Commitment and Argument Network: a formal framework for representing conversation dynamics

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Abstract: In the area of agent communication and dialogue processing, several researchers have dealt with dialogue modeling, semantics and conversational frameworks (conversation policies and dialogue games). However, few works have explored the representation of conversation dynamics. This paper presents a new formalism "commitment and argument network" (CAN) that provides an external representation of conversations and models its dynamics. Our purpose is to represent different actions that are likely to take place in a conversation. We argue that the CAN formalism can be used both to analyze conversations and to allow agents to participate in consistent conversations.

1. Introduction

When considering 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, or simply to exchange information. 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 (Searle, 1969).

Three main approaches have been proposed to model the communication between software agents in general. These approaches have been applied to agent communication languages (ACLs): the mental approach, the social approach, and the argumentative approach. Besides these approaches, certain researchers have proposed mixed methods, called intentional-conventional approaches (Maudet, 2001).

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 and that was proposed by Cohen, Perrault and Allen (Cohen and Perrault, 1979) (Allen and Perrault, 1980), speech acts were planned like non-communicative actions. Several researchers followed this idea and suggested different types of plans: domain plans and discourse plans (Litman and Allen, 1990), individual plans (Pollack, 1990) and shared plans (Grosz and Sidner, 1990). However, the fact that dialogue is a purely dynamic activity and dependent on the context of the action makes it difficult to model it using a planning approach. In particular, plan recognition that is necessary to deduce other agents' intentions is extremely complex. In fact, considering that agents plan all their speech acts is not realistic. In addition, Cohen and Levesque (1990) proposed an action theory upon which a rational interaction theory has been built. The fundamental idea of this approach is that illocutionary acts can only be derived from the analysis of the agents' mental states. This claim relies on two hypotheses: sincerity and cooperation. These two simplifying hypotheses are not always verifiable in an open agent environment. A similar approach was used by (Sadek, 1991) and by (Labrou, 1997) (Labrou and Finin, 1998) to define a formal semantics of ACLs. For example, according to this semantics, the fact that an agent Ag_1 *informs* another agent Ag_2 that a proposition p is true is interpreted as Ag_1 *believes* that p is true and *believes* that Ag_2 *intends* to find whether p is true or not. However, these semantics have been criticized for not being verifiable because one cannot verify whether the agents' behavior matches their private mental states (Singh, 2000) (Dignum and Greaves, 2000).

An alternative to the mental approach was proposed by (Singh, 1998) under the name of social approach. In opposition to the mental approach, this approach stresses the importance of conventions and the public and social aspects of dialogue. 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 (Cohen and Levesque, 1990). Social commitments do not only depend on the social structure in which they exist, but they also participate in the creation of such a structure (Singh, 1999). As a social notion, commitments are a base for a normative framework that makes it possible to model the agents' behavior. Indeed, considering their deontic nature, these commitments define constraints on the agents' behavior. The agent must behave in accordance to its commitments. For example, by committing towards other agents that a certain fact is true, the agent is compelled not to contradict itself during the conversation. It must also be able to explain, argue, justify and defend itself if another participant contradicts it. A speaker is committed to a statement when he made this statement or when he agreed with this statement made by another participant. In fact, we do not speak here about the expression of a belief, but rather about a particular relationship between a participant and a statement. What is important here is not that an agent agrees or disagrees with a statement, but rather the fact that the agent expresses agreement or disagreement, and acts accordingly. A social commitment is therefore a public attitude of a participant relative to a proposition. This notion of social commitment was proposed in order to define a formal semantics that is verifiable (Singh, 2000) (Colombetti, 2000). Thus, based on Habermas' work (1984), Singh proposed a three-level semantics such that each act is associated with three validity claims: the objective claim (that the communication is true), the subjective claim (that the communication is sincere) and the practical claim (that the speaker is justified in making the communication). For instance, by *informing* agent Ag_2 that proposition p is true, agent Ag_1 *commits* towards Ag_2 that p holds (objective conclusion), that it believes that p is true (subjective conclusion), and to the whole agent group that it has a reason to believe that p is true (practical conclusion). Singh's approach is based on the mental approach when considering the subjective claim and is embedded within a social attitude when considering the practical claim. The practical claim actually leads to a social commitment made by the speaker towards the listener. The commitment-based semantics has therefore been introduced in order to capture these three levels. Although it is verifiable at the objective level, this semantics remains unverifiable at the subjective level because this level is expressed in terms of mental states. Based on Singh's approach, Maudet (2001) proposes a model of dialogue game as a commitment structure. This model offers the advantage of being more flexible than fixed protocols. However, managing commitments in this social approach is an aspect that has not been extensively studied.

As outlined by Clark (1996), dialogue is both a cognitive and a social activity. The mere individual dispositions of the participants cannot explain this phenomenon in a satisfactory manner. This is why an increasing number of researchers often use the terms of mixed or reactive/deliberative approaches (Traum, 1997) (Hulstijn, 2000) (Pulman, 1997). During the conversation, deliberative processes related to the participants' intentions and desires can take place, as well as more reactive processes related to the conventional aspects of the interactions (Maudet, 2001). The idea is to integrate social attitudes (obligations, interpersonal relationships, roles, powers, etc.) into mental approaches. In this respect, Pulman (1997) introduces a BDIO (Belief-Desire-Intention-Obligation) approach. Moreover, (Bouzouba and Moulin, 1999) suggest adding mechanisms enabling agents involved in a conversation to manipulate social knowledge within the interaction context. They show that agents' social relationships should be taken into account in the interaction framework. Thus, they propose an architecture (a conversation manager) that stresses the importance of social relationships and allows agents to handle explicit and implicit information conveyed by speech acts.

Another approach, called the argumentative approach, was proposed by Amgoud et al. (2000) as an extension to Dung's work (1995). This approach is based upon an argumentation system with a preference relationship between arguments (Amgoud and Parsons, 2001). According to this approach, 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 of Amgoud et al. (2000) also relies upon the formal dialectics introduced by (Hamblin, 1970) and (MacKenzie, 1979). The monological models of argumentation, like Toulmin's model (Toulmin, 1958), focus on structural relationships between arguments. On the contrary, formal dialectics proposes dialogical structures to model the connectedness of utterances. Dialectical models focus on the issue of fallacious arguments, i.e., invalid arguments that appear to be valid. They are rule-governed structures of organized conversations in which two parties (in the simplest case) speak in turn in an orderly way. These rules are the principles that govern the participants' acts, and consequently the use of dialectical moves. The most important and fundamental idea in Hamblin's dialectical systems was called the *commitment store*. According to Hamblin, a person participating in a certain type of dialogue might be obliged to indicate agreement or disagreement relative to a preceding utterance of the other speaker and hence builds up a store of statements that represents his commitments in the dialogue. Furthermore, he is obliged to maintain consistency in his new utterances. When a participant asserts a proposition or an argument, this proposition or argument is inserted into the commitment store which is accessible by both participants. Amgoud and her colleagues used this approach to define a semantics of speech acts. According to this semantics, an agent Ag_1 can *inform* an agent Ag_2 that a proposition p is true only if Ag_1 has an argument in favor of p. Afterwards, agent Ag_1 must update its commitment store by including p in it. This argumentation approach, which has been applied to negotiation dialogues in (Parsons et al., 1998), has the advantage of linking communication and reasoning as well as being verifiable. However, the approach by itself does not allow capturing certain notions such as obligations, conventions, roles, etc. In our own research we combine it with a social approach.

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 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 (Clark, 1996) is very useful because it provides participants with a common understanding of the current state of the conversation and its advancement. Based on this 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. The objective is to be able to generate a complete conversation model that not only reflects the chaining of speech acts, but also related actions. These actions can be directly obtained from the speech act analysis or inferred using a set of derivation rules. Called "commitments and arguments network " (CAN) our formalism relies on an approach combining commitment and argument. 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. Thus, the formalism can clearly illustrate the creation phases of new commitments and the positioning phases on these commitments, as well as the argumentation and justification phases.

In Figure 1, we present our communication model, which takes into account both the agents' cognitive characteristics and the public and argumentative aspects of the conversation. 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 commitments/arguments 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 to be able to communicate. In this paper we propose an approach and formalism in order to model the elements composing the second layer.

