and A cannot defend itself against B.*

Henceforth, $C_{Undercut,Pref}$ will gather all non-undercut arguments and arguments defending themselves against all their undercutting arguments. In [1], it was shown that the set $\underline{\mathcal{S}}$ of acceptable arguments of the argumentation system $\langle \mathcal{A}(\Sigma), Undercut, Pref \rangle$ is the least fixpoint of a function $\mathcal{F}$:

$$\begin{aligned} \mathcal{S} &\subseteq \mathcal{A}(\Sigma) \\ \mathcal{F}(\mathcal{S}) &= \{(H,h) \in \mathcal{A}(\Sigma) | (H,h) \text{ is defended by } \mathcal{S}\} \end{aligned}$$

Definition 6 *The set of* acceptable *arguments for an argumentation system $\langle \mathcal{A}(\Sigma), Undercut, Pref \rangle$ is:*

$$\begin{aligned} \underline{\mathcal{S}} &= \bigcup \mathcal{F}_{i \geq 0}(\emptyset) \\ &= C_{Undercut,Pref} \cup \left[\bigcup \mathcal{F}_{i\geq 1}(C_{Undercut,Pref}) \right] \end{aligned}$$

An argument is acceptable if it is a member of the acceptable set.

Definition 7 *Let $\langle \mathcal{A}(\Sigma), Undercut, Pref \rangle$ be anAS. An argument $B \in \mathcal{A}(\Sigma)$ is rejected iff $\exists\ C \in \underline{\mathcal{S}}$ such that C strongly undercuts B.*

3 LAYERED SEMANTICS

Our account follows Pitt and Mandani's idea of a layered semantics in [10], but differs in the number of levels and the interpretion given to the different levels. Before presenting the semantics of each performative, we start by explaining our modelling of each level of the semantics.

3.1 The reasoning level

Communication is strongly related to the reasoning. Indeed, if an agent asserts a data then either it believes in this data or it does not believe at all. The semantic at this level aims at defining the link between the dialogue moves (ie. the performative) and the dialogue participants' mental states. We argue here that the semantics is crucially dependent of the agent's attitudes, and that these attitudes may vary.

Agent' attitudes concern the ability of the agents to construct arguments in favor of the statements they exchange with other agents. In [9], we have studied the effect of agents' attitudes on the way in which agents determine what locutions can be made within the confines of a given dialogue protocol through the application of differing rationality conditions. In particular, we were interested in agents' attitudes when asserting and when accepting information.

Theorem 1 *An agent may have one of two* assertion *attitudes.*

- *a* confident *agent can assert any proposition for which it can construct an argument.*
- *a* thoughtful *agent can assert any proposition for which it can construct an acceptable argument.*

We can easily prove the following theorem.

Theorem 2 *All the propositions asserted by a thoughtful agent can be asserted by a confident agent. The reverse is not true.*

A thoughtful agent will only put forward propositions which, so far as it knows, are correct. A confident agent won't stop to check that this is the case. Thus, thoughtful agents are not suitable in dialogues such as negotiation where the agents won't say all the truth. So, for the semantics of our ACL we will consider only *confident* agents.

We can define also acceptance attitudes as follows:

Theorem 3 *An agent may have one of two* acceptance *attitudes.*

- *a* credulous *agent can accept any proposition p if it is backed by an argument.*
- *a* cautious *agent can accept any proposition p if there is an acceptable argument for p.*

Thus a cautious agent will only accept propositions which are correct (true). A credulous agent won't stop to check that this is the case. Consequently, it can accept propositions that it can itself attack.

Theorem 4 *All the propositions accepted by a cautious agent can be accepted by a credulous agent. The reverse is not true.*

For the semantics of our ACL, we suppose that the different agents are *cautious*. This is due to the fact that credulous agents can be misled and thus the quality of information exchanged will not be good.

In the following we try to give the different agents' attitudes with respect to the remaining performatives.

Theorem 5 *An agent may have one of two* question *attitudes.*

- *an* ignorant *agent can ask a question on a fact p if it is unable to construct an argument for neither p nor $\neg p$.*
- *an* exam *agent can ask a question on a fact p even if it can construct an argument for it. This kind of question is called* rhetoric *or* exam *question.*

Theorem 6 *All the questions which can be asked by an ignorant agent can also be asked by an exam agent. The reverse is not true.*

In information seeking dialogues, an agent seeks to answer to some question from another agent. In this case, the agent asking the question does not have any idea on *p*. However, in persuasion dialogues, we can imagine the case where an agent instead of presenting an argument, asks questions so that the other agent detects itself that argument. This is considered as the strategy followed by that agent in order to persuade

another agent. If we consider only ignorant agents we forbid the agents to have such stretegy. So for our ACL we consider *exam agents*.
Agents have also different attitudes with respect to *challenge*.

