A dialogue-game for agent resolving conflicts by verbal means

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Abstract

We present in this paper a formal framework for argumentation-based dialogues between agents. These latter manage the dialogues with the help of three components: an argumentative component to generate arguments, a social component to interprete arguments, and a conventional component to manage the sequence of coherent moves. We formalize the notion of dialogue-game to address the gap between individual moves and the extended sequence of coherent moves that arise between agents. The moves are not associated with an intention, however the dialogues have a goal.

1 Introduction

During the last decade, many Agent Communication Languages (ACL) were designed for the interaction in Multi-Agent Systems (MAS). These ACL do not succeed to address formal inter-agent dialogues.

Most of the existing ACL are based on speech acts theory [8]. For example, FIPA-ACL [7] or KQML [4] define communicative acts by pre/post conditions bearing on the mental attitudes of agents. Many shortcomings come from this approach. We have identified here three main shortcomings. (1) The illocutionary force, *i.e.* the intention of the speaker, is considered as the main characteristic of the speech act. This is the reason why the agents must be understood in terms of mental concepts. (2) The institutional value of the speech acts is implicit. Then, the communication has no social semantics to be judged in a public perspective [9]. (3) This approach considers a communicative act as an epiphenomenon. Therefore, the semantics of communicative acts is so rich that it is far too complex to determine an answer by just inferring mental states[3].

By contrast, our work is inspired by formal dialectic [10]. We present in this paper an extension of the framework for argumentation-based dialogues between agents proposed by Parsons *et al.* [5, 1, 2].. The agents manage the dialogues with the help of three components, each of them addressing one of the previous issues. We formalize the notion of dialogue-game to address the gap between individual moves and the extended sequence of coherent moves that arise between agents. The moves are not associated with an intention, however the dialogues have a goal.

Paper overview. Section 2 presents the argumentation-based reasoning as defined in [1]. In accordance with this background, we modify the formal framework for dialogues proposed by Parsons *et al.* [5] in section 3. The agents share a knowledge language and a communication language (cf section 3.1) in order to reason together (cf section 3.2). We formalize the notion of dialogue in section 4. Then, the proprieties of the dialogues can be studied (cf section 4.2).

2 Argumentation system

An argumentation system as defined in [1] is a set of arguments with a conflicting relation and a preference relation from which could be extracted a set of acceptable arguments.

The knowledges are factual judgments gather in a knowledge base, written Σ. This base contains formulae of a propositional language, written $\mathcal{L}$. $\vdash$ stands for classical deduction and $\equiv$ for logical equivalence.

In order to evaluate preferences between the judgments, the knowledge base has a preference order captured by a preordering relation. This preference relation $\ll$ denotes a binary relation that is reflexive and transitive. This preference ordering makes it possible to deduce a stratification of the base Σ into non-overlapping sets $\Sigma^n \ll ... \ll \Sigma^1$ such that facts in Σ^i are all equally preferred and are more preferred than those in Σ^j with $i \leq j$. The number of the highest numbered layer that has a member in a non-empty set H is written level(H).

An argument is composed of a formula, called conclusion, and a set of formulae, called support, from which the conclusion can be inferred.

Definition 1. *An **argument** is a pair $P = (H, h)$ where h is a formula of $\mathcal{L}$ and H a subset of Σ such that:*

1. *$H \subseteq \Sigma$ is consistent;*

2. $H \vdash h$;

3. H is minimal, so no subset of H satisfying both 1 and 2 exists.

*H is called the **support** of P, written $H = support(P)$ and h is the **conclusion** of P, written $h = conclusion(P)$.*

An argument P is **trivial** iff support$(P) = \{$conclusion$(P)\}$. Let $\mathcal{A}(\Sigma)$ denote the set of arguments built on Σ.

Since Σ can be inconsistent, arguments may conflict. The next definition precises the notion of undercutting to capture these conflicts. An argument is undercut iff there is one of the formulae of its support which is denied by another argument.

Definition 2. *Let P_1 and P_2 two arguments of $\mathcal{A}(\Sigma)$. P_1 **undercuts** P_2 iff $\exists h \in support(P_2)$ such that $h \equiv \neg conclusion(P_1)$.*

Moreover, the preferences between arguments can be evaluated.

Definition 3. *Let P_1 and P_2 two arguments of $\mathcal{A}(\Sigma)$. P_1 **is preferred to** P_2 (written P_1 pref P_2) iff: $level(support(P_2)) > level(support(P_1))$.*

These two orders make it possible to distinguish different types of relations between arguments.