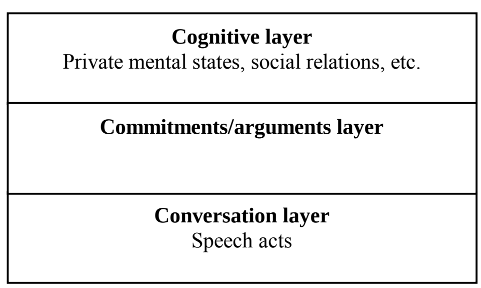

Figure 1: Communication model

The paper is structured as follows. In Section 2 we propose a model of social commitments and we show how speech acts can be interpreted as actions on these commitments. We also enhance the commitment concept with the notion of content state. In Section 3 we briefly present a classification of different types of commitments that can be used in conversations. In Section 4 we introduce argumentation aspect into these conversations. 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 compare our approach to related works and conclude the paper.

2. 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*) (Castelfranchi, 1995). The *commitment contents* is characterized by time t_φ, 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: $SC(id_n, Ag_1, A^*, t_{sc}, \varphi, t_\varphi)$

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, φ its contents and t_φ the time associated with the contents φ. 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:

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

This example illustrates that there is a mapping between a speech act and a social commitment. Singh (2000) proposes a "social semantics of speech acts" using such a mapping. For example, by performing a speech act of the *inform* type, the speaker commits that its contents is true. By performing a speech act of the *promise* type, it commits that its contents will be accomplished. Using a similar approach, Colombetti (2000) considers that a speech act of the commissive type is a commitment made by the speaker, towards every addressee, to execute an action within a limited period of time. 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. We have:

Definition 2: $SA(i_k, Ag_1, Ag_2, t_u, U) \vdash_{déf} Act(Ag_1, t_u, SC(id_n, Ag_1, Ag_2, t_{sc}, \varphi, t_\varphi))$

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. *Act* can take one of four values: *Create*, *Withdraw* (or *Cancel*), *Violate* and *Fulfill* (or *Discharge*). These actions are similar to the operations suggested by (Singh, 1999). For example, when *Act* takes the value *Create*, the above formula becomes:

$$SA(i_k, Ag_1, Ag_2, t_u, U) \vdash_{déf} Create(Ag_1, t_u, SC(id_n, Ag_1, Ag_2, t_{sc}, \varphi, t_\varphi))$$

For the utterance of *Example 1* we have:

$SA(i_0, Ag_1, Ag_2, t_u, U) \vdash_{déf} Create(Ag_1, t_u, SC(id_0, Ag_1, Ag_2, t_{sc}, Meet(Ag_1, Ag_3, MSN), t_{sc}–1h).$

This formula represents the creation of a new commitment. The debtor is the speaker and the creditors are the interlocutors of the underlying speech act.

The four actions referred to above 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. *Example 2* illustrates this aspect.

(Example 2)

U1: Quebec is the capital of Canada.

U2: No, the capital of Canada is Ottawa.

The utterance *U1* leads the debtor to create a commitment whose contents is "Quebec is the capital of Canada". On the other hand, the utterance *U2* highlights a creditor's action (a refusal) on this contents.We thus propose modeling the creditors' actions which do not apply to the commitment, but to the contents of this commitment. For example, any agent can accept, refuse or question a commitment contents. In addition, the debtor can act on its own commitments as well as on the contents of these commitments by committing itself, by withdrawing its commitment or by fulfilling its commitment. On the other hand, the creditors can only act on the contents. Figure 2 illustrates this idea.

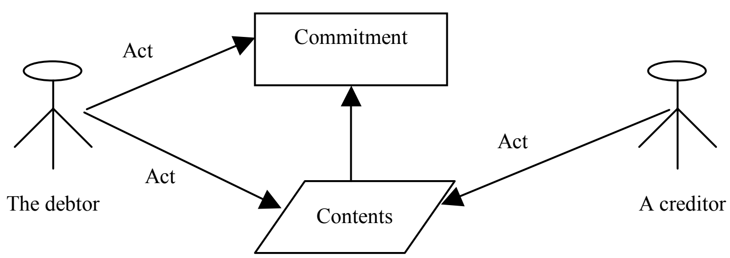

Figure 2: Debtor and creditors actions on a commitment and its contents

Hence, one must make a difference between the actions applied on a commitment and the actions performed on the contents of a commitment. We denote an action applied on the contents of a commitment as follows:

Definition 3: $Act\text{-}contents(Ag_k, t_u, SC(id_n, Ag_i, Ag_2, t_{sc}, \varphi, t_\varphi))$

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

Agent Ag_k can thus act on the contents of its own commitment (in this case we get $k=i$) or on the contents 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 contents are different from the actions that can be carried out by the creditor. The debtor can change the contents of its own commitment, can defend it if the debtor refuses it or questions it. The creditor can refuse the contents of another agent's commitment, accept it or question it.

Considering for example the *Refuse-contents* act, the formula becomes:

$SA(i_k, Ag_1, Ag_2, t_u, U) \vdash_{déf} Refuse\text{-}contents(Ag_1, t_u, SC(id_n, Ag_2, Ag_1, t_{sc}, \varphi, t_\varphi))$

This specifies the fact that the creditor (agent Ag_1) refuses the contents of the commitment of the debtor (agent Ag_2), which is identified by id_n. This can be thought of as an attempt to change the partner's commitment.
For an acceptance act we have:

$$SA(i_k, Ag_1, Ag_2, t_u, U) \vdash_{déf} Accept\text{-}contents(Ag_1, t_u, SC(id_n, Ag_2, Ag_1, t_{sc}, \varphi, t_\varphi))$$

This reflects that the creditor (agent Ag_1) accepts the commitment contents identified by id_n and created by the debtor (agent Ag_2).

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 contents when the speaker is the debtor or the creditor. The semantics associated with these kinds of actions is expressed in terms of arguments (see Section 4.2). When an agent acts on the contents of a commitment created by another agent we refer to this as taking a position on a commitment contents. However, it should be noted that the same utterance can lead both to taking a position on the contents of an existing commitment and to the creation of a new commitment. *Example 3* illustrates this idea:

(Example 3)

U1: Quebec is the capital of Canada.

The utterance *U1* leads to the creation of a new commitment:

$$SA(i_0, Ag_1, Ag_2, t_{u1}, U1) \vdash_{déf} Create(Ag_1, t_{u1}, SC(id_0, Ag_1, Ag_2, t_{sc1}, Capital(Canada, Québec), t_{\varphi 1})$$

U2: No, the capital of Canada is Ottawa.

The utterance *U2* leads at the same time to a positioning on the contents of the commitment created following the utterance *U1* and to the creation of another commitment. Formally:

$$\begin{aligned} &SA(i_1, Ag_2, Ag_1, t_{u2}, U2) \vdash_{déf} \\ &\quad Refuse\text{-}contents(Ag_2, t_{u2}, SC(id_0, Ag_1, Ag_2, t_{sc1}, Capital(Canada, Quebec), t_{\varphi 1})) \\ &\quad \wedge Create(Ag_2, t_{u2}, SC(id_1, Ag_2, Ag_1, t_{sc2}, Capital(Canada, Ottawa), t_{\varphi 2})). \end{aligned}$$

Generally, a speech act leads to an action on a commitment and/or an action on a commitment contents. Formally:

Definition 4 : $SA(Ag_1, Ag_2, t_u, U) \vdash_{déf} \begin{cases} Act(Ag_1, t_u, SC(id, Ag_1, Ag_2, t_{sc}, \varphi, t_\varphi)) \\ \text{and/or} \\ Act\text{-}contenu(Ag_k, t_u, SC(id, Ag_i, Ag_j, t_{sc}, \varphi, t_\varphi)) \end{cases}$

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

This commitment formulation remains incomplete since it does not consider all the speech act components. Indeed, according to the speech act theory, a speech act includes not only propositional contents, but also an illocutionary force (Searle and Vanderveken, 1985). Thus, we propose enhancing the commitment structure with a modality *M* which will express the illocutionary force of the underlying act. Considering this modality at the commitment level will allow the agents to reason properly on these commitments, e.g., they will be able to distinguish between a weak assertion (*"I believe that"*) and a strong assertion (*"I am certain that"*). According to the speech act theory, the illocutionary force is divided into six components. As noted by Bouzouba and Moulin (2001), the propositional contents conditions and the preparatory conditions are related to the semantics interpretation. However, the illocutionary point and the degree of strength are related to a commitment. We have been inspired by the parameters proposed by Bouzouba and Moulin (2001) in a KQML+ message (knowledge query and manipulation language)[1] to express the modality at the commitment level. This modality will be composed of the performative verb and the associated degree *(v, d)*, for example *(request, polite)*, and possibly a representation mode *p*, for example *"with pleasure"*.(see *Example 4*)