Theorem 7 *An agent may ask another agent to justify its point of view in one of the three following situations.*

- *an* ignorant *agent can make a challenge on a fact p if it is unable to construct an argument for p.*
- *an agent can make a challenge if it has an argument in favor of $\neg p$.*
- *an agent can make a challenge even if it has an acceptable argument in favor of p.*

Theorem 8 *All the challenges done by an ignorant agent can be done by agents of the second category. And all the challenges done by agents of the second category can be done by agents of the last category. The reverses are not true.*

As for questions, we will consider the last category of agents in order to let agents to have any strategy, particularly, the strategy cited above. Agents can retract an information or a promise they have already done. This is possible in case they have a *rejected* argument in favor of the information or the promise.

Definition 8 *An agent can retract p in case it has a rejected argument in favor of p.*

In the following, we suppose that each agent is equipped with an argumentation system (AS).

3.2 The commitment level

In the scientific litterature, one can find proposals where the semantics of an ACL is defined in terms of commitment. Examples of these are given by Colombetti [5] and Singh [12, 13]. The authors argued that agents are social entities, involved in social interactions, then they are committed to what they say.
In recent years, it has been argued that informal logic has much to offer to the analysis of inter-agent communication. Central in these approaches are the notions of dialogue games and (social) commitments. One rather influential dialogue game is DC, proposed by MacKenzie [8] in the course of analysing the fallacy of question-begging. DC provides a set of rules for arguing about the truth of a proposition. Each player has the goal of convincing the other, and can assert or retract facts, challenge the other player's assertions, ask whether something is true or not, and demand that inconsistencies be resolved.
Associated with each player is a *commitment store*, which holds the commitments of the players during the dialogue. Commitments here are the informations given by the players during the dialogue. There are then rules which define how the commitment stores are updated. Take for instance the assertion, it puts a propositional statement in the speaker's commitment store. What this basically means is that, when challenged, the speaker will have to justify his claim. But this does not presuppose that the challenge will come at the next turn in the dialogue.

For our purpose, we adopt this presentation of commitments. We suppose that, in addition to its knowledge base containing its beliefs, each agent is equipped with a further knowledge base, accessible to all agents, containing its commitments made in the dialogue. These commitment stores are denoted CS_{A_i} where A_i stands for agent i. The union of the commitment stores can be viewed as the state of the dialogue at turn t.

We adopt a commitment store much more structured than the one presented in previous work on dialogue [2, 3]. It keeps tracks of two categories of commitments:

- The commitments made in the dialogue by the agent itself such as assertions and promises.
- The commitments made by other agents, such as requests, challenges and questions. For instance if an agent A_i requests p from another agent A_j, p is stored in the commitment store of A_j.

In sum, each agent A_i gets a personal commitment store, containing statements and issues to be resolved. More precisely, we adopt the following structure:

$$CS_{A_i} = \langle \mathcal{S}, \mathcal{I}^R, \mathcal{I}^Q, \mathcal{I}^C \rangle$$

where

- $\mathcal{S}$ stands for the set of asserted and promised statements and is called *statements set*;
- $\mathcal{I}^R$ stands for the set of requests done to agent A_i;
- $\mathcal{I}^Q$ stands for the set of questions asked to agent A_i;
- $\mathcal{I}^C$ stands for the set of challenges done to agent A_i;

4 CATEGORIES OF PERFORMATIVES

To capture the different types of dialogue using a formal model of argumentation, we define a minimal language χ containing the following performatives:
$\chi = \{Question, Challenge, Assert, Accept, Refuse, Request, Promise, Retract, Argue\}$.
Assert allows the exchange of information such as "the weather is beautiful" and "It is my intention to hang a picture". *Request* is invoked when an agent cannot, or prefer not to, achieve its intentions alone. The proposition requested differs from an asserted proposition in that it cannot be proved true or false. The decision on whether to accept it or not hinges upon the relation it has to the agent's intentions. An agent will make a *Promise* when it needs to request something from another, and has something it doesn't need which can offer in return. In replying to an assertion, a request or a promise, an agent can accept, refuse or ask a question such as "is it the case that p is true ?". Another kind of question is called a challenge. It allows an agent to ask another agent why it has asserted a proposition or requested something, for example "why newspapers can't publish the information X?". The answer to a challenge should be an *argument*. *Argue* allows agents to exchange arguments, and *Retract* allows them to retract propositions previously asserted or requested.

