Towards a formal framework for conversational agents

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ABSTRACT
This paper proposes a formal framework which offers an external representation of conversations between conversational agents. Using this formalism allows us: (1) to represent the dynamics of conversations between agents; (2) to analyze conversations; (3) to help autonomous agents to take part in consistent conversations. The proposed formalism, called "commitment and argument network", uses a combined approach based on commitments and arguments. Commitments are used to capture the social and the public aspect of conversations. Arguments on the other side are used to capture the reasoning aspect. We also propose a layered communication model in which the formalism and the approach take place.

Keywords
Conversational agents, communication model, commitment and argument network.

1. INTRODUCTION
In the multi-agent domain, it is widely recognized that communication between autonomous agents is a challenging research area that involves several disciplines: philosophy of language, social psychology, artificial intelligence, logics, mathematics, etc. In a multi-agent system, agents may need to interact in order to negotiate, to solve conflicts of interest, to cooperate, etc [15]. All these communication requirements cannot be fulfilled by simply exchanging messages. Agents must be able to take part in coherent conversations which result from the performance of coordinated speech acts [27].

Three main approaches have been proposed to model communication between software agents in general and to define a semantics for agent communication languages (ACLs). These approaches are: the mental approach, the social approach, and the argumentative approach.

In the mental approach, so-called agent's mental structures (e.g. beliefs, desires and intentions) are used to model conversations and to define a formal semantics of speech acts. In the first system that was based on these notions, speech acts were planned like non-communicative actions [9]. It was used by [19] and [20] to define a formal semantics of KQML. However, this semantics has been criticized for not being verifiable because one cannot verify whether the agents' behavior matches their private mental states [12] [5].

An alternative to the mental approach was proposed by [29] under the name of social approach. In contrast to the mental approach, this approach emphasizes the importance of conventions as well as the public and social aspects of conversations. It is based on social commitments that are thought of as social and deontic notions. Social commitments are commitments towards the other members of a community. They differ from the agent's internal psychological commitments which capture the persistence of intentions as specified in the rational interaction theory [8]. As a social notion, commitments are a base for a normative framework that makes it possible to model the agents' behaviour. This notion has been used to define a formal semantics that is verifiable [28] [10].

Another approach, called the argumentative approach, was proposed by [2] as a method for modelling dialogue. It also has been used to define a semantics of some communicative acts [1] and to define protocols [23] [25]. It is based upon an argumentation system where the agents' reasoning capabilities are often linked to their ability to argue. They are mainly based on the agent's ability to establish a link between different facts, to determine if a fact is acceptable, to decide which arguments support which facts, etc. The approach relies upon the formal dialectics introduced by [18] and [21]. Dialectical models are rule-governed structures of organized conversations in which two parties (in the simplest case) speak in turn in an orderly way.

Recently, researchers have begun to address the issues raised by conversation policies. According to [22] two approaches can be distinguished: Commitment-based protocols and dialogue-game based protocols. The first approach is based on social commitments to specify the sequences of utterances. The second one considers that protocols are captured within appropriate structures that can be combined in different ways to form the global structure of dialogue [11].

Despite all this research focused on modeling dialogue and semantic issues, few researchers have addressed the issue of representing the dynamics and the coherence of conversations. The purpose of this paper is to propose a formal framework that can represent agent actions likely to take place in a conversation. These actions are interpreted in terms of creation and of positioning on social commitments and arguments. The proposed formalism allows us to model the dynamics of conversations and offers an external representation of the conversational activity. This notion of external representation [6] is very useful because it provides conversational agents with a common understanding of the current state of the conversation and its advancement. An

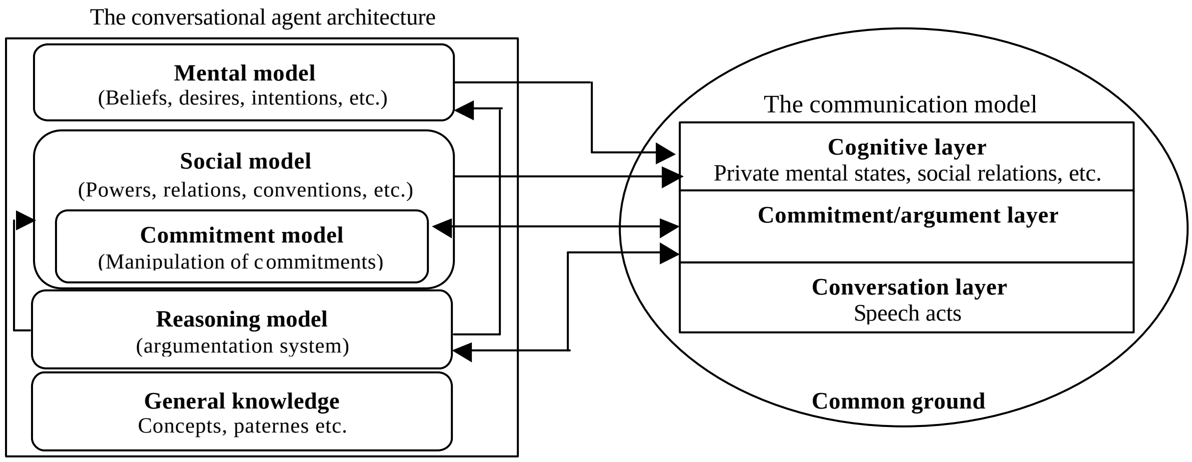

Figure 1. The links between the conversational agent architecture and the communication model

example of such an external representation is the conversational model proposed by [26]. Based on our formalism, a model is made available to the agents and they can access it simultaneously. The formalism also allows us to ensure conversational consistency when considering the actions performed by the agents. Called "commitment and argument network" (CAN) our formalism relies on an approach combining commitments and arguments [3]. This approach has the advantage of capturing both the social and public aspects of a conversation, and the reasoning aspect required in order to take part in coherent conversations. The formalism can clearly illustrate the creation steps of new commitments and the positioning steps on these commitments, as well as the argumentation and justification steps. This formalism supposes that the conversational agents are able to manipulate commitments and arguments. Therefore, the agents architecture must take into account this aspect.

The layout of this paper is as follows. In Section 2 we present our vision of a communication model. In Section 3 we discuss a model of social commitments which is a part of our communication model, and we show how speech acts can be interpreted as actions on these commitments. In Section 4 we introduce the argumentation aspect and we illustrate the link between commitments and arguments. The foundations of the CAN formalism are presented in Section 5. We also give an example of the analysis of a dialogue and we show how our formalism can be used either to analyze a conversation or as a means that allows agents to take part in conversations. Finally, we provide a mathematical proof to show that our formalism is able to represent any coherent conversation.

2. A COMMUNICATION MODEL

The model that we propose combines the three approaches discussed in the introduction. It is based on a hybrid approach that we call MSA (Mental-Social-Argumentative). Indeed, if they are taken individually, the three approaches introduced earlier do not allow us to model all the aspects of conversations. For this reason, we suggest to combine them in a unified approach. In addition, the conversation is a cognitive and social activity which requires a mechanism making it possible to reason on mental states, on what other agents say (public aspects) and on the social aspects (conventions, standards, obligations, etc). These three approaches are thus not exclusive but rather complementary.

The MSA approach has the advantage of capturing simultaneously the mental aspect that characterizes the agents participating in a conversation, the social aspect that reflects the context in which these agents communicate and the reasoning aspect which is essential to be able to take part in coherent conversations. The combination of commitments and arguments seems essential to us because agents must be able to justify the facts on which they are committed and to justify their actions on commitments. This justification cannot be made if the agents do not have the necessary argumentation mechanisms. In addition, the combination of commitments and private mental states is necessary because public commitments reflect these mental states. Finally, the combination of argumentation and mental states is significant because agents have to reason on their mental states before committing in a conversation.