(Example 4)

U1: I believe that all the students finished the test

The utterance *U1* leads to the creation of the commitment:

$SA(i_0, Ag_1, Ag_2, t_{u1}, U1) \vdash_{déf}$

$Create(Ag_1, t_{u1}, SC(id_0, Ag_1, Ag_2, t_{sc},$ **(inform, believe, null)**, $Finish(\text{All the students, Test}), t_{\varphi 1}))$

in which *(v, d, p)=(inform, believe, null).*

2. 1. The Notion of state

A commitment can evolve and be transformed as result of the actions that the debtor performs on it (creation, cancellation, violation and discharge). Its contents 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 contents 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, one must distinguish between the notion of the commitment state (Verdicchio and Colombetti, 2002) and the notion of the contents 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 contents of a commitment, the contents state is transformed. One could also speak about a commitment lifecycle in which this commitment evolves through different states, and a commitment contents lifecycle in which the contents evolves through different states. Indeed, the notion of commitment state alone does not reflect the conversation dynamics since it only captures the debtor's acts on its commitment. The two states (the commitment state and the contents 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 contents. Contrary to the notion of the commitment store (Hamblin, 1970), which allows us only to track "who said what", the notion of state makes it possible to illustrate how participants change the dialogue state by performing actions on existing commitments or on their contents.

Here are the states that we propose using in our model. Once created, a commitment will take the *active* state and its contents the *submitted* state. This expresses the fact that the contents is presented for possible negotiation. A commitment can be in one of four states: *active*, *fulfilled*, *cancelled,* and *violated*. Figure 3 shows the state diagram of a commitment.

[1] KQML is a language and protocol for exchanging information and knowledge between software agents (KQML, 1993). It focuses on an extensible set of performatives, which defines the permissible operations that agents may carry out on other's knowledge stores. It allows agents to communicate attitudes about information, such as querying, stating, believing, and offering. KQML+ is a KQML extension proposed by Bouzouba and Moulin (2001).

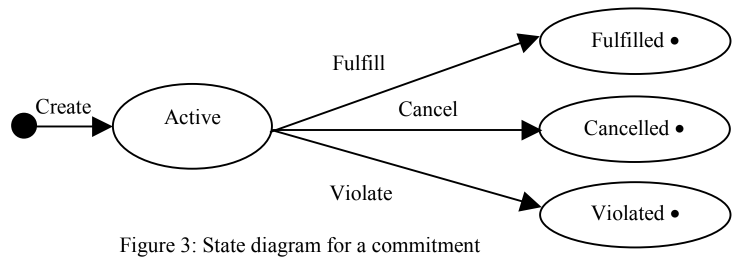

Figure 3: State diagram for a commitment

A commitment contents 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 contents 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 9-uple:

Definition 5: $SC(id_n, Ag_1, Ag_2, t_{sc}, M, S, S_{contents}, \varphi, t_\varphi)$

where M is a triple: $M (v, d, p)$, S a vector presenting the various commitment states and $S_{contents}$ a vector presenting the various contents states. Using vectors as parameters for commitment and contents states makes it possible to keep track of all the transitions that reflect the evolution of the commitments and their contents. The following example illustrates this notion of state and its evolution:

(Example 5: dialogue D1)

U1: The book is not allowed during the test.
U2: Why?
U3: Because the answers are given in this book.
U4: Ok, Thank you.

By utterance *U1*, agent Ag_1 creates a commitment, whose state is “active”. The state of the contents is submitted. Formally:

$SA(i_0, Ag_1, Ag_2, t_{u1}, U1) \vdash_{déf}$
$Create(Ag_1, t_{u1}, SC(id_0, Ag_1, Ag_2, t_{sc1}, (inform, null, null), (\textbf{active}), (\textbf{submitted}), \neg Allow(Book, Test), t_{\varphi 1}))$

By utterance *U2*, agent Ag_2 questions the contents of the commitment identified by id_0. This commitment always remains in the “active” state, but its contents takes the state “questioned”. Formally:

$SA(i_1, Ag_2, Ag_1, t_{u2}, U2) \vdash_{déf}$
$Question(Ag_2, t_{u2}, SC(id_0, Ag_1, Ag_2, t_{sc1}, (inform, null, null), (\textbf{active}), (submitted, \textbf{questioned}), \neg Allowed(Book, Test), t_{\varphi 1}))$

By utterance *U3*, agent Ag_1 creates a new commitment. The state of this commitment is “active”, and the state of its contents is “submitted”. By the same utterance, this agent justifies the contents of its commitment identified by id_0. The state of this commitment is always “active” and “justified” becomes the current state of its contents. Formally:

$SA(i_2, Ag_1, Ag_2, t_{u3}, U3) \vdash_{déf}$

$Create(Ag_1,\ t_{u3},\ SC(id_1,\ Ag_1,\ Ag_2,\ t_{sc2},\ (inform,\ null,\ null),\ (\mathbf{active}),\ (\mathbf{submitted}),$
$Give(Answers, Book), t_{\varphi 2}))$
$\wedge Justify(Ag_1,\ t_{u3},\ SC(id_0,\ Ag_1,\ Ag_2,\ t_{sc1},\ (inform,\ null,\ null),\ (\mathbf{active}),$
$(submitted, questioned, \mathbf{justified}), \neg Allow(Book, Test), t_{\varphi 1}))$

By utterance *U4*, agent Ag_2 accepts the contents of the commitment identified by id_1. Thus, "fulfilled" becomes the current state of this commitment and "accepted" becomes the state of its contents. Consequently, this agent also accepts the contents of the commitment identified by id_0. Thus, "fulfilled" and "accepted" are the current states respectively of this commitment and its contents. Formally:

$SA(i_3, Ag_2, Ag_1, t_{u4}, U4) \vdash_{déf}$
$Accept(Ag_2,\ t_{u4},\ SC(id_1,\ Ag_1,\ Ag_2,\ t_{sc2},\ (inform,\ null,\ null),\ (active,\ \mathbf{fulfilled}),$
$(submitted, \mathbf{accepted}),\ Give(Answers, Book), t_{\varphi 2}))$
$\wedge Accept(Ag_2,\ t_{u4},\ SC(id_0,\ Ag_1,\ Ag_2,\ t_{sc1},\ (inform,\ null,\ null),\ (active,\ \mathbf{fulfilled}),$
$(submitted,\ questioned,\ justified,\ \mathbf{accepted}),\ \neg Allow(Book,$
$Test), _{\varphi 1}))$

3. Classification

In the literature (Walton and Krabbe, 1995) (Singh, 1999) (Fornara and Colombetti, 2002), several commitment types have been proposed. Similarly to the classification suggested by (Fornara and Colombetti, 2002) we distinguish *absolute commitments*, *conditional commitments* and *commitment attempts*.

3. 1. Absolute commitments

Absolute commitments (denoted *C*) are commitments whose fulfillment does not depend on any particular conditions. Two types can be distinguished: *propositional commitments* and *action commitments*.

3. 1. 1. Propositional commitments

Propositional commitments are related to the state of the world (see *Example 6*). 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 6: $PC(id_n, Ag_1, Ag_2, t_{pc}, M, S, S_{contents}, p, t_p)$

where p is the proposition on which Ag_1 commits.

(Example 6)

U: "The door is open"

$SA(i_0, Ag_1, Ag_2, t_u, U) \vdash_{déf}$
$Create(Ag_1, t_u, PC(id_0, Ag_1, Ag_2, t_{pc}, (inform, null, null), (active), (submitted), open(door), t_p))$

Such that $t_{pc} = t_p$.

3. 1. 2. 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 realization 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 7: $AC(id_n, Ag_1, Ag_2, t_{ac}, M, S, S_{contents}, \alpha, t_\alpha)$

where α is the action to be carried out (see *Example 7*).

(Example 7)

U: "I will give you 10 dollars in one hour"

$SA(i_0, Ag_1, Ag_2, t_u, U) \vdash_{déf}$

$Create(Ag_1, t_u, AC(id_0, Ag_1, Ag_2, [t_{ac}^{inf}, t_{ac}^{inf} +1h], (promise, null, null), (active), (submitted), Give(Ag_1, Ag_2, 10\ dollars), t_\alpha))$

The state diagram of an absolute commitment is similar to that of Figure 3. The state diagram associated with the contents of such a commitment is presented at Figure 5. It contains the possible states for the commitment contents and the transitions corresponding to the operations which can be applied to these contents. The dotted transitions in the figure correspond to the creditor's actions and the non-dotted transitions correspond to the debtor's actions. These operations are reflected by the participants' utterances. Thus, the debtor can submit a commitment contents, defend it and change it. The creditor can accept this contents, refuse it and question it.