We adopt here a common distinction made between *initiative* and *reactive* moves.

Initiative performatives : these performatives allow an agent to elicit a response. Examples of such performatives are *Question* and *Challenge*. Initiative performatives generally commits the receiver to react.

Reactive performatives : these performatives come as answers to initiative performatives. Examples of such performatives are *Assert*, *Accept*, *Reject* and *Promise*. Reactive performatives generally commit the adressee relative to the receiver.

Initiative	Reactive
Assert, Request	Accept, Refuse, Promise
Question	Assert
Challenge	Argue, Retract

Note that *Assert* is a particular performative since it can be initiative and reactive. One can assert a proposition when starting a dialogue or when answering a question.
In the following, we define the semantics of each performative of the set χ in terms of the two levels : reasoning level and commitment level. We suppose that agent A_i addresses a move to agent A_j.

4.1 Initiative performatives

1. Question(p). The questioned fact is put in the corresponding set of the receiver's commitment store. This means that the receiver is committed to give an answer to the addressee.
Reasoning level: $\emptyset$ (*this means that there is no condition*).
Commitment level: $CS_{A_j}.\mathcal{I}^Q = CS_{A_j}.\mathcal{I}^Q \cup \{p\}$.

2. Challenge(p). A challenge puts the facts in the set of challenges, at the condition that the challenged fact is a commitment of the partner.
Reasoning level: $\emptyset$.
Commitment level: if $p \in CS_{A_j}.\mathcal{S}$ then $CS_{A_j}.\mathcal{I}^C = CS_{A_j}.\mathcal{I}^C \cup \{p\}$.

3. Assert(p). As we consider *confident* agents, an agent which asserts a proposition p is supposed to have an argument in favor of it. So the agent commits to p in the sense that, if attacked by other agents, it is able to justify it and then defend it. An assertion is thus stocked in the commitment store of the agent. In case the assertion is reactive to a question under discussion, the question is removed from the set.
Reasoning level: Agent A_i has an argument in favor of p.
Commitment level:

- $CS_{A_i}.\mathcal{S} = CS_{A_i}.\mathcal{S} \cup \{p\}$
- If p $\in CS_{A_i}.\mathcal{I}^Q$ then $CS_{A_i}.\mathcal{I}^Q = CS_{A_i}.\mathcal{I}^Q - \{p\}$

4. Request(p). A request is invoked when an agent cannot achieve its intentions alone. In this case, the agent finds an argument (H, h) in favor of one intention h (an argument in favor of an intention is seen as the plan to achieve that intention) and one element, p, of that argument is missing. A request is stored in the CS of the receiving agent because, if accepted, it becomes a commitment of that agent, i.e the agent should achieve it.
Reasoning level: Agent A_i checks whether it has an argument (H, h) in favor of one of its intentions such that $p \in H$ and $p \notin \Sigma$.
Commitment level: $CS_{A_j}.\mathcal{I}^R = CS_{A_j}.\mathcal{I}^R \cup \{p\}$

4.2 Reactive performatives

5. Promise(p). Broadly speaking, an agent will make a promise when it has something it does not need (because the thing is not needed to achieve any intentions).
Reasoning level: A_i checks that there is no acceptable argument D for one of its intentions such that $p \in D$.
Commitment level: $CS_{A_i}.\mathcal{S} = CS_{A_i}.\mathcal{S} \cup \{p\}$.

6. Accept(p). Since we consider *cautious* agents, they should have an acceptable argument in favor of the facts they accept. The accepted facts are then stocked in the statements set of that agent. If the accept comes as an answer to a *request*, this last is removed from the corresponding set. Note that an *accept* doesn't come necessarily after a *request*.
Reasoning level: Agent A_i has an acceptable argument in favor of p.
Commitment level:

- $CS_{A_i}.\mathcal{S} = CS_{A_i}.\mathcal{S} \cup \{p\}$.
- If $p \in CS_{A_i}.\mathcal{I}$ then $CS_{A_i}.\mathcal{I}^R = CS_{A_i}.\mathcal{I}^R$ - $\{p\}$.

7. Refuse(p). An agent A_i can refuse a *request* made to him by another agent in case the requested fact is needed to achieve one of his intentions.
Reasoning level: A_i checks if there is an acceptable argument D for one of its intentions such that $p \in H$.
Commitment level: $CS_{A_i}.\mathcal{I}^R = CS_{A_i}.\mathcal{I}^R - \{p\}$.