The model of communication is composed of three layers: the conversation layer, the commitment/argument layer and the cognitive layer. This stratification in layers is justified by the abstraction levels. The conversation layer is directly observable because it is composed of the speech acts that the agents perform. These acts are not performed in an isolated way, but within a particular conversation. The commitment/argument layer is used to correctly manage the social commitments and the arguments that are related to the conversation. These commitments and arguments are not directly observable, but they should be deduced from the speech acts performed by the agents. Finally, the cognitive layer is used to take into account the private mental states of the agents, the social relations and other elements that the agents use in order to communicate. In this paper we propose a formalism that is used to model the elements composing the second layer.

In order to allow conversational agents to suitably use the communication model, this model must be compatible with the agent architecture. Thus, we propose an architecture of conversational agent which is composed of three models: the mental model, the social model and the reasoning model (Figure 1). The mental model includes beliefs, desires, goals, etc. The social model captures the social concepts such as conventions, roles, etc. Social commitments constitute a significant component of this model. A social commitment is a participant public attitude relative to a proposition. It defines a particular relationship between a participant and a statement. The commitments that the agent makes public when performing speech acts are different from the private mental states, but these two elements are not independent. Indeed, social commitments reflect mental states. Thus, agents must use their reasoning capabilities to reason on their mental states before producing or manipulating social commitments. The agent's reasoning capabilities are represented by the reasoning model via an argumentation system. The conversational agent model is formed by general knowledge, such as the knowledge on the conversation subject. This knowledge will be used by the agent in order to build the *common ground* that it must share with its partners. The notion of common ground introduced by the philosophers of language Clark and Haviland [7] indicates the set of knowledge, beliefs and presuppositions which the agents believe that they share during their conversations.

3. SOCIAL COMMITMENT FORMULATION

A *social commitment* is a commitment made by an agent (called the *debtor*), that some fact is true. This commitment is directed to a set of agents (called *creditors*) [4]. The *commitment content* is characterized by time t_j, which is different from the utterance time denoted t_u and from the time associated with the commitment and denoted t_{sc}. Time t_{sc} refers to the time during which the commitment is in vigor. It can correspond to a fixed value or an interval. When it is an interval, this time is denoted $[t_{sc}^{\inf}, t_{sc}^{\sup}]$. When a temporal bound is instantiated, it takes a numerical value which respects the time unit used by the agents. We denote a social commitment as follows:

Definition 1: $SC(id_n, Ag_1, A^*, t_{sc}, j, t_j)$

where id_n is an integer identifying the commitment, Ag_1 the debtor, A^* the set of the creditors ($A^*=A/\{Ag_1\}$, where A is the set of participants), t_{sc} is the time associated with the commitment, j its content and t_j the time associated with the content j. To simplify the notation, we suppose throughout this paper that $A=\{Ag_1, Ag_2\}$. For example, the utterance:

(Example 1)

U: "I met agent Ag_3 on MSN one hour ago"

leads to the creation of the commitment:

$$SC(id_n, Ag_1, Ag_2, t_{sc}, Meet(Ag_1, Ag_3, MSN), t_{sc} - 1h).$$

The creation of such a commitment is an *action* denoted:

$$Create(Ag_1, t_u, SC(id_n, Ag_1, Ag_2, t_{sc}, Meet(Ag_1, Ag_3, MSN), t_{sc} - 1h)).$$

In general an action ACT performed by an agent Ag_1 on a social commitment SC is denoted:

Definition 2: $Act(Ag_1, t_u, SC(id_n, Ag_1, Ag_2, t_{sc}, j, t_j))$

Example 1 illustrates that there is a mapping between a speech act and a social commitment. Singh [28] and Colombetti [10] propose a social semantics of speech acts using such a mapping. In our approach, we go beyond Singh's and Colombetti's models and interpret a speech act as an action performed on a commitment in order to model the dynamics of conversations. This interpretation can be denoted by :

Definition 3: $SA(i_k, Ag_1, Ag_2, t_u, U) \vdash_{déf} Act(Ag_1, t_u, SC(id_n, Ag_1, Ag_2, t_{sc}, j, t_j))$

where $\vdash_{def}$ means "is interpreted by definition as", SA is the abbreviation of "Speech Act", i_k the identifier of the speech act and Act indicates the action performed by the debtor on the commitment. The definiendum ($SA(i_k, Ag_1, Ag_2, t_u, U)$) is defined by the definiens ($Act(Ag_1, t_u, SC(id_n, Ag_1, Ag_2, t_{sc}, j, t_j))$) as an action performed on a social commitment. The agent that performs the speech act is the same agent that performs the action *Act*. *Act* can take one of four values: *Create*, *Withdraw*, *Violate* and *Fulfill*. These four actions are the actions that the debtor can apply to a commitment. This reflects only the debtor's point of view. However, we must also take into account the creditors when modeling a conversation which is, by definition, a joint activity. We thus propose modeling the creditors' actions which do not apply to the commitment, but to the contents of this commitment This separation between the commitment and its content enables us to remain compatible with the semantics of commitments, i.e. the fact that only the debtor can handle its commitment. The semantics associated with this types of actions is expressed in terms of argumentation (see Section 4.2).

Hence, we must differentiate between the actions applied on a commitment (*Act*) and the actions performed on the content of a commitment (*Act-content*). We denote an action applied on the content of a commitment as follows:

Definition 4: $Act\text{-}content(Ag_k, t_u, SC(id_n, Ag_i, Ag_2, t_{sc}, j, t_j))$

where $i, j \in \{1, 2\}$ and ($k=i$ or $k=j$). Agent Ag_k can thus act on the content of its own commitment (in this case we get $k=i$) or on the content of the commitment of another agent (in this case we get $k=j$).

In addition, the actions that can be carried out by the debtor on the commitment content are different from the actions that can be carried out by the creditor. The debtor can change the content of its own commitment, can defend it if the debtor refuses it or questions it. The creditor can refuse the content of another agent's commitment, accept it or question it.

Thus, a speech act leads either to an action on a commitment when the speaker is the debtor, or to an action on a commitment content when the speaker is the debtor or the creditor. When an agent acts on the content of a commitment created by another agent we refer to this as "taking a position on a commitment content". However, it should be noted that the same utterance can lead both to taking a position on the content of an existing commitment and to the creation of a new commitment. Generally, a speech act leads to an action on a commitment and/or an action on a commitment content. Formally:

Definition 5: $SA(Ag_1, Ag_2, t_u, U) \vdash_{déf}$

$$\begin{cases} Act(Ag_1, t_u, SC(id, Ag_1, Ag_2, t_{sc}, j, t_j)) \\ and/or \\ Act\text{-}content(Ag_k, t_u, SC(id, Ag_i, Ag_j, t_{sc}, j, t_j)) \end{cases}$$

where $i, j \in \{1, 2\}$ and ($k=i$ or $k=j$).

3.1 The notion of state

A commitment can evolve and be transformed as a result of the actions that the debtor performs on it (creation, withdrawal, violation and fulfillment). Its content may also be transformed following the actions that the debtor and the creditors apply to it (change, acceptance, justification, etc.). Therefore, the agents act on their own commitments and on the content of both these commitments and other agents' commitments, which leads to their transformation. Hence the notion of state, which makes it possible to capture the evolution of commitments and their contents. However, we must distinguish between the notion of the commitment state [16] and the notion of the content state relative to this commitment as we propose here. Indeed, whenever an agent acts on its commitment, the commitment state is affected; whereas when the agent acts on the content of a commitment, the content state is transformed. Indeed, the notion of commitment state alone does not reflect the conversation dynamics since it only captures the debtor's actions on its commitment. The two states (the commitment state and the content state of the commitment) reflect this dynamics. This notion is of great importance since it allows us to keep a trace of the dialogue evolution in so far as each speech act leads to an action performed on a commitment or on its content.