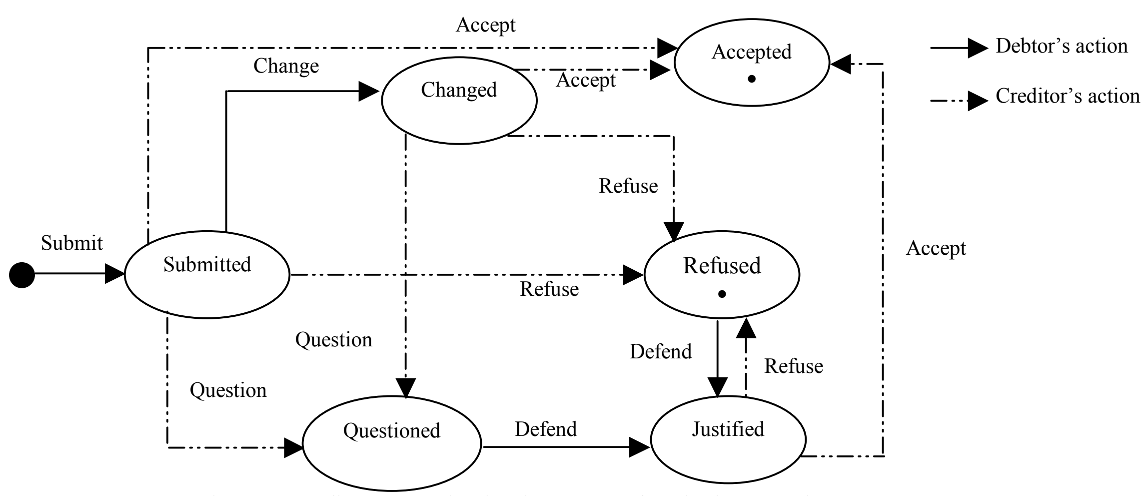

Figure5: State diagram associated to the contents of an absolute commitment.

Considering absolute commitments directed towards the future, the relation between the utterance time, the time associated with the commitment and the time associated with the action satisfies the formula:

$t_u \le t_{ac}^{inf} \le t_\alpha \le t_{ac}^{sup}$ (see Figure 4).

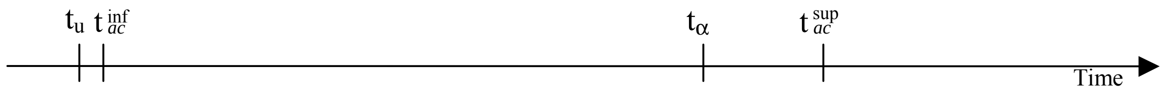

Figure 4: Relations between the utterance time, the time associated with the commitment and the time associated with the action.

A commitment towards the future can be interpreted either as a propositional commitment or as an action commitment. For example, the utterance *"tomorrow the door will be open"* may be interpreted as a propositional commitment made by the speaker on a future state of the world. It can also be interpreted as an action commitment if the speaker is responsible for opening the door in question. Therefore, the commitment made by the speaker depends on the conversation context. It is in this sense that social context is a fundamental issue in communication (Moulin, 1998). In particular, this allows us to handle properly indirect speech acts (Bouzouba and Moulin, 1999).

3. 2. Conditional commitments

Absolute commitments do not consider the conditions that may restrain their fulfillment. These commitments are sufficient to account for basic situations. However, in several cases, agents need to make commitments not in absolute terms but under given conditions. Another commitment type is therefore required in order to be able to capture situations defined by certain conditions. 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 5***). We denote a conditional commitment as follows:

Definition 8: $CC(id_n, Ag_1, Ag_2, t_{cc}, M, S, S_{contents}, (\beta, t_\beta) \Rightarrow (\gamma, t_\gamma))$

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 so that γ is true at time t_γ (see *Example 8*). There is a similarity between action commitments and conditional commitments since both relate to a future time (the future for a conditional commitment depends not only on time but also on the fulfillment of the underlying condition). The state diagram associated with a conditional commitment is similar to that of Figure 3. The state diagram associated with the contents of such a commitment is identical to that of the contents of an absolute commitment (Figure 5). Indeed, we can consider any social commitment as a conditional commitment whose underlying condition is always true. Thus, a social commitment can be denoted:

Definition 9: $SC(id, Ag_1, Ag_2, t_{sc}, M, S, S_{contenu}, (true, \forall t) \Rightarrow (\varphi, t_\varphi))$

Definition 5 can be considered as a simplification of ***Definition 9***. However for simplification purposes, we will use ***Definition 5*** instead of ***Definition 9*** when considering a social commitment.

(Example 8)

U: "If you help me now, I will help you in two hours"

$SA(i_0, Ag_1, Ag_2, t_u, U) \vdash_{déf}$

$Create(Ag_1, t_u, CC(id_0, Ag_1, Ag_2, [t_{cc}^{inf}, t_{cc}^{inf}+2h], (promise, null, null), (active), (submitted), (help(Ag_2, Ag_1), t_\beta) \Rightarrow (help(Ag_1, Ag_2), t_\gamma))$

where $t_\gamma = t_\beta + 2h$.

3. 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 (Colombetti, 2000). 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: $CT(id_n, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \varphi, t_\varphi)$

where φ is the contents of the commitment attempt. This formulation seems more intuitive than Colombetti's, according to which the agent Ag_2 is the debtor and the agent Ag_1 is the creditor.

A commitment attempt is thought of as a type of social commitment because it conveys contents 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 contents. 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 contents of a commitment attempt. On the other hand, the debtor agent can cancel a commitment attempt. It can also change the contents of a commitment attempt and defend it. The states of a commitment attempt and those of its contents can also be described by a state diagram. Like a social commitment, a commitment attempt can be related to a proposition, an action or a condition.

The agents also manipulate the commitment attempts. Thus, the refusal, the acceptance and the conditional acceptance of a commitment attempt automatically lead to the creation of new commitments. The three following rules illustrate this characteristic when the commitment attempt relates to a proposition or an action λ :

R1: $CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda)$
$\wedge Refuse(Ag_2, t_{refuse}, CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda))$
$\Rightarrow Create(Ag_2, t_{refuse}, SC(id_2, Ag_2, Ag_1, t_{sc}, M,(active), (submitted), \neg\lambda, t_\lambda))$

R2: $CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda)$
$\wedge Accept(Ag_2, t_{accept}, CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda))$
$\Rightarrow Create(Ag_2, t_{accept}, SC(id_2, Ag_2, Ag_1, t_{sc}, M, (active), (submitted), \lambda, t_\lambda))$

R3: $CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda)$
$\wedge Accept\text{-}condit(Ag_2, t_{accept\text{-}condit}, CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda), (\mu, t_\mu)\Rightarrow(\lambda, t_\lambda))$
$\Rightarrow Create(Ag_2, t_{accept\text{-}condit}, CC(id_2, Ag_2, Ag_1, t_{cc}, M, (active), (submitted), (\mu, t_\mu)\Rightarrow(\lambda, t_\lambda)))$.

When it is refused or accepted, a commitment attempt becomes a new commitment that is in the active state. The debtor and creditor of this new commitment are respectively the creditor and debtor of the commitment attempt. When it is conditionally accepted by Ag_2, the commitment attempt of Ag_1 involves the creation of a conditional commitment by Ag_2. In this case, the condition μ can be a simple condition or a commitment attempt. In this last case, the rule R3 becomes: (see *Example 9*).

R3': $CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda)$

$\wedge Accept\text{-}condit(Ag_2, t_{accept\text{-}condit}, CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, \lambda, t_\lambda), (\mu, t_\mu)\Rightarrow(\lambda, t_\lambda))$

$\Rightarrow Create(Ag_2, t_{accept\text{-}condit}, CC(id_2, Ag_2, Ag_1, t_{cc}, M, (active), (submitted), (\mu, t_\mu)\Rightarrow(\lambda, t_\lambda)))$

$\wedge Create(Ag_2, t_{accept\text{-}condit}, CT(id, Ag_2, Ag_1, t_{ct}, M', (active), (submitted), \mu, t_\mu)$

where $t_\mu < t_\lambda$.

(Example 9)

U1: Can you help me to carry this big box?
U2: Provided that you first help me to solve my mathematics problem.