Definition 4. *Let P_1, P_2 be two arguments of $\mathcal{A}(\Sigma)$ and $S \subseteq \mathcal{A}(\Sigma)$ be a set of arguments.*

- *P_1 **defends itself against** P_2 iff P_2 undercut $P_1 \wedge P_1$ pref P_2. We denote P_1 defend_itself P_2;*
- *S **defends** P_1 iff $\forall P_2 \in \mathcal{A}(\Sigma)$ s.a P_2 undercuts P_1 and P_1 does not defend itself again P_2 then $\exists P_3 \in S$ s.a. P_3 undercut P_2 and P_2 does not defend itself against P_3. We denote S defend P_1;*

The notion of acceptability links the preference ordering and the undercutting relation.

Definition 5. *Let $AS = \langle \mathcal{A}(\Sigma),\ undercut\ ,\ pref \rangle$ be an argumentation system. The **set of acceptable arguments**, written $\mathcal{S}$ is the least fixpoint of a function $\mathcal{F}$: $S \in \mathcal{A}(\Sigma)$ and $\mathcal{F}(S) = \{P \in \mathcal{A}(\Sigma);\ S \text{ defend } P\}$.*

The following section formalizes the framework for inter-agent dialogues based upon this argumentation-based reasoning.

3 Dialogical system

A dialogical multi-agent system consists of a set of agents. They share a knowledge language and a communication language. An agent is associated with an argumentation system in order to deliberate. The arguments of its peers must be taken into account to be interpreted and to generate counter-arguments.

3.1 Common languages

Since the judgments of agents may be different, each agent has its own belief base, Σ_i^B and its own preordering, $\ll_i$. These belief bases contain formulas of a **common knowledge language**, written $\mathcal{L}_{\mho}$. Consequently, the agents share the same inference rule, denoted $\vdash_{\mho}$.

Dialogue agents utter messages each its turns. Each message has an identifier M_k. The syntax of messages is in conformance with a **communication language**, $\mathcal{CL}_{\mho}$ defined in a similar way of FIPA-ACL or KQML. A message is also called dialogical move by reference to the game theory.

Definition 6. *A **dialogical move** $M_k \in \mathcal{CL}_{\mho}$ is defined by a 5-tuple, $M_k = \langle S_k, H_k, R_k, DG_k, L_k \rangle$ where:*

- *M_k is the identifier of the k^{th} move in the dialogue between the speaker and the hearer. It can be referenced later in the dialogue;*
- *$S_k = speaker(M_k)$ is the agent that utters the move;*
- *$H_k = hearer(M_k)$ is the addressee;*
- *$R_k = reply(M_k)$ is the identifier of the move to which M_k responds ($R_1 = \emptyset$);*
- *$DG_k = dialogue\text{-}game(M_k)$ is the dialogue game used to generate the answer ;*
- *$L_k = locution(M_k)$ is the locution composed of a performative and a propositional content. The verb is one of the following: question, assert, unknow, accept, challenge, withdraw.*

A move uttered by a speaker is addressed to a hearer, i.e. one agent in the audience that receives and interprets the move in order to respond. The meaning of locutions is defined by the three components used to manage the dialogue. (cf sections 3.2.1,3.2.2,4.1). We propose a dialogue-game in section 4.2.

Thanks to these two languages, we present here the two components used by the agents to reason together. They take into account the arguments of their peer, interpret them and generate counter-arguments: they argue together.

3.2 Co-argumentation

During dialogue, agents take a stand for propositions. The commitment store, written CS_j^i, consists of the set of formulae perceived by the agent ag_i to which the agent ag_j commits [10]. An agent is in conformance with the following definition:

Definition 7. *A **dialogical agent** $ag_i \in AG_{\mho}$ is a triple $ag_i = \langle \Sigma_i^B, \cup_{j \neq i} CS_j^i, \ll_i \rangle$ such as:*

- *Σ_i^B is a belief base;*
- *$\cup_{j \neq i} CS_j^i$ is the set of commitment stores built by the agent ag_i;*
- *$\ll_i$ is the preordering relation on Σ_i^B.*

The formulae in the commitment stores are taken into account to generate arguments.

3.2.1 Argumentation component

The argumentation component precises the rational conditions of utterances and the relative tactics.