Here are the states that we propose to use in our model. Once created, a commitment will take the *active* state and its content the *submitted* state. This expresses the fact that the content is presented for possible negotiation. A commitment can be in one of four states: *active*, *fulfilled*, *cancelled*, and *violated*.

A commitment content can take six states: *submitted*, *changed*, *refused*, *accepted*, *questioned* and *justified*. These states and the operations which trigger them depend on the commitment type. Hence, the commitment state and the content state are two parameters which characterize this commitment at any moment. Thus, we need to revise the definition of a commitment (***Definition 1***) by adding 3 new parameters. So, a social commitment is a 8-uple:

Definition 6: $SC(id_n, Ag_1, Ag_2, t_{sc}, S, S_{content}, \varphi, t_\varphi)$

where S a vector presenting the various commitment states and $S_{content}$ a vector presenting the various content states. Using vectors as parameters for commitment and content states makes it possible to keep track of all the transitions that reflect the evolution of the commitments and their contents.

3.2 Classification

In the literature [33] [16], several commitment types have been proposed. Similarly to the classification suggested by [16] we distinguish *absolute commitments*, *conditional commitments* and *commitment attempts*.

3.2.1 Absolute commitments

Absolute commitments are commitments whose fulfillment does not depend on any particular condition. Two types can be distinguished: *propositional commitments* and *action commitments*.

Propositional commitments

Propositional commitments are related to the state of the world. They are generally, but not necessarily, expressed by assertives. They can be directed towards the past, the present, or the future. We denote a propositional commitment as follows:

Definition 7: $PC(id_n, Ag_1, Ag_2, t_{pc}, S, S_{content}, p, t_p)$

where p is the proposition on which Ag_1 commits.

Action commitments

Contrary to propositional commitments, *action commitments* (also called *commitments to a course of action*) are always directed towards the future and are related to actions that the debtor is committed to carrying out. The fulfillment and the lack of fulfillment of such commitments depend on the performance of the underlying action and the specified delay. This type of commitment is typically conveyed by promises. We denote an action commitment as follows:

Definition 8: $AC(id_n, Ag_1, Ag_2, t_{ac}, S, S_{content}, \alpha, t_\alpha)$

where α is the action to be carried out.

3.2.2 Conditional commitments

Absolute commitments do not consider the conditions that may restrain their fulfillment. However, in several cases, agents need to make commitments not in absolute terms but under given conditions. Another commitment type is therefore required. These commitments are said to be *conditional*. The structure of a *conditional commitment* which must reflect the underlying condition, is different from the structure of a social commitment (***Definition 6***). We denote a conditional commitment as follows:

Definition 9: $CC(id_n, Ag_1, Ag_2, t_{cc}, S, S_{content}, (\beta, t_\beta) \Rightarrow (\gamma, t_\gamma))$

where $\Rightarrow$ stands for classical implication. This commitment expresses the fact that if β is true (or carried out) at time t_β, then Ag_1 will be committed towards Ag_2 to making γ or that γ is true at time t_γ. The addition of the symbol $\Rightarrow$ in the formula enables us to better illustrate the implication relation existing between the condition and the action.

3.2.3 Commitment attempts

The commitments described so far directly concern the debtor who commits either that a certain fact is true or that a certain action will be carried out. For example, these commitments do not allow us to explain the fact that an agent asks another one to be committed to carrying out an action (by a speech act of a directive type). To solve this problem, we propose the concept of *commitment attempt* inspired by the notion of *pre-commitment* proposed in [10]. We consider a commitment attempt as a request made by a debtor to push a creditor to be committed. Thus, when an agent Ag_1 requests another agent Ag_2 to do something, we say that the first agent is trying to induce the other agent to make a commitment. We denote a commitment attempt as follows:

Definition 10: $CT(id_n, Ag_1, Ag_2, t_{ct}, S, S_{content}, \varphi, t_\varphi)$

where φ is the content of the commitment attempt. A commitment attempt is thought of as a type of social commitment because it conveys content which is made public once the attempt is performed. However, in our approach, there is a true commitment only after the creditor agent reacts in response to the commitment attempt. The debtor and the creditor of a commitment attempt can act both on the attempt and on its content. On the one hand, the creditor agent reserves the right to accept a commitment attempt definitively, to accept it conditionally, to refuse it or to suspend it by asking for a period of reflection. It can also question the content of a commitment attempt. On the other hand, the debtor agent can cancel a commitment attempt. It can also change the content of a commitment attempt and defend it. Like a social commitment, a commitment attempt can be related to a proposition, an action or a condition. The evolution of the states of commitments and of their contents as well as the different rules of manipulating the commitment attempts are detailed in [3].

4. ARGUMENTATION

In artificial intelligence, argumentation is used in two distinct ways: to structure knowledge or to model dialectical reasoning. The first approach aims at determining how utterances form arguments and how arguments can be decomposed. This approach has been used in Toulmin's model [31]. On the other hand, the second approach deals with argument construction. Models suggested for example in [13] et [14] follow this approach. When considering dialogue modeling, the second approach seems to be more relevant because agents must be able to produce arguments supporting their propositions.

4.1 Formulation

An argumentation system essentially includes a logical language, a definition of the argument concept, a definition of the attack relation between arguments and finally a definition of acceptability. Several definitions were also proposed for the argument concept. In our model, we adopt the following definitions of [14]. Here Γ indicates a possibly inconsistent knowledge base with no deductive closure. $\vdash$ Stands for classical inference and $\equiv$ for logical equivalence.

Definition 11: *An argument is a pair (H, h) where h is a formula of L and H a sub-set of Γ 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 its conclusion.*

Definition 12: *Let (H_1, h_1), (H_2, h_2) be two arguments.*
(H_1, h_1) attack (H_2, h_2) iff $\exists\ h \in H_2$ such that $h \equiv \neg h_1$. In other words, an argument is attacked if and only if there exists an argument for the negation of an element of its support.

We can now define the concept of acceptability [13]:

Definition 13: *An argument (H, h) is acceptable for a set S of arguments iff for any argument (H', h'): if (H', h') attacks (H, h) then (H', h') is attacked by S.*

Intuitively, an argument is acceptable if it is not attacked, if it defends itself against all its attackers, or if it is defended by an acceptable argument.

4.2 Linking commitments and arguments

Argumentation is based on the construction of arguments and counter-arguments (arguments attacking other arguments), the comparison of these various arguments and finally the selection of the arguments that are considered to be acceptable. In our approach, agents must reason on their own mental states in order to build arguments in favor of their future commitments, as well as on other agents' commitments in order to be able to take position with regard to the contents of these commitments. The systems proposed in the literature, for example in [13] and [32], do not take into account the arguments which can support actions on commitments. It is these arguments which we define in this section.

In fact, before committing to some fact h being true (i.e. before creating a commitment whose content is h), the speaker agent must use its argumentation system to build an argument (H, h). On the other side, the addressee agent must use its own argumentation system to select the answer it will give (i.e. to decide about the appropriate manipulation of the content of an existing commitment). For example, an agent Ag_1 accepts the commitment content h proposed by another agent Ag_2 if its argumentation system is compatible with h. i.e. if it is able to build an argument which supports this content from its knowledge base. If Ag_1 has an argument $(H', \neg h)$, then it refuses the commitment content proposed by Ag_2. Now, if Ag_1 has an argument neither for h, nor for $\neg h$, then it must ask for an explanation. Surely, an argumentation system is essential to help agents act on commitments and their contents. However, reasoning on other mental and social attitudes (beliefs, intentions, conventions, etc.) should be taken into account in order to explain the agents' decisions in a broader context than the agents interactions [24]. We do not address this issue in this paper.