Let :λ*=help(Ag*$_2$*, Ag*$_1$*, Carry this big box) and* μ*=help(Ag*$_1$*, Ag*$_2$*, Solve my mathematics problem).*
By utterance *U1*, the agent Ag_1 creates a commitment attempt:

$SA(i_0, Ag_1, Ag_2, t_u, U1) \vdash_{déf}$

$Create(Ag_1, t_{u1}, CT(id_1, Ag_1, Ag_2, t_{ct1}, (request, null, null), (active), (submitted), \lambda, t_\lambda)$

By utterance *U2*, the agent Ag_2 accepts conditionally the commitment attempt of the agent Ag_1. It commits conditionally that if μ is carried out then λ will be carried out with (t_μ<t_λ). In the same utterance, it tries to induce agent Ag_1 to carry out μ :

$SA(i_1, Ag_2, Ag_1, t_u, U2) \vdash_{déf}$

$Create(Ag_2, t_{u2}, CC(id_2, Ag_2, Ag_1, t_{cc}, (promise, null, null), (active), (submitted), (\mu, t_\mu)\Rightarrow(\lambda, t_\lambda)))$

$\wedge Create(Ag_2, t_{u2}, CT(id_3, Ag_2, Ag_1, t_{ct}, (request, null, null), (active), (submitted), \mu, t_\mu)$

When the commitment attempt relates to a condition, the rules R1 and R2 become:

R1': $CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, (\beta, t_\beta)\Rightarrow(\gamma, t_\gamma))$

$\wedge Refuse(Ag_2, t_{refuse}, CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, (\beta, t_\beta)\Rightarrow(\gamma, t_\gamma)))$

$\Rightarrow Create(Ag_2, t_{refuse}, SC(id_2, Ag_2, Ag_1, t_{sc}, M, (active), (submitted), \neg((\beta, t_\beta)\Rightarrow(\gamma, t_\gamma))))$

R2': $CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, (\beta, t_\beta)\Rightarrow(\gamma, t_\gamma))$

$\wedge Accept(Ag_2, t_{accept}, CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, (\beta, t_\beta)\Rightarrow(\gamma, t_\gamma)))$

$\Rightarrow Create(Ag_2, t_{accept}, CC(id_2, Ag_2, Ag_1, t_{cc}, M, (active), (submitted), (\beta, t_\beta)\Rightarrow(\gamma, t_\gamma)))$

According to rule R1', refusing a commitment attempt which relates to a condition consists of refusing its contents without committing towards its condition β. However, according to rule R2', accepting a commitment attempt consists of accepting it under its condition, which leads to a conditional commitment. We can also speak about a conditional acceptance which consists of negotiating the condition. Thus, instead of accepting a commitment attempt under its condition β, the interlocutor proposes another condition β' (see rule R3'').

R3'' : $CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, (\beta, t_\beta)\Rightarrow(\gamma, t_\gamma))$

$\wedge Accept\text{-}condit(Ag_2, t_{accept\text{-}condit}, CT(id_1, Ag_1, Ag_2, t_{ct}, M, S, S_{contents}, (\beta, t_\beta)\Rightarrow(\gamma, t_\gamma), (\beta', t_{\beta'})\Rightarrow(\gamma, t_\gamma))$

$\Rightarrow Create(Ag_2, t_{accept\text{-}condit}, CC(id_2, Ag_2, Ag_1, t_{cc}, M, (active), (submitted), (\beta', t_{\beta'})\Rightarrow(\gamma, t_\gamma)))$

where $\beta \neq \beta'$.

4. Argumentation

In artificial intelligence, argumentation is used in two distinct ways: to structure knowledge or to model dialectical reasoning. The first approach deals with the macrostructure of arguments. It is a top-down approach which aims at determining how utterances form arguments and how arguments can be decomposed. This approach has been used in Toulmin's model (Toulmin, 1958) and its extensions proposed by (Bench-Capon et al., 1998) and (Stranieri and Zeleznikow, 1999). On the other hand, the second approach deals with the microstructure of arguments. It is a bottom-up approach which deals with argument construction. Models suggested in (Pollock, 1992), (Elvang-Goransson et al., 1993), (Dung, 1995), (Vreeswijk, 1997) and (Amgoud, 1999) 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 and their actions.

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 have been proposed in the literature. For example, (Vreeswijk, 1997) proposes:

Definition 11: *An argumentation system is a triple $<L, N, \leq>$ such that L is a propositional language, N is a set of inference rules given in terms of L. These rules define the possible inferences. $\leq$ is a preference relation (reflexive and transitive) between the arguments.*

Several definitions were also proposed for the argument concept. In our model, we adopt the following definitions of (Elvang-Goransson et al., 1993). Here Γ indicates a possibly inconsistent knowledge base with no deductive closure. $\vdash$ Stands for classical inference and $\equiv$ for logical equivalence.

Definition 12: *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 13: *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 (Dung, 1995):

Definition 14: *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. According to (Dung, 1995), any argumentation system includes two essential elements: one element is used to build and generate the arguments, the other is used to analyze these arguments by determining their acceptability. This view is important for our communication model. Indeed, 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 (Dung, 1995), (Vreeswijk, 1997) and (Amgoud, 1999) do not take into account the arguments which can support the communicative actions. It is these arguments which we formulate in this Section.

In fact, before committing to some fact h being true (i.e. before creating a commitment whose contents 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 select the appropriate manipulation of the contents of an existing commitment). For example, un agent Ag_1 accepts the commitment contents 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 contents from its knowledge base. If Ag_1 has an argument $(H', \neg h)$, then it refuses the commitment contents 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. We do not address this issue in this paper.

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

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

With 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 $Act\text{-}contents$ performed by agent Ag_k. $Act\text{-}contents$ is an action on the contents of the commitment SC. The relation between H and the commitment contents φ depends on the values of Act and $Act\text{-}contents$.
Thus, 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 "Discharge", then *H* defends φ. In the same way:

$$Act{=}Withdraw \Rightarrow H \vdash \neg\varphi$$
$$Act\text{-}contenents \in \{Accept, Change, Defend\} \Rightarrow H \vdash \varphi$$
$$Act\text{-}contenu{=}Refuse \Rightarrow H \vdash \neg\varphi$$

To illustrate this idea, let us dialogue *D1* of *Example 5* (Section 2.1). By utterance *U3*, agent Ag_1 presents the support $H{=}Give(Answers, Book)$ in order to justify the content $\varphi{=}\neg Allow(Book, Test)$ of the commitment identified by id_0. Formally we have:

$$Arg(Ag_1, Give(Answers, Book),$$
$$Create(Ag_1, t_{u1}, SC(id_0, Ag_1, Ag_2, t_{sc1}, inform, null, null), (active),$$
$$(submitted, questioned, justified), \neg Allow(Book, Test), t_{\varphi 1})))$$

An agent can create a commitment attempt related to a proposition *p*, if it has an argument neither for *p* nor for $\neg p$. Formally we have:

$$\exists H \text{ such that } H \vdash p \text{ or } H \nvdash \neg p$$

This reasoning is also valid for a commitment attempt related to a condition. However, the creation of a commitment attempt related to an action α depends on the context. For example, to create a commitment attempt in the form of an order, the debtor must have the social capacity to give orders to the other agent.

When considering the acceptance, the conditional acceptance, the refusal and the withdrawal of a commitment attempt, we have:

$$Act \in \{Accept, accept\ conditionally\} \Rightarrow H \vdash \varphi$$
$$Act \in \{Refuse, withdraw\} \Rightarrow H \vdash \neg\varphi$$

For conditional acceptance, the agent has an argument for φ, but one of the elements of the support *H* is not yet true. It also should be noted that these actions also depend on the social context. For example, an agent may have to accept an order even if it finds an argument which is inconsistent with the contents of this order. This happens when considering a social context in which the agent must obey without discussion. For the action of change and justification of the contents of a commitment attempt, we have:

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

When considering the creation of a new commitment, the agent must always have a reason supporting it, i.e. an argument for the action which is different from the argument that supports the contents. *Example 10* illustrates this idea:

(*Example 10*)

U: "The book "Agent technology" is interesting"

$$SA(i_0, Ag_1, Ag_2, t_u, U) \vdash_{déf}$$
$$Create(Ag_1, t_u, PC(id_0, Ag_1, Ag_2, t_{pc}, (inform, null, null), (active), (submitted),$$
$$Interesting(book, Agent\ technology), t_p))$$

Such that $t_{pc} = t_p$.