Since agents reason together, their arguments are built on their own beliefs and on the commitments of the agents it is speaking to. Then, each agent is associated with an extended argumentation system:

$$\begin{aligned} &\mathrm{AS}_i^* = \langle \Sigma_i,\ \text{undercut}\ ,\ \text{pref}\ _i^* \rangle \\ &\quad \text{where } \Sigma_i = \Sigma_i^B \cup [\bigcup_{i \neq j} \mathrm{CS}_j^i] \text{ the extended belief base} \\ &\quad \text{and}\ \ \text{pref}\ _i^* \text{the extension of the preference relation on} \mathcal{A}(\Sigma_i). \end{aligned}$$

We denote $\mathcal{S}_i^*$ the corresponding set of acceptable arguments. $\text{pref}\ _i^*$ will be explained in section 3.2.2.

The rational condition of a locution depends on its performative and its propositional content. An agent can assert a formula iff it has an argument for it.

Definition 8. *The predicate* $can\_assert(ag_i, H)$*, called* ***rational condition for the assertion*** *of a propositional content* H *by the agent* ag_i*, is defined s.a.:*

$$\forall h \in H\ \exists P \in \mathcal{A}(\Sigma_i)\ conclusion(P) = h.$$

Contrary to [5], the rational condition for the assertion and the rational condition for the acceptance of the same propositional content by the same agent distinguish themselves.

Definition 9. *The predicate* $can\_accept(ag_i, H)$*, called* ***rational condition for the acceptance*** *of a propositional content* H *by the agent* ag_i*, is defined s.a.:*

$$\forall h \in H\ \exists P \in \mathcal{A}(\Sigma_i)\ conclusion(P) = h \text{ with } (support(P) \neq \{h\} \wedge support(P) \not\subseteq \cup_{j \neq i} CS_j^i).$$

Agents can assert propositions whatever they are supported by a trivial argument or not. By contrast, agents do not accept all the propositions he hears in spite of they are all supported by a trivial argument.

The other locutions (question(h), challenge(h), unknow(h), withdraw(h)) have no particular rational conditions.

Then, the rational conditions of utterances are not necessary mutually excluded. These nondeterministic situations make it possible for agents to choice. That is the reason why we define as Parsons *et al.* [5] a set of argumentative tactics.

Definition 10. *The predicate* $want\_assert(ag_i, H)$ *called* ***argumentative tactic for the assertion*** *of a propositional content* H *by the agent* ag_i*, depends on the* ***assertive attitude*** *of the agent* ag_i*:*

- *if* ag_i *is thoughtful then* $want\_assert(ag_i, H) \Leftrightarrow \forall h \in H\ \exists P \in \mathcal{S}_i^*\ conclusion(P) = h$*;*
- *if* ag_i *is confident then* $want\_assert(ag_i, H) \Leftrightarrow can\_assert(ag_i, H)$*.*

The argumentative tactic for the acceptance is defined in a similar way.

Definition 11. *The predicate* $want\_accept(ag_i, H)$ *called* ***argumentative tactic for the acceptance*** *of a propositional content* H *by the agent* ag_i*, depends on the* ***acceptance attitude*** *of the agent* ag_i*:*

- *if* ag_i *is skeptical then* $want\_accept(ag_i, H) \Leftrightarrow \forall h \in H\ \exists P \in \mathcal{S}_i^*\ conclusion(P) = h \text{ with } (support(P) \neq \{h\} \wedge support(P) \not\subseteq \cup_{j \neq i} CS_j^i)$*;*
- *if* ag_i *is credulous then* $want\_accept(ag_i, H) \Leftrightarrow can\_accept(ag_i, H)$*.*

However the rational conditions of utterances are shared by all the agents, the argumentative tactics are individual choices. The social component makes it possible to interpret arguments.

3.2.2 Social component

This component provides the social semantics for the locution [9]. The move's meaning must not only have a private perspective to be expressed, but also a public perspective in order to be interpreted.

In a similar way with [5], we associate a set of commitment stores to each agent, which hold the commitments perceived during the dialogue. Commitments stores are updated according to the following rules:

Definition 12. ***Updating rules.***
Let $M_{k+1} \in \mathcal{CL}_{\mho}$, s.a. speaker$(M_{k+1}) = ag_j$ and $ag_i \in AG_{\mho}$ is in the audience.