Thus, we claim that an agent should always use its argumentation system before creating a new commitment or positioning itself on an existing commitment and on its content. Consequently, an argument of an agent Ag_1 must support an action performed by this agent on a given commitment and/or on its content. Formally we denote:

Definition 14: $Arg(Ag_k, H, Act(Ag_k, t_u, SC(id, Ag_i, Ag_j, t_{sc}, S, S_{contenu}, \varphi, t_\varphi)))$

Definition 15: $Arg(Ag_k, H, Act\text{-}content(Ag_k, t_u, SC(id, Ag_i, Ag_j, t_{sc}, S, S_{contenu}, \varphi, t_\varphi)))$

such that H being the support of the argument and the agent identifiers i, j, k verify: $i, j, k \in \{1, 2\}$, $i \neq j$ and ($k=i$ or $k=j$). In the first formula, H is the support of the action *Act* performed by agent Ag_k on commitment *SC*. In the second formula, H is the support of the action *Act-content* performed by agent Ag_k. *Act-content* is an action on the content of the commitment *SC*.

The relation between H and the commitment content φ is defined according to the value of *Act* and *Act-content*. For instance, for an absolute or a conditional commitment we have:

$Act \in \{Create, Discharge\} \Rightarrow H \vdash \varphi$

I.e. if *Act* takes the value "Create" or "Fulfill", then H defends φ. In the same way:

$Act \in \{Withdraw\} \Rightarrow H \vdash \neg\varphi$

$Act\text{-}contenent \in \{Accept, Change, Defend\} \Rightarrow H \vdash \varphi$

$Act\text{-}content \in \{Refuse\} \Rightarrow H \vdash \neg\varphi$

An agent can question a commitment content φ if it has an argument neither for φ nor for $\neg\varphi$. Formally we have:

$\nexists H$ *such that* $H \vdash \varphi$ *or* $H \vdash \neg\varphi$

For the other types of commitments, this relation is detailed in [3]. A speech act can lead to an action not only on a commitment as explained in Section 3, but also on an argument. An agent can thus accept, refuse, defend or attack an argument. Thus we have:

Definition 16: $SA(i_l, Ag_i, Ag_j, t_u, U) \vdash_{déf}$
$Act\text{-}arg(Ag_i, t_u, Arg(Ag_k, H, Act(Ag_m, t_u, SC(id, Ag_x, Ag_y, t_{sc}, S, S_{content}, \varphi, t_\varphi))))$

Definition 17: $SA(i_l, Ag_i, Ag_j, t_u, U) \vdash_{déf}$
$Act\text{-}arg(Ag_i, t_u, Arg(Ag_k, H, Act\text{-}content(Ag_m, t_u, SC(id, Ag_x, Ag_y, t_{sc}, S, S_{content}, \varphi, t_\varphi))))$

where : *Act-arg* $\in$ *{Accept, Refuse, Defend or Attack}*, $i, j, k, m, x, y \in \{1, 2\}$ and $i \neq j$, $x \neq y$, ($k, m=i$ or $k, m=j$).

5. USING THE CAN FORMALISM FOR CONVERSATION REPRESENTATION

So far, we presented our framework of commitments and of the relations between these commitments and arguments. Indeed, our goal is to represent speech acts in a single approach based on commitments and arguments. This approach aims at offering software agents a flexible means to interact in a coherent way. Thus, agents can participate in conversations by manipulating commitments and by producing arguments. It is the agents' responsibility (and not the designers' role) to choose, in an autonomous way, the actions to be performed by using their argumentation systems.

In this section, we show how a conversation can be modeled using the CAN formalism on the basis of this framework. In a conversational activity, agents manage commitments and arguments whose chaining must be coherent. Our purpose is to present the dynamics of conversations using our formalism. This representation allows us to ensure conversational consistency in terms of the actions performed by the agents on the commitments and arguments. Indeed, this formalism has two objectives: it can be used to analyze conversations, as well as a means to allow agents to take part in coherent conversations.

5.1 Formal definition of a CAN

A commitment and argument network is a mathematical structure which we define formally as follows:

Definition 18: *A commitment and argument network is a 15-uple: <A, E, SC_0, I, W, S, F, D, P, a, b, d, q, g, h> where:*

- *A: a finite and nonempty set of participants. A={Ag_1, …, Ag_n}*
- *E: a finite and nonempty set of social commitments. These commitments can be absolute commitments (C), conditional commitments (CC) or commitment attempts (CT) . E={SC_0, …, SC_n}.*
- *SC_0: a distinguished element of E: the initial commitment. This element allows us to define the subject of a conversation.*
- *I : a finite and nonempty set of speech act indices (or identifiers) which can be related to the creation and the positioning actions and to the argumentation relations and to the connection relations. I={i_0, …, i_n}.*
- *W: a finite and nonempty set of both creation actions of elements of E and positioning actions on elements of E, of W ´ I and of å ´ I. W={Create, Accept, Accept conditionally, Refuse, Question, Change, Withdraw, Satisfy}*
- *S : a finite and possibly empty set of argumentation relations. S={Defend, Attack}.*
- *F : a finite and possibly empty set of connection relations that can exist between elements of E or between elements of E and elements of å ´ I. F ={Satisfy, Not satisfy, Contradict, Explain, etc.}*
- *D: a partial function relating a commitment to another commitment using one argumentation relation characterized by an identifier i of I.*

D: E ´ E ® å ´ I

- *P : a partial function relating a commitment to a pair made up of an argumentation relation and an element of I using one argumentation relation (characterized by an identifier i of I).*

P: E ´ å ´ I ® å ´ I

- *a : a partial function relating an agent (a participant) to a commitment using a set of pairs made up of a creation or a positioning action and an element of I.*

a: A ´ E ® $2^{W ´ I}$

- *b : a partial function relating an agent to an argumentation relation (characterized by an identifier i of I) using a set of pairs made up of a creation or positioning action and of an element of I.*

b: A ´ å ´ I ® $2^{W-\{Change\} ´ I}$

- *d: a partial function relating an agent to a creation or a positioning action (characterized by an identifier i of I) using a set of pairs made up of a positioning action and an element of I*

d: A ´ W ´ I ® $2^{W-\{Create, Withdraw, Change\} ´ I}$

- *q: a partial function relating a commitment to a creation or a positioning action (characterized by an identifier i of I) using one argumentation relation.*

q: E ´ W ´ I ® å ´ I

- *g: a partial function relating two commitments using a connection relation (characterized by an identifier i of I).*

g: E ´ E ® F ´ I

- *h: a partial function relating a commitment to an argumentation relation using a connection relation (characterized by an identifier i of I).*

h: E ´ å ´ I ® F ´ I

Let us now comment upon these sets and functions. In a conversation, the sets *A*, *E*, *W*, *S*, *F* and *I* must be instantiated. For example, in a given conversation we can have: *A={Ag_1, Ag_2}*, *E={PC_0, PC_1, PC_2}*, *W={Create, Accept, Question}*, *S={Defend}* etc.

The function *D* allows us to define the argumentation relation which can exist between two commitment contents, i.e. a defense or an attack relation. For example:

D(SC_i, SC_j) = (Defend, i_k).

This means that the content of the commitment SC_i (called *source* of the defense relation) defends the content of the commitment SC_j (called *target* of the defense relation). The index i_k associated with the defense relation is the identifier of the speech act whose performance gives rise to this relation. Associating such an index with argumentation relations and with various actions allows us to distinguish a relation from another and an action from another of the same type.

The function Õ allows us to define an argumentation relation on another argumentation relation. For example:

Õ(SC_i, Defend, i_k) = (Attack, i_l).