To create this commitment, Ag_1 must have a reason to do it, as for example in order to ask another agent to buy the book. This argument supporting the creation action is different from the argument supporting the contents, corresponding for example to “this book is interesting because its editors are well known authors”. It is thus significant in this case to distinguish the argument supporting the action (noted *H’*) and the argument supporting the contents (noted *H*). Formally:

$$Arg(Ag_1, H, H', Create(Ag_1, t_u, SC(id, Ag_1, Ag_2, t_{sc}, M, S, S_{contents}, \varphi, t_\varphi)))$$

$$\text{Such that } H \vdash \varphi, H' \vdash Create(Ag_1, t_u, SC(id, Ag_1, Ag_2, t_{sc}, M, S, S_{contents}, \varphi, t_\varphi)), H' \nvdash \varphi$$

A speech act can lead to an action not only on a commitment as explained in Section 2, but also on an argument. An agent can thus accept, refuse, defend or attack an argument. Thus we have:

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

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

Example 11 in the following section presents a case in which an agent acts on an argument.

5. Using The CAN formalism for conversation representation

So far, we have presented our formulations 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 these formulations. 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 commitments and arguments network is a mathematical structure which we define formally as follows:

Definition 15: *A commitments and arguments network is a 15-uple:* $<A, E, SC_0, I, \Omega, \Sigma, \Phi, \Delta, \Pi, \alpha, \beta, \delta, \theta, \gamma, \eta>$ *where:*

- *A: a finite and nonempty set of participants.* $A=\{Ag_1, \ldots, Ag_n\}$

- *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}.*
- *Ω: a finite and nonempty set of both creation actions of elements of E and positioning actions on elements of E, of $\Omega \times I$ and of $\sum \times I$. Ω={Create, Accept, Accept conditionally, Refuse, Question, Change, Withdraw, Satisfy}*
- *Σ: a finite and possibly empty set of argumentation relations. Σ={Defend, Attack}.*
- *Φ: a finite and possibly empty set of connection relations that can exist between elements of E or between elements of E and elements of $\sum \times I$. Φ={Satisfy, Not satisfy, Contradict, Explain, etc.}*
- *Δ: a partial function relating a commitment to another commitment using one argumentation relation characterized by an identifier i of I.*

$\Delta: E \times E \rightarrow \sum \times I$

- *Π: 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).*

$\Pi: E \times \sum \times I \rightarrow \sum \times I$

- *α: 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.*

$\alpha: A \times E \rightarrow 2^{\Omega \times I}$

- *β: 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.*

$\beta: A \times \sum \times I \rightarrow 2^{\Omega\text{-}\{Changer\} \times I}$

- *δ: 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*

$\delta: A \times \Omega \times I \rightarrow 2^{\Omega\text{-}\{Create,\ Withdraw,\ Change\} \times I}$

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

$\theta: E \times \Omega \times I \rightarrow \sum \times I$

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

$\gamma: E \times E \rightarrow \Phi \times I$

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

$\eta: E \times \sum \times I \rightarrow \Phi \times I$

Let us now comment upon these sets and functions. In a conversation, the sets *A*, *E*, *Ω*, *Σ*, *Φ* 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}*, *Ω={Create, Accept, Question}*, etc.

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

$$\Delta(SC_i, SC_j) = (Defend, i_k).$$

This means that the contents of the commitment SC_i (called *source* of the defense relation) defends the contents 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. Schematically, the function Δ is presented in the following way (Figure 6):

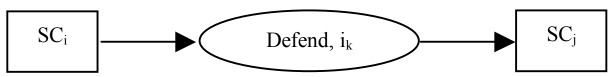

Figure 6: The function Δ.

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

$$\Pi(SC_i, Defend, i_k) = (Attack, i_l).$$

This relation points out that the contents of the commitment SC_i attacks a defense relation characterized by the index i_k. This defense relation is defined using the function Δ. The attack relation defined by the function Π is characterized by the index i_l. Schematically, we present the function Π in the following way (Figure 7):

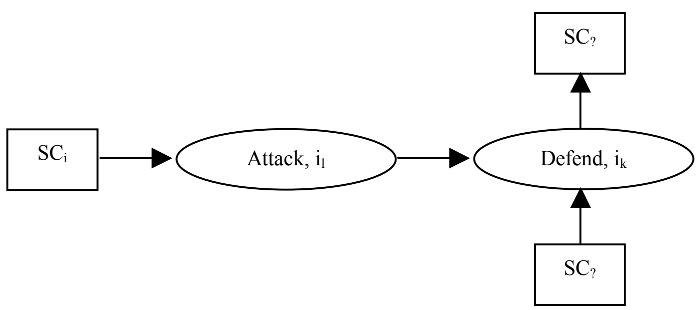

Figure 7: The function Π.

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

$$\alpha(Ag_1, SC_i)=\{(Accept, i_k)\}$$

This reflects the acceptance of the contents 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. Schematically, we present the function α as follows (Figure 8):

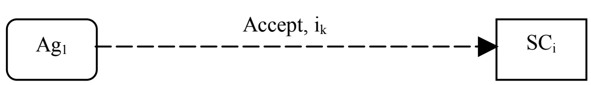

Figure 8: The function α.

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

$$\beta(Ag_1, Defend, i_k)=\{(Refuse, i_l)\}$$

This means that the agent Ag_1 refuses the defense relation which is defined by the function Δ and characterized by the index i_k.. The refusal relation is characterized by the index i_l The function β is presented as follows (Figure 9):

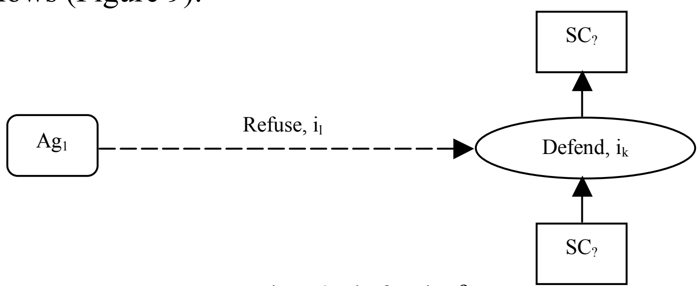

Figure 9: The function β.

The function δ 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 α or the function β. For instance:

$$\delta(Ag_1, Refuse, i_k)=\{(Question, i_l)\}$$

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. Schematically (Figure 10):

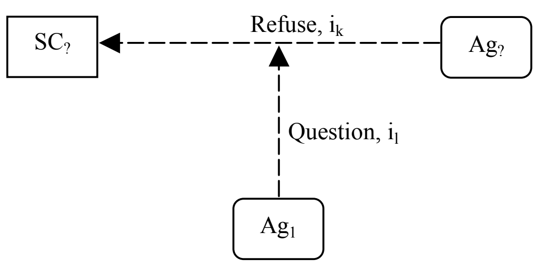

Figure 10: The function δ.

The function θ 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 α. For example:

$$\theta(SC_i, Refuse, i_k)=(Defend, i_l)$$

This example highlights the case in which the contents of the commitment SC_i defends the refusal action characterized by the index i_k. The refusal action is defined by the function α . The index i_l characterizes the defense action. The graphical representation of this function is shown as follows (Figure 11):

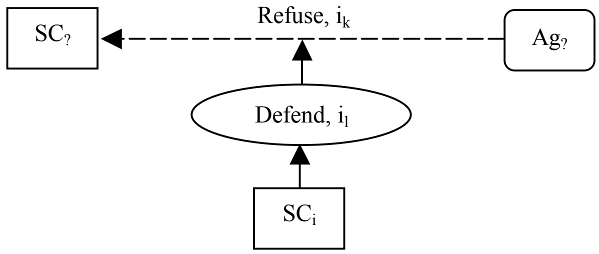

Figure 11: The function θ.

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

$$\gamma(SC_i, SC_j) = (Contradict, i_k).$$

This translates the fact that the contents of the commitment SC_i contradicts the contents of the commitment SC_j. If p is the contents of SC_i, then the contents of SC_j is $\neg p$. This contradiction relation is characterized by the index i_k. Schematically, the function γ is presented in the following way (Figure 12):

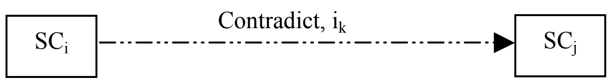

Figure 12: The function γ.