- *if L_{k+1} = question(h) or L_{k+1} = unknow(h) or L_{k+1} = challenge(h) or L_{k+1} = withdraw(h) with h a formula of $\mathcal{L}_{\mho}$ then $CS^i_j(M_{k+1}) = CS^i_j(M_k)$;*
- *if L_{k+1} = assert(H) or L_{k+1} = accept(H) with H a set of formulae of $\mathcal{L}_{\mho}$ then $CS^i_j(M_{k+1}) = CS^i_j(M_k) \cup H$.*

The performative withdraw (not present in [5]) has no effect on the commitment stores but closes the dialogue (cf section 4.1.2). The arguments which are received must be valuated.

Since the agents are more or less authoritative, the commitments are considered in accordance with the estimated reliability of the agents from whom the information is obtained. For this purpose, each agent ag_i ranks the competence of the other agents with a strict total order on $\mathrm{AG}_{\mho}$, denoted $\prec_i$. Contrary to[2], this preference relation defines a subjective power relation between the agents.

The preference between formulae are evaluated in accordance with the following cooperative principle of arguments adoption: *"ag_i will prefer ag_j's statements iff ag_j is regarded as more competent".* This principle defines $\ll^*_i$ as a preordering relation on Σ_i and so pref^*_i on $\mathcal{A}(\Sigma_i)$. Then, the preference between arguments coming from different sources, the belief base ($\mathcal{A}(\Sigma^B_i)$) or the different commitment stores ($\mathcal{A}(\mathrm{CS}^i_j)$,($\mathcal{A}(\mathrm{CS}^i_k)$,...), can always be evaluated.

Thanks to the formal framework described here, the agents argue together. They take into account the arguments of their peer, interpret them and generate counter-arguments. However, the agents do not jointly reason to reach common goals. We formalize the notion of dialogue-game to address this gap.

4 Dialogue-game

Walton and Krabbe [10] have proposed a categorization of dialogues. This classification is especially based upon the initial informational status of the participants and the goals they share, also called the goals of the dialogue.

A dialogue-game describes the possible sequence of coherent moves to reach a goal. The conventional component manages the sequence of moves.

4.1 Conventional component

In order to manage the sequence of moves, this component uses dialogical rules, sequence rules, and related tactics.

4.1.1 Dialogical rules

The following basic rules regulate the dialogues whatever the dialogue-game is. The first rule initializes the dialogue with a question on a topic. The second one avoids redundancy of information in assertions [6]. Therefore, no loop will happen in dialogues. The third rule takes care of turn-taking. The fourth warrants to keep the same dialogue-game during the dialogue.

Definition 13. *The moves* $M_1, M_{k+1} \in \mathcal{CL}_{\mho}$ *(with* $k \geq 0$*) are in conformance with the following* ***dialogical rules****:*

1. *initialization*
   $locution(M_1) = question(p)$. *p is called the topic of the dialogue ;*

2. *non-redundancy*
   $locution(M_{k+1}) = assert(H) \rightarrow \forall p \in H\ \forall l \leq k\ locution(M_l) = assert(H')$, $p \notin H'$;

3. *turn-taking*
   $hearer(M_{k+1}) = speaker(M_k) \wedge speaker(M_{k+1}) = hearer(M_k)$;

4. *dialogue-game keeping*
   $dialogue\text{-}game(M_{k+1}) = dialogue\text{-}game(M_k)$.

We immediately deduce that a dialogue takes place between the speaker and the hearer of the first move. A participant play one of the following **conventional roles**: *initiator* (init), i.e. the agent beginning the dialogue or *partner* (part), i.e. the agent it is speaking to. The agents that do not participate directly are the *bystanders* of the dialogue.

All the agents use these four dialogical rules whatever the dialogue-game is. However these rules are canonical, sequence rules specify the answers allowed or not in a given situation. The following section enumerates a set of sequence rules. The section 4.2 presents the dialogue-game using these rules.

4.1.2 Sequence rules

The sequence rules specify the answers that are (or not) allowed in a given situation by constraining the locution and the reply field. The argumentative tactics of the allowed moves are not necessary mutually excluded. These nondeterministic situations renders a choice possible. That is the reason why we define as Parsons *et al.* [5] a set of conventional tactics and attitudes.

Respond to a question. The rule of "Question/Answer" allows the hearer of a question (question(h)) to respond: either with a confirmation (assert(h)), either with an invalidation (assert($\neg h$)), or with a plea of ignorance (unknow(h)).

In replying to a question, an agent that can either give its opinion, a confirmation or an invalidation, or plead ignorance is *cooperative* if it responds to the request. Otherwise, it is *egoist*. An agent that can either respond with a confirmation or with an invalidation is: *positive* if it confirms whenever possible ; *negative* if it invalidates whenever possible.