This relation points out that the content of the commitment SC_i attacks a defense relation characterized by the index i_k. This defense relation is defined using the function *D*. The attack relation defined by the function Õ is characterized by the index i_l.

The function *a* allows us to define a set of creation and positioning actions (acceptance, refusal, etc.) performed by an agent on a commitment content. For example:

a(Ag_1, SC_i)={(Accept, i_k)}

This reflects the acceptance of the content related to the commitment SC_i. This acceptance relation is characterized by the index i_k. Ag_1 belongs to the debtors set associated with this commitment.

The function *b* allows an agent to take position by accepting, accepting conditionally or refusing an argumentation relation. For instance:

b(Ag_1, Defend, i_k)={(Refuse, i_l)}

This means that the agent Ag_1 refuses the defense relation which is defined by the function *D* and characterized by the index i_k. The refusal relation is characterized by the index i_l

The function *d* allows an agent to position itself relative to a positioning action characterized by an index *i* by accepting it, accepting it conditionally, refusing it or questioning it. The positioning action on which an agent can take positions can be defined by the function *a* or the function *b*. For instance:

d(Ag_1, Refuse, i_k)={(Question, i_l)}

This example shows the case in which agent Ag_1 questions a refusal action characterized by index i_k. The question action is characterized by the index i_l.

The function *q* allows us to define an argumentation relation binding a commitment SC_i to a creation or a positioning action. The action is defined by the function *a*. For example:

q(SC_i, Refuse, i_k)=(Defend, i_l)

This example highlights the case in which the content of the commitment SC_i defends the refusal action characterized by the index i_k. The refusal action is defined by the function *a*. The index i_l characterizes the defense action.

The function *g* allows us to define the connection relation which can exist between the contents of two commitments. For example:

g(SC_i, SC_j) = (Contradict, i_k).

This translates the fact that the content of the commitment SC_i contradicts the content of the commitment SC_j. If *p* is the content of SC_i, then the content of SC_j is Ø*p*. This contradiction relation is characterized by the index i_k.

The function *h* allows us to define a connection relation between a commitment and an argumentation relation. For instance:

$$h(SC_i, Defend, i_k) = (Contradict, i_l).$$

This relation points out that the content of the commitment SC_i contradicts the defense relation characterized by the index i_k. The connection relation thus defined is characterized by the index i_l.

5.2 Example

In this section, we show how to represent a dialogue using the CAN formalism. We use the *conceptual graphs notation* (CG) proposed by Sowa [30] in order to describe the propositional contents of commitments. Conceptual graphs are a system of logic and a knowledge representation language consisting of concepts and relations between these concepts. They are labeled graphs in which concept nodes are connected by relation nodes. With their direct mapping to natural language, CG serve as an intermediate language for translating computer-oriented formalisms to and from natural languages. A concept is represented by a type (ex. PERSON) and a referent (ex. john) and denoted [TYPE: Referent] (ex. [PERSON: John]). A conceptual relation links two concepts and is represented between brackets. When representing natural language sentences, case-relations are usually used. Examples are: AGNT (agent), PTNT (patient), OBJ (object), CHRC (characteristic), PTIM (point in time). The advantage of CG over predicate calculus is that they can be used to represent the literal meaning of utterances without ambiguities and in a logically precise form.

Let us consider the following dialogue *D1*:

(Example 2: dialogue D1)

$SA(i_0, Ag_1, \{Ag_2\}, t_{u0}, U_0)$: The disease M is not genetic.

$SA(i_1, Ag_2, \{Ag_1\}, t_{u1}, U_1)$: Why?

$SA(i_2, Ag_1, \{Ag_2\}, t_{u2}, U_2)$: Because it does not appear at birth.

$SA(i_3, Ag_2, \{Ag_1\}, t_{u3}, U_3)$: A disease which does not appear at birth can be genetic as well.

$SA(i_4, Ag_1, \{Ag_2\}, t_{u4}, U_4)$: How?

$SA(i_5, Ag_2, \{Ag_1\}, t_{u5}, U_5)$: It can be due to a genetic anomaly in the DNA appearing at a certain age.

$SA(i_6, Ag_1, \{Ag_2\}, t_{u6}, U_6)$: It is true, you are right.

By its speech act identified by i_0, agent Ag_1 creates, as explained in Section 3, a propositional commitment, i.e.:

$SA(i_0, Ag_1, \{Ag_2\}, t_{u0}, U_0) \vdash_{déf}$
$Create(Ag_1, t_{u0}, PC_0(id_0, Ag_1, \{Ag_2\}, t_{pc0}, (active), (submitted), p_0, t_{p0}))$

where PC_0 is the initial commitment of the dialogue, $t_{pc0} = t_{p0}$ and p_0 is the propositional content which can be described by the following CG:

¬[[DISEASE : M]→(CHRC)→[GENETIC]]

In the CAN formalism this speech act results in the function:

$$a(Ag_1, PC_0)=\{(Create, i_0)\}$$

Thereafter, agent Ag_2 performs the speech act identified by i_1 and takes position on the content of PC_0 by questioning it. Thus, "questioned" becomes the current state of PC_0. Hence, we have:

$SA(i_1, Ag_2, \{Ag_1\}, t_{u1}, U_1) \vdash_{déf}$
$Question(Ag_2, t_{u0}, PC_0(id_0, Ag_1, \{Ag_2\}, t_{pc0}, (active), (submitted, questioned), p_0, t_{p0}))$

In the CAN formalism this speech act results in the function:

$$a(Ag_2, PC_0)=\{(Question, i_1)\}$$

Then, agent Ag_1 defends the propositional content p_0 of its commitment PC_0 by performing the speech act identified by i_2. Hence, it creates another commitment PC_1 whose content is p_1. Thus, "justified" becomes the current state of PC_0. We have:

$SA(i_2, Ag_1, \{Ag_2\}, t_{u2}, U_2) \vdash_{déf}$
$Defend(Ag_1, t_{u2}, PC_0(id_0, Ag_1, \{Ag_2\}, t_{pc0}, (active), (submitted, questioned, justified), p_0, t_{p0}))$
Ù$Create(Ag_1, t_{u2}, PC_1(id_1, Ag_1, \{Ag_2\}, t_{pc1}, (inform, null, null), (active), (submitted), p_1, t_{p1}))$

where $t_{pc1} = t_{p1}$ and p_1 is described by the following CG:

¬[[DISEASE : M]←(AGNT)←[APPEAR]→(PTIM)→[BIRTH]]

In argumentation terms, agent Ag_1 presents its argument (p_1, p_0) (see Section 4). Thus, we have:

$Arg(Ag_1, p_1, Defend(Ag_1, t_{u0}, PC_0(id_0, Ag_1, \{Ag_2\}, t_{pc0}, (active), (submitted, questioned, justified), p_0, t_{p0}))$

This is represented in the CAN formalism by the functions:

$$a(Ag_1, PC_1)=\{(Create, i_2)\}, D(PC_1, PC_0)=(Defend, i_2)$$

By the speech act identified by i_3, agent Ag_2 refuses the Ag_1's argument. Then, it creates a new commitment PC_2 whose content is p_2. We have:

$SA(i_3, Ag_2, \{Ag_1\}, t_{u3}, U_3) \vdash_{déf}$
$Refuse(Ag2, t_{u3}, Arg(Ag_1, p_1, Defend(Ag_1, t_{u0}, PC_0(id_0, Ag_1, \{Ag_2\}, t_{pc0}, (active), (submitted, questioned, justified), p_0, t_{p0})))$
Ù $Create(Ag_2, t_{u3}, PC_2(id_2, Ag_2, \{Ag_1\}, t_{pc2}, (active), (submitted), p_2, t_{p2}))$

where $t_{pc2} = t_{p2}$ and the content p_2 is described by the following CG[1] :

¬[¬[[DISEASE :*x]←(AGNT)←[APPEAR]→(PTIM)→BIRTH]] ∧ [[*x]→(CHRC)→[GENETIC]]].