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

$$\eta(SC_i, Defend, i_k) = (Contradict, i_l).$$

This relation points out that the contents 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 Schematically, we present the function η in the following way (Figure 13):

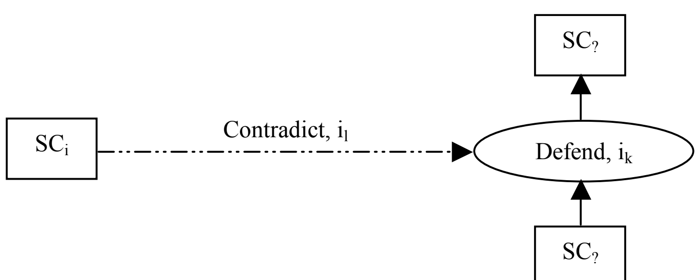

Figure 13: The function η.

5. 2. Example

In this section, we show how to represent a dialogue using the CAN formalism. We use the *conceptual graphs notation*[2] proposed by Sowa (1984) in order to describe the propositional

[2] Conceptual graphs (CGs) 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, CGs serve as an intermediate language for translating computer-

contents of commitments. The advantage of conceptual graphs 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 11 : dialogue D2)

$SA(i_0, Ag_1, \{Ag_2\}, t_{u0}, U_0)$: 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 2, a propositional commitment, i.e.:

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

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

¬[[DISEASE : M]→(CHRC)→[GENETIC]]

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

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

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

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

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

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

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

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

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).

$\wedge Create(Ag_1, t_{u2}, PC_1(id_1, Ag_1, \{Ag_2\}, t_{pc1}, (inform, null, null), (active), (submitted), p_1, t_{p1}))$

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

$$\neg[[\text{DISEASE : M}]\leftarrow(\text{AGNT})\leftarrow[\text{APPEAR}]\rightarrow(\text{PTIM})\rightarrow[\text{BIRTH}]]$$

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

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

This is represented in the CAN formalism by the functions:

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

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 contents is p_2. We have:

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

where $t_{pc2} = t_{p2}$ and the contents p_2 is described by the following conceptual graph[3] :

$$\neg[\neg[[\text{DISEASE : *x}]\leftarrow(\text{AGNT})\leftarrow[\text{APPEAR}]\rightarrow(\text{PTIM})\rightarrow[\text{BIRTH}]] \wedge [[\text{*x}]\rightarrow(\text{CHRC})\rightarrow[\text{GENETIC}]]].$$

This is represented in the CAN formalism by the functions:

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

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

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

In the CAN formalism, this results in the function:

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

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

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

[3] 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.

where t_{pc3} = t_{p3} and the contents p_3 is described by the following conceptual graph :

[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:

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

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

$$\alpha(Ag_2, PC_3)=\{(Create, i_5)\}$$
$$\Delta(SC_3, PC_2)=(Defend, i_5)$$

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

$$SA(i_6, Ag_1, \{Ag_2\}, t_{u6}, U_6) \vdash_{déf}$$
$$Accept(Ag1, t_{u6}, Arg(Ag_2, p_3, Defend(Ag_2, t_{u5}, PC_2(id_2, Ag_2, \{Ag_1\}, t_{pc2},(inform, null, null), (active), (submitted, questioned, justified), p_2, t_{p2})))$$
$$\wedge Accept(Ag_1, t_{u6}, PC_3(id_3, Ag_2, \{Ag_1\}, t_{pc3}, (inform, null, null), (active), (submitted, accepted), p_3, t_{p3}))$$

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

$$\beta(Ag_1, Defend, i_5)=\{(Accept, i_6)\}$$
$$\alpha(Ag_1, PC_3)=\{(Accept, i_6)\}$$

To summarize, the dialogue *D1* can be represented by the following CAN: $<A, E, PC_0, I, \Omega, \Sigma, \Phi, \Delta, \Pi, \alpha, \beta, \delta, \theta, \gamma, \eta>$ such that:

$A=\{Ag_1, Ag_2\}$
$E=\{PC_0, PC_1, PC_2, PC_3\}$
$\Omega=\{Create, Question, Refuse, Accept, \}$
$\Sigma=\{Defend\}$
$\Phi=\emptyset$
$I=\{i_0, \ldots, i_6\}$
$\alpha(Ag_1, PC_0)=\{(Create, i_0)\}$
$\alpha(Ag_2, PC_0)=\{(Question, i_1)\}$
$\alpha(Ag_1, PC_1)=\{(Create, i_2)\}$
$\Delta(SC_1, PC_0)=(Defend, i_2)$
$\beta(Ag_2, Defend, i_2)=\{(Refuse, i_3)\}$
$\alpha(Ag_2, PC_2)=\{(Create, i_3)\}$
$\alpha(Ag_1, PC_2)=\{(Question, i_4)\}$
$\alpha(Ag_2, PC_3)=\{(Create, i_5)\}$
$\Delta(SC_3, PC_2)=(Defend, i_5)$
$\alpha(Ag_1, PC_3)=\{(Accept, i_6)\}$
$\beta(Ag_1, Defend, i_5)=\{(Accept, i_6)\}$

Figure 14 shows the graphical representation of the network.

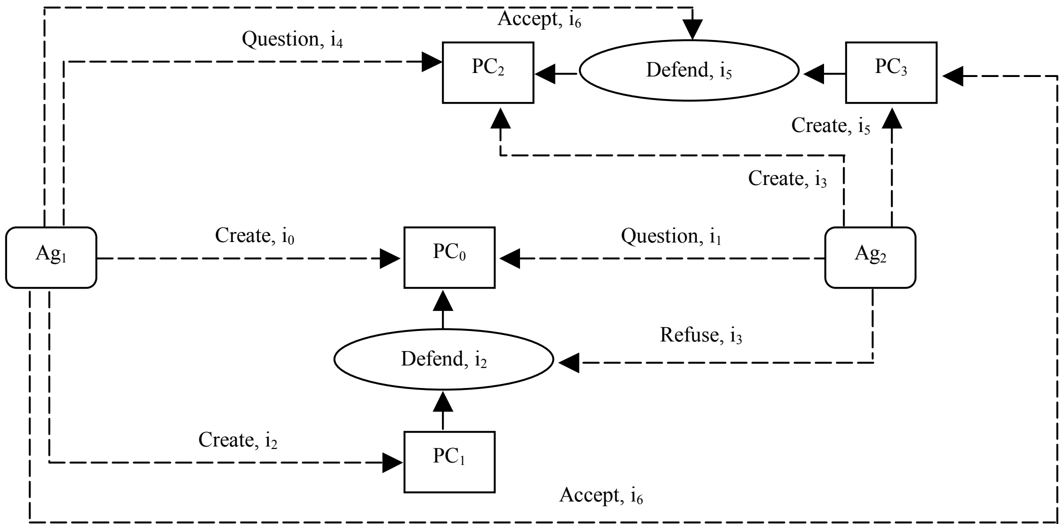

Figure 14: The network associated with the dialogue *D2*.

5. 3. Towards a more complete representation of conversations

From a conversation, we can build an initial version of the network based on the idea that any speech act leads to the creation of a commitment and/or to the positioning on existing commitments. This idea allows us to define argumentation relations as explained in Sections 2, 3 and 4. As illustrated above, this network results from the *direct* and *explicit* interpretation of the contents of the speech acts that were performed during the conversation. We call this network the *initial* network associated with a conversation. From this network, we can infer *implicit* actions that enable us to complete the representation of the conversation. The new version of the network, which we call the *final* or *saturated* version, can be built by a progressive process based on a set of inference rules (see Figure 15). The final version of the network allows us to illustrate not only the sequence of direct actions but also what can be implicitly inferred from the conversation.

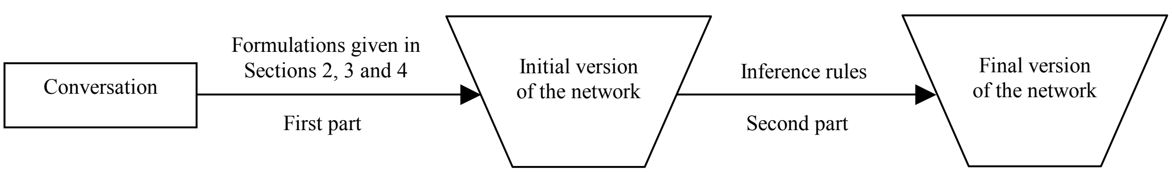

Figure 15 : The building Process of the final network

In the example of Section 5.2, we have only built the initial version of the network associated with the dialogue *D1*.Thus, the first part of the process illustrated by Figure 15 is presented. Now, we show how to build the final version of this example. We propose a preliminary set of rules which we call *saturation rules*. These rules, which we have determined empirically, enable us to illustrate the second part of the building process (Figure 15):

- If an agent *Ag* refuses the contents of a commitment SC_x (respectively an argumentation relation *AR*), then, it creates another commitment SC_y whose contents contradicts SC_x*'s contents* (respectively *AR*). This can be specified formally by two rules:

$\forall x, y, n \in N$

R1: $\alpha(Ag, SC_x)=\{(Refuse, i_n)\} \Rightarrow \alpha(Ag, SC_y)=\{(Create, i_n)\} \wedge \gamma(SC_y, SC_x)=(Contradict, i_n)$.