Respond to an assertion. the rule of "Assertion/Refutation" allows the hearer of an assertion (assert(H)) to respond: either with a hearty welcome (accept(H)), either with a refutation (assert($\neg h$), with $h \in H$), or with a challenge (challenge(h'), with $h' \in H$).

In replying to an assertion, an agent that can either give its opinion, an hearty welcome or a refutation, or challenge is: *argumentative* if it challenges; *open-minded* if it gives its opinion. an agent that can either respond with a hearty welcome or with a refutation is: *optimistic* if it accepts whenever possible ; *pessimistic* if it refutes whenever possible.

Respond to a challenge. The rule of "Challenge/Argument" allows the hearer ag_i of a challenge (challenge(h)) to respond: either with an argument (assert(H), with $H = \text{support}(P)$, $P \in \mathcal{A}(\Sigma_i)$ s.a. $h = \text{conclusion}(P)$), or with a withdrawal ($withdraw(h')$) making reference to its first assertion.

In replying to a challenge, an agent *patient* respond with an argument whenever possible. Otherwise, it is *impatient*.

Then, an algorithm selects the privileged responding move for each sequence rule. These algorithms are defined such as there is a single effective responding move which is in conformance with the corresponding sequence rule.

Closing the dialogue. The moves with performatives: unknow, accept or withdraw close the dialogue.

A dialogue-game of persuasion consists of the combinaison of these sequence rules.

4.2 Dialogue-game of persuasion

The topic of persuasion dialogues is only discursive. The participants try to reach an agreement, not a decision to act (or not to act). We aim at proving the termination of persuasion dialogues whatever the initial situation is. By contrast, the goals of a persuasion dialogue are reached if some particular initial conditions are verified.

The figure 4.2 shows a persuasion dialogue-game in the extensive form game representation where nodes are game situations and edges are associated with moves. For example, 2.3^{init} denotes a game situation where the exponent indicates that the initiator is the speaker of the next move. $2.1^{\square}$,$3.2^{\square}$, and $4.2^{\square}$ denote game-over situations.

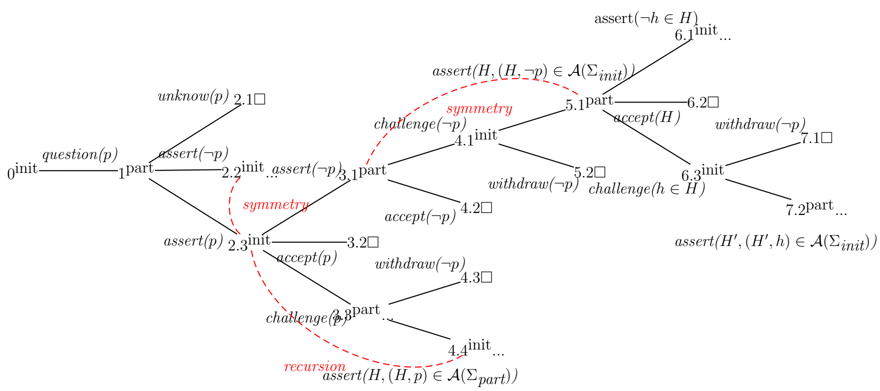

Figure 1: Persuasion dialogue in an extensive form game representation

4.2.1 Termination

The termination of persuasion dialogues can be warranted, whatever the (argumentative and conventional) attitudes and the initial informational status of the participants are.

Theorem 1. *A persuasion dialogue which takes place between two agents of* $AG_{\mho}$ *and with a topic in* $\mathcal{L}_{\mho}$ *always terminates.*

Proof. Thanks to the definition of the algorithms selecting the privileged responding move, the hearer can always respond whatever the sequence rule is. The game situations 2.2^{init} and 2.3^{init} are equivalent by symmetry on the propositional content of the previous assertion. The game situation 2.3^{part} is equivalent to the game situation 4.4^{init} by symmetry on the propositional content of the previous assertion even if the conventional roles are inverted. The game situations 3.1^{part} and 5.1^{part} are equivalent by symmetry on the propositional content of the previous assertion. Moreover, the second dialogical rule avoids redundancy of information in assertions. Then, no loop will happen in dialogues. Σ_{part} and Σ_{init} are finite because the belief bases of participants are finite. Consequently, the recursion is finite and the dialogue closes. □

4.2.2 Success

The goal of a persuasion dialogue is to reveal the position of the participants, to spread the participants'arguments and to verbally resolve the conflict. Contrary to the termination of a persuasion dialogue, the goals are reached if some particular initial conditions are verified.