This is represented in the CAN formalism by the functions:

$$b(Ag_2, Defend, i_2)=\{(Refuse, i_3)\}, a(Ag_2, PC_2)=\{(Create, i_3)\}$$

Agent Ag_1's speech act identified by i_4 questions the content of the commitment PC_2. This allows us to transfer the content to the "questioned" state:

$SA(i_4, Ag_1, \{Ag_2\}, t_{u4}, U_4) \vdash_{déf}$
$Question(Ag_1, t_{u4}, PC_2(id_2, Ag_2, \{Ag_1\}, t_{pc2}, (active), (submitted, questioned), p_2, t_{p2}))$

In the CAN formalism, this results in the function:

$$a(Ag_1, PC_2)=\{(Question, i_4)\}$$

Then, agent Ag_2 defends the content of its commitment PC_2 by performing the speech act identified by i_5. It then creates another commitment PC_3 whose content is p_3. Thus, "Justified" becomes the current state of PC_2. We have:

$SA(i_5, Ag_2, \{Ag_1\}, t_{u5}, U_5) \vdash_{déf}$
$Defend(Ag_2, t_{u5}, PC_2(id_2, Ag_2, \{Ag_1\}, t_{pc2}, (active), (submitted, questioned, justified), p_2, t_{p2}))$
Ù $Create(Ag_2, t_{u5}, PC_3(id_3, Ag_2, \{Ag_1\}, t_{pc3}, (active), (submitted), p_3, t_{p3}))$

where $t_{pc3} = t_{p3}$ and the content p_3 is described by the following CG:

[ANOMALY-DNA : *x]-
(AGNT)←[CAUSE]→(PTNT)→[DISEASE : y]
[*x]←(AGNT)←[APPEAR]→(PTIM)→[AGE : @certain]

In argumentation terms, agent Ag_2 presents its argument (p_3, p_2). Thus, we have:

$Arg(Ag_2, p_3, Defend(Ag_2, t_{u5}, PC_2(id_2, Ag_2, \{Ag_1\}, t_{pc2}, (active), (submitted, questioned, justified), p_2, t_{p2}))$

---

[1] To get this graph, we use the rule:

$p \Rightarrow q \equiv \neg(p \wedge \neg q)$, with $p = \neg$("there is a disease that appears at birth") and $q = \neg$("this disease is genetic").

Note that in the formula *x is a mark of coreference which appears in the referent part of a concept.

In the CAN formalism, this results in the following functions:

$a(Ag_2, PC_3)=\{(Create, i_5)\}, D(SC_3, PC_2)=(Defend, i_5)$

Agent Ag_2's speech act identified by i_6 reflects the Ag_2's acceptance of both PC_3's content and the argument defending it. Thus, "Accepted" is the final state of p_3. We have:

$SA(i_6, Ag_1, \{Ag_2\}, t_{u6}, U_6) \vdash_{déf}$

$Accept(Ag1, t_{u6}, Arg(Ag_2, p_3, Defend(Ag_2, t_{u5}, PC_2(id_2, Ag_2, \{Ag_1\}, t_{pc2},, (active), (submitted, questioned, justified), p_2, t_{p2})))$

$Ù\ Accept(Ag_1, t_{u6}, PC_3(id_3, Ag_2, \{Ag_1\}, t_{pc3}, (active), (submitted, accepted), p_3, t_{p3}))$

In the CAN formalism, this is represented by the functions:

$b(Ag_1, Defend, i_5)=\{(Accept, i_6)\}, a(Ag_1, PC_3)=\{(Accept, i_6)\}$

To summarize, the dialogue *D1* can be represented by the following CAN: $<A, E, PC_0, I, W, S, F, D, P, a, b, d, q, g, h>$ such that:

$A=\{Ag_1, Ag_2\}$,

$E=\{PC_0, PC_1, PC_2, PC_3\}$,

$\Omega=\{Create, Question, Refuse, Accept, \}$,

$\Sigma=\{Defend\}$,

$\Phi=\varnothing$,

$I=\{i_0, \ldots, i_6\}$

$\alpha(Ag_1, PC_0)=\{(Create, i_0)\}, \alpha(Ag_2, PC_0)=\{(Question, i_1)\}$

$\alpha(Ag_1, PC_1)=\{(Create, i_2)\}, \Delta(SC_1, PC_0)=(Defend, i_2)$

$\beta(Ag_2, Defend, i_2)=\{(Refuse, i_3)\}, \alpha(Ag_2, PC_2)=\{(Create, i_3)\}$

$\alpha(Ag_1, PC_2)=\{(Question, i_4)\}, \alpha(Ag_2, PC_3)=\{(Create, i_5)\}$

$\Delta(SC_3, PC_2)=(Defend, i_5), \alpha(Ag_1, PC_3)=\{(Accept, i_6)\}$

$\beta(Ag_1, Defend, i_5)=\{(Accept, i_6)\}$

Figure 2 shows the graphical representation of the network.

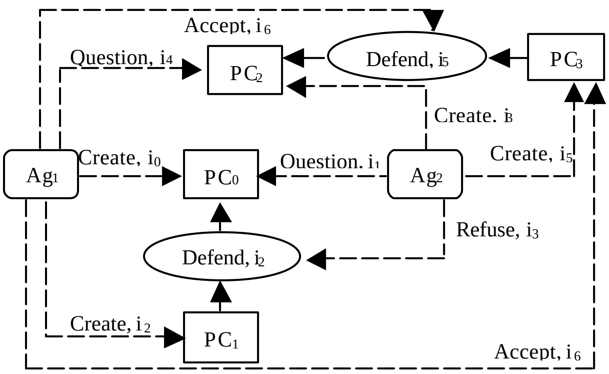

Figure 2. The network associated with the dialogue *D1*

5.3 CAN : a means of inter-agent communication

So far, we have shown how the CAN formalism enables us to illustrate the connectedness of speech acts performed by the agents in a conversation. In the example of the previous section, we started from a pre-established dialogue, we examined it and we modeled it using a CAN. This highlights a process that enables us to analyze a conversation using the CAN formalism. But the formalism also offers a means that enables agents to take part in consistent conversations.

Agents can jointly build the network that represents their conversation as it progresses. This allows the agents:

1- To make sure at any time that the conversation is consistent;

2- To determine which speech act to perform on the basis of the current state of the conversation, and using an argumentation system and other cognitive elements.

Consistency is ensured by the relationships existing between different commitments, different argumentation relations and different actions (creation, acceptance, fulfillment, etc.). A speech act is consistent with the rest of the conversation if it leads to the creation of a new commitment related to another commitment through a connection or an argumentation relation, or if it makes it possible to take position on a commitment, on an argumentation relation or on an action. Moreover, the agent must know every thing about the current state of the conversation in order to determine its next speech act. For example, when an agent creates a commitment and/or an argumentation relation, one of the other agents may decide to act on what has been created by accepting it, by refusing it or by questioning it, depending on its argumentation system. Similarly, when an agent finds that its commitment, argument or action is being questioned, it must create a commitment in order to defend it. The network is built as the conversation progresses. This process differs from the one used to analyze a conversation. Therefore, agents use a dynamic process in order to build the network while taking part in the conversation.

To illustrate this way of using the CAN formalism, we take the example of Section 5.2 and demonstrate how agents build the final network piece by piece. By doing that, agents are able to continue conversing.