8. Argue(H). An argue move removes the challenge in the agent commitment store, at the condition that this is a correct support for the challenged fact. The argument is also added to the *statement set* of that agent.
Reasoning level: (H, p) is an argument of agent A_i.
Commitment level:

- $CS_{A_i}.\mathcal{S} = CS_{A_i}.\mathcal{S} \cup D$
- if $\exists p \in CS_{A_i}.\mathcal{I}^C$ s.t D supports p then $CS_{A_i}.\mathcal{I}^C = CS_{A_i}.\mathcal{I}^C$ - $\{p\}$.

9. Retract(p). An agent A_i retracts its assertion or its promise if it has a rejected argument for the assertion or the promise. Since assertions and promises are stocked in the *statement set* of the agent, they are removed after a retract.
Reasoning level: The agent A_i has a rejected argument in favor of p.
Commitment level: $CS_{A_i}.\mathcal{S} = CS_{A_i}.\mathcal{S}$ - $\{p\}$

This means that the commitment store is non-cumulative.

5 RELATED WORK

The first standard agent communication language is KQML [6]. It has been developed within the Knowledge Sharing Effort, a vast research program funded by DARPA (the US Defense Advanced Research Projects Agency). More recently,

the Foundation for Intelligent Physical Agents (FIPA) has proposed a new standard, named ACL [7]. Both KQML and ACL have been given a mentalistics semantics.
The semantics is based on a notion of speech act close to the concept of illocutionary act as developed in speech act theory [4, 11]. Such semantics assumes, more or less explicitly, some underlying hypothesis in particular, that the agents are sincere and cooperative. This is equivalent to consider only *thoughtful* agents. While this may be well fitted for some special cases of interactions, it is obvious that some dialogue types listed by Walton and Krabbe are not cooperative. For example, assuming sincerity and cooperativity in negotiation may lead to poor negotiators.

In the second approach, called *social* and developed in [5, 12, 13], primacy is given to the interactions among the agents. The semantics is based on social *commitments* brought about by performing a speech act. For example, by affirming a data, the agent commits on the truth of that data. After a promise, the agent is committed carrying it out. There are several weak points of this approach and we summarize them in the three following points:
1. The definition of semantics in terms of commitments complicates the agent architecture in the sense that it needs an ad hoc apparatus. The commitments are introduced especially for modelling communication. Thus agents should reason not only on their beliefs, etc but also on the commitments. In our approach, we didn't introduce any new language to treat commitments. We call a commitment any information stocked in the commitment stores. Handling these commitments (to add a new commitment, to retract a commitment, to achieve a commitment, to violate a commitment) is done directly on the commitment store.
2. The level at which communication is treated is very abstract, and there is a considerable gap to fill in order to bring the model down to the level of implementation. However, the semantics presented in this paper can be implemented easily.
3. The concept of commitment is ambiguous and its semantics is not clear. According to the performative act, the semantics of the commitment differs. For example:

Inform: by affirming a data, the agent commits on the truth of that data. The meaning of the commitment here is not clear. It may be that the agent can justify the data or can defend it against any attack, or the agent is sincere.

Request: According to Colombetti [5] after a request, the receiver precommits to carry it out. This idea is in our opinion drawn from the notion of protocol. The protocol specifies for each act the set of allowed replies. So after a request, generally the receiver can accept it, reject it or propose another alternative.

The last approach developed by Pitt and Mandani in [10] is based on the notion of protocol. A protocol defines what sequences of moves are conventionaly expected in the dialogue. The meaning of a performative then equates with the set of the possible following answers.
However, protocols are often technically finite state machines. This turns out to be too rigid in several circumstances. Current research aims at defining flexible protocols, which rely more on the *state of the dialogue*, and less on dialogue history. This state of dialogue is captured through the notion of commitment.

6 CONCLUSION

This paper has introduced an ACL which allows heterogenous agents to engage in the different kinds of dialogues identified by Walton and Krabbe in [14]. The performatives are a superset of those in [3], including additional ones which simplify the handling of arguments. The semantics of the new ACL is a combination of the *mentalistic* approach and the *social* approach which is based on commitments. However, our modelling of these notions is very different from the existing approaches. The mentalistic part is concerned with the reasoning of the agent. We are particularly interested in the ability of the agents to construct arguments in favor of statements and also their ability to evaluate that arguments. The commitments are modelled as in MacKenzie's system DC [8]. A commitment is any information stocked in the commitment store of the agent. Thus each performative is precisely defined in terms of the arguments an agent can build and the commitment brought about by performing that performative. Our approach goes somewhat beyond the existing approaches in giving an operational semantics. Moreover, with such semantics we get more flexible protocols. We are now working in this direction.

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