Theorem 2. *Let a persuasion dialogue take place between two agents of $AG_{\mho}$ such as the topic p is a formula of $\mathcal{L}_{\mho}$. If the initial informational status of participants are such as they have conflicting thesis, even if it inverts:*

- *the initiator is convinced of $\neg p$:*
  $[\exists P'_{init} \in \mathcal{S}^*_{init}\ conclusion(P'_{init}) = \neg p] \wedge$
  $[\nexists P_{init} \in \Sigma_{init}\ conclusion(P_{init}) = p]$;
- *the partner is convinced of p:*
  $\left[\exists P_{part} \in \mathcal{S}^*_{part}\ conclusion(P_{part}) = p\right] \wedge$
  $\left[\nexists P'_{part} \in \Sigma_{part}\ conclusion(P'_{part}) = \neg p\right]$.

*Let a **witness** agent (denoted bystander) be a bystander of the dialogue with an initially empty belief base.*
If the partner is cooperative and the initiator is open-minded then the three goals will be reached at the end of the dialogue:

1. ***revealing position:***
   $p \in CS^{init}_{part} \wedge \neg p \in CS^{part}_{init}$;
2. ***spread of argument:***
   $\exists P \in \mathcal{A}(CS^{init}_{part}) \cap \mathcal{A}(CS^{bystander}_{part})\ conclusion(P) = p$
   $\wedge\ \exists P' \in \mathcal{A}(CS^{part}_{init}) \cap \mathcal{A}(CS^{bystander}_{init})\ conclusion(P') = \neg p$;
3. ***resolving the conflict by verbal means:*** *the witness agent is prone to one of the participants' thesis (even if inverts p with $\neg p$):*
   $\exists P' \in \mathcal{S}^*_{bystander}\ conclusion(P') = \neg p \wedge$
   $\nexists P \in \mathcal{S}^*_{bystander}\ conclusion(P) = p$.

Proof. The partner is convinced of p and it is cooperative. Therefore, the game situation 2.3^{init} is reached. The commitment store is updated then the partner has revealed its position. The initiator is convinced of $\neg p$ and it is open-minded. Then, the game situation 3.1^{part} is reached. The commitment store is updated then the initiator has revealed its position. Whatever the participants'arguments are, each of them has spread a trivial argument for its thesis.
In game-over situation $4.2^{\Box}$ and $5.2^{\Box}$, the witness agent has a trivial argument for p and a trivial argument for $\neg p$. They undercut each other. Because the sources of the arguments are different, only one is acceptable. Then, the witness is prone to one of the participant thesis. In the game-over situation $6.2^{\Box}$ and $7.1^{\Box}$, $P' = (H', \neg p)$ is the only acceptable argument of the witness. Therefore, this agent is prone to $\neg p$. The other game situations are equivalent by recursion on the content of the previous move. Consequently, the witness is prone to one of the participant's thesis however the dialogue is closed. $\Box$

However we define the resolution of the conflict by verbal means in a different way than Walton and Krabbe [10], we can demonstrate that these two definitions are equivalent.

5 Conclusions

We have presented in this paper a formal framework for the argumentation-based dialogues between agents. These latter manage the dialogues with the help of three components: the argumentation component specify the rational condition of utterances and the relative tactics ; the social component provides the meaning of the locutions to be interpreted ; and the conventional component manages the sequence of moves. We have formalized the notion of dialogue-game to address the gap between individual moves and the extended sequence of coherent moves that arise between agents. However the moves are not associated with an intention, the dialogues have a goal. The termination of the dialogue is demonstrated, whatever the initial status and attitudes of the participants are. By contrast, the goals of a dialogue are reached if some particular initial conditions are verified.

We are currently implementing this dialogical multi-agent system with MAST[1], which is an environment for the development of multi-agent applications. It provides some tools to design agents in a component-based approach, in particular a component for inter-agent communication and an interaction model of the agent-level components.

[1]http://www.emse.fr/~vercoute/mast

We aim at extending this dyadic dialogue framework to a multi-party one. At first, removing the restriction of two participants makes it possible to have participants that may join and/or leave the system during the dialogue. At second, the division of the multi-party dialogue among ontology-based channels is not limited to unobtrusive observations but allows unsolicited suggestions like in a newsgroup.

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