Agent Ag_1 decides to start a conversation (a dialogue) with another agent Ag_2 about a particular topic p_0 that interests it (the underlying mechanism related to this choice belongs to the cognitive layer and thus is not considered here (Figure 1)). Hence, Ag_1 creates a propositional commitment whose content is p_0, i.e.:

$a(Ag_1, PC_0)=\{(Create, i_0)\}$

This corresponds to the speech act identified by i_0.

Then, agent Ag_2 decides to take position on the content of PC_0 by questioning it since it does not have any argument in favor or against it. As a matter of fact, Ag_2 wants to know which Ag_1's argument supports the content of PC_0. Therefore, Ag_2 performs the action corresponding to the speech act identified by i_1:

$a(Ag_2, PC_0)=\{(Question, i_1)\}$

Now, Ag_1 must defend its proposition: it creates the commitment PC_1 whose content defends the content of PC_0. In doing so, this agent performs the action corresponding to the speech act identified by i_2:

$a(Ag_1, PC_1)=\{(Create, i_2)\}, D(PC_1, PC_0)=(Defend, i_2)$

Ag_2 has an argument against the defense relation. It refuses it by creating the commitment PC_2. It performs the action corresponding to the speech act identified by i_3:

$b(Ag_2, Defend, i_2)=\{(Refuse, i_3)\}, a(Ag_2, PC_2)=\{(Create, i_3)\}$

Agent Ag_1 questions the content of PC_2 using its argumentation system. By doing that, it performs the action corresponding to the speech act identified by i_4:

$a(Ag_1, PC_2)=\{(Question, i_4)\}$

The content of Ag_2's commitment PC_2 being questioned. The agent must try to defend it. Thus, it creates the commitment PC_3 and performs the actions corresponding to the speech act identified by i_5:

$a(Ag_2, PC_3)=\{(Create, i_5)\}, D(SC_3, PC_2)=(Defend, i_5)$

Thereafter, agent Ag_1 accepts the content of PC_3 and the argumentation relation $(Defend, i_5)$ that are compatible with its argumentation system. It performs the actions corresponding to the speech act identified by i_6:

$b(Ag_1, Defend, i_5)=\{(Accept, i_6)\}, a(Ag_1, PC_3)=\{(Accept, i_6)\}$

5.4 CAN and conversations representation

So far, we have shown how the CAN formalism allows us to represent conversations by illustrating the connectedness of speech acts performed by the agents. However, we did not show if it can represent any coherent conversation. To do this we have to provide a mathematical demonstration. The purpose is to show that the formalism is a powerful means to support conversations for conversational agents. First, we have to define what is a conversation and what is a coherent conversation. For us, a conversation is a sequence of utterances (i.e. a sequence of speech acts). A coherent conversation is a conversation in which the sequence of utterances is coherent. Each new utterance must be coherent with one or more previous utterances. This coherence between utterances is defined in terms of the relation existing between these utterances (i.e. positioning relation, argumentation relation or connection relation).

5.4.1 Notation

We denote *D* the set of coherent conversations and *N* the set of commitment and argument networks. We denote a commitment and argument network which is associated to a coherent conversation *C* by *CAN(C)* with *C* is an element of *D* and *CAN(C)* an element of *N*.

5.4.2 Theorem

" C Î D, $CAN(C) Î N.

In other words, for any coherent conversation, there is always a CAN which represents it.

Before demonstrating this theorem, we should initially show that the CAN formalism covers all the elements describing a conversation. We use for that purpose the following formal presentation due to [17].

A conversation is a finite sequence of triples, each of which consists of: a name Ag_i Î *A*, a well-formed expression j_i Î *L*, and a performative verb v_i Î *V*. The well-formed expressions represent the participants' statements. The sequence term highlights the temporal order in which these expressions are used. The names represent the participants in the conversation. The performative verb indicates the type of the speech act performed by the use of the expression.

Formally : *C is a conversation iff : $ a language L, $ a set A of participants, $ a set V of performative verbs, $ n Î N, " 1£ i £n, $* Ag_i *ÎA, $* j_i *ÎL, $*$v_i$ *ÎV, $* p_i *ÎP and C=(*$(Ag_1, j_1, g_1, p_1),\ldots, (Ag_i, j_i, g_i, p_i), \ldots, (Ag_n, j_n, g_n, p_n)$*).*

The CAN formalism allows us to represent these various elements. The language *L* is used to describe the commitment content (for example predicate calculus or CG). The expressions j_i are thus represented by the commitment content *j*. The set of the participants is the set *A* of the CAN formalism. The performative verbs are captured by a modality *M* associated to each commitment structure (this modality is discussed in detail in [3]). The sequence of the triples is illustrated by the utterance times indicated in each commitment structure. It also illustrated by the set *I* of speech act indices which we associate to the set of the actions *W* and to the set of the argumentation relations *S* (see *Definition 18*). According to [17], a conversation can also highlight the goal of the accomplished actions. In the CAN formalism this is illustrated by the fact that it is possible to justify not only a commitment content, but also an action on a commitment, on another action or on an argumentation relation.

We also suppose that the various statements of a conversation can be described by commitments and arguments. This assumption can be justified if we refer to Singh's, Colombetti's and Amgoud et al.'s work on the semantics of ACLs. It can also be justified by our framework defined in sections 3 and 4.

5.4.3 Proof

We use a proof by contradiction. A conversation *C* can be described in the simplest form as a sequence of utterances U_0, …U_i, …U_n. Each utterance is associated to a participant Ag_j. Assuming that: ∃ a coherent conversation *C*, ∄ *CAN(C)*. In other words, let us assume that there is a coherent conversation *C* such that no network can represent it. That implies the existence of an utterance U_i which one cannot represent in a network. Let C' and C'' two subsets of C such that: *C'È{*U_i*}ÈC''=C*. Therefore the utterance U_i does not allow us to carry out one of the following actions:

- To create a new commitment.
- To take position on a commitment of *CAN(C')*.
- To take position on an action of *CAN(C')*.
- To take position on an argumentation relation of *CAN(C')*.

It remains only two possibilities to interpret U_i:

1. To take position on a commitment, an action or an argumentation relation which does not belong to *CAN(C')*. In this case the resulting conversation is not coherent because it highlights a positioning on an element which was not created. For example, to question the content of a commitment which does not exist (see our definition of coherence above).
2. U_i cannot result in an element which can be supported by the elements of CAN. This can be due to one of the two following reasons:

- R1: The utterance U_i cannot lead to the creation of a commitment, a positioning action and/or an argumentation relation. This is false by hypothesis.
- R2: The positioning action reflected by U_i cannot be presented by one of the functions of the CAN (i.e. the functions: *D, P, a, b, d, q*). This is false because it is possible to take position by *nesting*, *n* times, on a positioning action, or on an argumentation relation. The reason is that a positioning action of an unspecified order *X* is always represented by the Cartesian product: *W ´I.*

Let us show this last issue by the illustration of Figure 3.

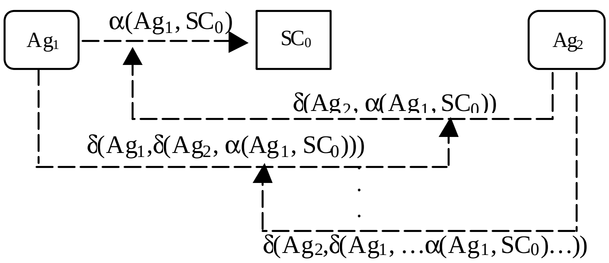

Figure 3. Illustration of nested positioning actions

Let *W={*$W_0, \ldots, W_m$*}* we have:

a(Ag_1, SC_0*)=(* W_0,t_1*)* (by the definition of the function *a*)

d(Ag_2*, a(*Ag_1, SC_0*))=d(*Ag_2, W_0,t_1*) =(*W_1,t_2*)* (by the definition of the function *d*)

d(Ag_1*,d(*Ag_2*, a(*Ag_1, SC_0*)))=d(*Ag_1, W_1,t_2*) =(*W_2,t_3*)*

.
.
.

$$\overbrace{\quad}^{n}$$

$d(Ag_2, d(Ag_1, \ldots a(Ag_1, SC_0)\ldots)) = d(Ag_2, W_{n-2}, t_{n-1}) = (W_{n-1}, t_n)$.

In the same way, one can show that it is always possible to define an argumentation relation on any argumentation relation created previously, considering that an argumentation relation of any order is represented by the Cartesian product: *S´I*.

Therefore, the starting assumption is false. Thus, we proved that any coherent conversation can be represented by a CAN formalism. Intuitively, this CAN is unique since any speech act can be interpreted in our approach in a unique way as an action performed on a commitment or on an argument.

In section 5.1 we presented the CAN formalism structure, and we illustrated its construction process through the *Example 2* of section 5.2. In these two sections, we only highlighted the fact that the CAN formalism can represent the coherence of the conversations. However, in the theorem developed in this section, we showed generally that the CAN formalism is able to represent any coherent conversation, in particular by showing the falseness of the reason R2. The theorem is thus not a "petitio principii" since “nesting property” (see the reason R2) is not an assumption in our proof. Our proof is rather a proof by construction because we showed that we can build a CAN for any coherent conversation.

This theoretical result is of a great utility, because it offers a formal framework to represent different types of conversation, for example according to the classification of [33].

6. CONCLUSION

In this paper, we proposed a formalism to represent the dynamics of conversations. The formalism offers an external representation of the conversational activity. In essence, the formalism has two purposes: on the one hand it helps to analyze conversations, and on the other hand it is a means of helping agents to take part in consistent conversations. This formalism uses an approach based on commitments and arguments to model conversations between autonomous agents. Using this approach, we can capture both the social and public aspects of conversations as well as the reasoning aspect. We also proposed a communication model and an architecture for conversational agents that is compatible with this approach and this formalism. As an extension to our work, we intend to prove mathematically the existence of one and only one CAN to represent a given coherent conversation (proof of uniqueness). We also intend to integrate our formalism in dialogue games to provide more flexibility to agent communication and to define a formal semantics for our formalism.

7. REFERENCES

[1] Amgoud, L., Maudet, N., and Parsons, N. An argumentation-based semantics for agent communication languages. 15th European Conference on Artificial Intelligence, 2002.

[2] Amgoud, L., Maudet, N., and Parsons, N. Modelling dialogues using argumentation. Proceeding of the 4th International Conference on MAS, 2000, 31-38.

[3] Bentahar, J., Moulin, B., and Chaib-draa, B. Vers une approche à base d’engagements et d’arguments pour la modélisation du dialogue. 2ème Journées Francophones des Modèles Formels de l’Interaction, 2003 (to appear).

[4] Castelfranchi, C. Commitments: from individual intentions to groups and organizations. Proceedings of the International Conference on Multi-Agent Systems, 1995, 41-48.

[5] Chaib-draa, B., and Dignum, F. Trends in agent communication languages. Computat ional Intelligence, 2002.

[6] Clark, H.H. Using language. Cambridge University Press, 1996.

[7] Clark, H.H., and Haviland, S.E. Psychological processes in linguistic explanation. Cohen, D. (eds.). Explaining Linguistic Phenomena, 1974, 91-124.

[8] Cohen, P.R., and Levesque, H.J. Persistence, intentions and commitment. Cohen, P.R., Morgan. J., and Pollack, M.E. (eds.). Intentions in Communication, MIT Press, Cambridge, 1990, 33-69.

[9] Cohen, P.R., and Perrault, C.R. Elements of a plan-based theory of speech acts. Cognitive Science, 3, 1979, 177-212.

[10] Colombetti, M. A commitment-based approach to agent speech acts and conversations. Proceedings of the Autonomous Agent Workshop on Conversational Policies. 4th International Conference on Autonomous Agent, 2000, 21-29.

[11] Dastani, M., Hulstijn, J., and der Torre, L.V. Negotiation protocols and dialogue games. Proceedings of the Belgium/Dutch AI Conference, 2000.

[12] Dignum, F., and Greaves, M. Issues in agent communication: an introduction, Dignum. F., and Greaves. M. (eds.). Issues in Agent Communication, 2000, 1-16.

[13] Dung, P.M. On the acceptability of arguments and its fundamental role in non-monotonic reasoning, logic programming and n-person games. Artificial Intelligence, 77, 1995, 321-357.

[14] Elvang-Goransson, M., Fox, J., and Krause, P. Dialectic reasoning with inconsistent information. Proceedings of the 9th Conference on Uncertainty in Artificial Intelligence, 1993, 114-121.

[15] Ferber, J. Les Systèmes Multi-Agents : vers une intelligence collective. InterEditions (eds.), 1995.

[16] Fornara, N., and Colombetti, M. Operational specification of a commitment-based agent communication language. The First International Joint Conference in Autonomous Agent and Multi-Agent Systems, 2002, 535-542.

[17] Günter, A. Some ways of representing dialogues. Cognitive Constraints on Communication, Vatina, L. and Hintikka, J. (eds.), 1984, 241-250.

[18] Hamblin, C.L. Fallacies, Methuen, 1970.

[19] Labrou, Y. Semantics for an agent communication language, Ph.D. Thesis, University of Maryland, USA, 1997.

[20] Labrou, Y., and Finin, T. Semantics and conversation for an agent communication language. Huhns, M. and Singh, M.P. (eds.). Readings in Agents, Morgan Kaufman Publisher, 1998, 235-242.

[21] MacKenzie, J. Question-begging in non-cumulative systems. Journal Of Philosophical Logic, 8, 1979, 117-133.

[22] Maudet, N., and Chaib-draa, B. Commitment-based and dialogue-game based protocols, new trends in agent communication languages. Knowledge Engineering Review, 17(2), Cambridge University Press, 2002, 157-179.

[23] McBurney, P., Parsons, S., and Wooldridge, M. Desiderata for agent argumentation protocols. Proceedings of the First International Conference on Autonomous Agent and Multi-Agents Systems, 2002, 402-409.

[24] Moulin, B. The social dimension of interactions in multi-agent systems. Wobcke, W., Pagnucco, M., and Zhang, W. (eds.). Agent and Multi-Agent Systems, Formalisms, Methodologies and Applications. Artificial Intelligence, 1441, 1998, 109-122.

[25] Parsons, S., Wooldridge, M., and Amgoud, L. An analysis of formal inter-agent dialogues. Proceedings of the First International Joint Conference on Autonomous Agents and Multi-Agent Systems, 2002, 394-401.

[26] Rousseau, D., Moulin, B., and Lapalme, G. Interpreting communicative acts and building a conversation model. Journal Natural Language Engineering, 2(3), 1996, 253-276.

[27] Searle, J.R. Speech acts: an essay in the philosophy of language. Cambridge University Press, England, 1969.

[28] Singh, M.P. A social semantics for agent communication language, Dignum. F and Greaves. M. (eds.). Issues in Agent Communication, 2000, 31-45.

[29] Singh, M.P. Agent communication languages: rethinking the principles. IEEE Computer, 1998, 40-47.

[30] Sowa, J.F. Conceptual structures: information processing in mind and machines. Addison-Wesley, Reading, MA, 1984.

[31] Toulmin, S. The uses of argument, Cambridge University Press, England, 1958.

[32] Vreeswijk, G.A.W. Abstract argumentation systems. Artificial Intelligence, 90 (1-2), 1997, 225-279.

[33] Walton, D.N., and Krabbe, E.C.W. Commitment in dialogue: basic concepts of interpersonal reasoning. State University of New York Press, NY, 1995.