R2: $\beta(Ag, AR, i_x)=\{(Refuse, i_n)\} \Rightarrow \alpha(Ag, SC_y)=\{(Create, i_n)\} \wedge \eta(SC_y, AR, i_x)=(Contradict, i_n)$.

In our example, agent Ag_2 refuses the argumentation relation *(Defend,* i_2*)*, then it creates the commitment PC_2 whose contents contradicts the relation *(Defend,* i_2*)*. In the CAN formalism this results in the function:

$$\eta(PC_2, Defend, i_2)=(Contradict, i_3)$$

- If the contents of a commitment SC_y contradicts the contents of another commitment SC_z (respectively an argumentation relation *AR*), and if thereafter the contents of another commitment SC_x defends (respectively attacks) SC_y, then the contents of SC_x attacks (respectively defends) the contents of SC_z (respectively the relation *AR*). Formally this results in the following rules:

$\forall x, y, z, n, m, k \in N, m>n>k$

R3: $\gamma(SC_y, SC_z)=(Contradict, i_n) \wedge \Delta(SC_x, SC_y)=(Defend, i_m) \Rightarrow \Delta(SC_x, SC_z)=(Attack, i_m)$

R4: $\gamma(SC_y, SC_z)=(Contradict, i_n) \wedge \Delta(SC_x, SC_y)=(Attack, i_m) \Rightarrow \Delta(SC_x, SC_z)=(Defend, i_m)$

R5: $\eta(SC_y, AR, i_k)=(Contradict, i_n) \wedge \Delta(SC_x, SC_y)=(Defend, i_m) \Rightarrow \Pi(SC_x, AR, i_k)=(Attack, i_m)$

R6: $\eta(SC_y, AR, i_k)=(Contradict, i_n) \wedge \Delta(SC_x, SC_y)=(Attack, i_m) \Rightarrow \Pi(SC_x, AR, i_k)=(Defend, i_m)$

In our example, the contents of the commitment PC_3 defends the contents of the commitment PC_2 which contradicts the relation *(Defend,* i_2*)*. Consequently, PC_3's contents attacks at the same time the argumentation relation *(Defend,* i_2*)*. In the CAN formalism, this is specified by the function:

$$\Pi(PC_3, Defend, i_2)=(Attack, i_5)$$

- When an agent *Ag* creates a commitment SC_x in order to defend or to attack the contents of another commitment SC_y (respectively an argumentation relation AR') using an argumentation relation AR, this agent obviously creates at the same time the relation AR. Formally:

$\forall x, y, n \in N$

R7: $\alpha(Ag, SC_x)=\{(Create, i_n)\} \wedge \Delta(SC_x, SC_y)=(AR, i_n) \Rightarrow \beta(Ag, AR, i_n)=\{(Create, i_n)\}$

R8: $\alpha(Ag, SC_x)=\{(Create, i_n)\} \wedge \Delta(SC_x, AR'. i_y)=(AR, i_n) \Rightarrow \beta(Ag, AR, i_n)=\{(Create, i_n)\}$

In our example, when agent Ag_1 creates the commitment PC_1 in order to defend PC_0's contents, then it also creates the relation *(Defend,* i_2*)*. The two creation actions are characterized by the same index i_2. In the same way, agent Ag_2 creates the two relations *(Defend,* i_5*)* and *(Attack,* i_5*)* following the creation of commitment PC_3. In the CAN formalism, this is described by the following functions:

$$\beta(Ag_1, Defend, i_2)=\{(Create, i_2)\}$$
$$\beta(Ag_2, Defend, i_5)=\{(Create, i_5)\}$$
$$\beta(Ag_2, Attack, i_5)=\{(Create, i_5)\}$$

- If the contents of a commitment SC_x defends the contents of another commitment SC_y (respectively an argumentation relation AR) using a defense relation, and if at some point, an agent Ag accepts SC_x and the defense relation, then Ag accepts SC_y's contents (respectively the relation AR). Formally:

$\forall x, y, n, m, k \in N, m>n, k>n, l=max(m,k)$

R9: $\Delta(SC_x, SC_y)=(Defend, i_n)$
$\wedge \alpha(Ag, SC_x)=\{\ldots, (Accept, i_m)\}$
$\wedge \beta(Ag, Defend, i_n)=\{\ldots, (Accept, i_k\}$
$\Rightarrow \alpha(Ag, SC_x)=\alpha(Ag, SC_x) \cup \{(Accept, i_l)\}$

R10: $\Pi(SC_x, AR, i_y)=(Defend, i_n)$
$\wedge \alpha(Ag, SC_x)=\{\ldots, (Accept, i_m)\}$
$\wedge \beta(Ag, Defend, i_n)=\{\ldots, (Accept, i_k$
$\Rightarrow \beta(Ag, AR, i_y)= \beta(Ag, AR, i_y) \cup \{(Accept, i_l)\}$

Notations:

$\alpha(Ag, SC_x)=\alpha(Ag, SC_x) \cup \{(Accept, i_l)\}$ and $\beta(Ag, AR, i_y)= \beta(Ag, AR, i_y) \cup \{(Accept, i_l)\}$

point out that the acceptance action has just been added to the set defined respectively by the functions $\alpha(Ag, SC_x)$ and $\beta(Ag, AR, i_y)$.

In our example, agent Ag_1 accepts the contents of the commitment PC_3 which defends the contents of the commitment PC_2 and accepts the relation $(Defend, i_5)$. Then, this agent also accepts PC_2's contents. We notice here that the three acceptance actions are characterized by the same index i_6. In the CAN formalism this is described by the function:

$$\alpha(Ag_1, PC_2)=\{(Question, i_4), (Accept, i_6)\}$$

The question action that appears in this function is directly reflected by the speech act identified by i_4 . So, it is related to the first part of the building process (see Section 5.2). Thus, The current state of the PC_2's contents is "accepted":

$PC_2(id_2, Ag_2, \{Ag_1\}, t_{pc2}, (inform, null, null), (active), (submitted, questioned, accepted), p_2, t_{p2})$.

- If an agent Ag accepts the contents of a commitment SC_x that contradicts the contents of its commitment SC_y (respectively its argumentation relation AR), then this agent withdraws its commitment (respectively its argumentation relation). This is expressed by the two following rules:

$\forall x, y, n, m \in N, m>n$

R11: $\gamma(SC_x, SC_y)=(Contradict, i_n)$
$\wedge \alpha(Ag, SC_x)=\{\ldots, (Accept, i_m)\}$
$\Rightarrow \alpha(Ag, SC_y)=\alpha(Ag, SC_y) \cup \{(Withdraw, i_m)\}$

R12: $\eta(SC_x, AR, i_y)=(Contradict, i_n)$
$\wedge \alpha(Ag, SC_x)=\{\ldots, (Accept, i_m)\}$
$\Rightarrow \beta(Ag, AR, iy)=\beta(Ag, AR, i_y) \cup \{(Withdraw, i_m)\}$

In our example, agent Ag_1 accepts the contents of the commitment PC_2 which contradicts the defense relation (Defend, i2). Thus, Ag_1 withdraws this defense relation. In the CAN formalism, this is described by the function:

$$\beta(Ag_1, Defend, i_2)=\{(Create, i_2), (Withdraw, i_6)\}$$

- When an agent withdraws all the defense relations of a commitment SC_x , then it also withdraws this commitment. To be able to specify this rule formally, we define the set $D_{Target,\, SCx}$ as the set of the defense relations in which SC_x is the target. We also define the set D_{Target} as follows:

$$D_{Target}=D_{Target,\, SC0}\cup\ldots\cup D_{Target,\, SCn}.$$

Thus, we define the function β' that will enable us to define the withdrawal action of the elements of $D_{Target,\, SCx}$ as follows:

$$\beta' : A\times D_{Target}\rightarrow\Omega_{Withdraw}\times I. \text{ With } \Omega_{Withdraw} = \{Withdraw\}$$

Figure 16 presents the set $D_{Target,\, SCx}$ schematically:

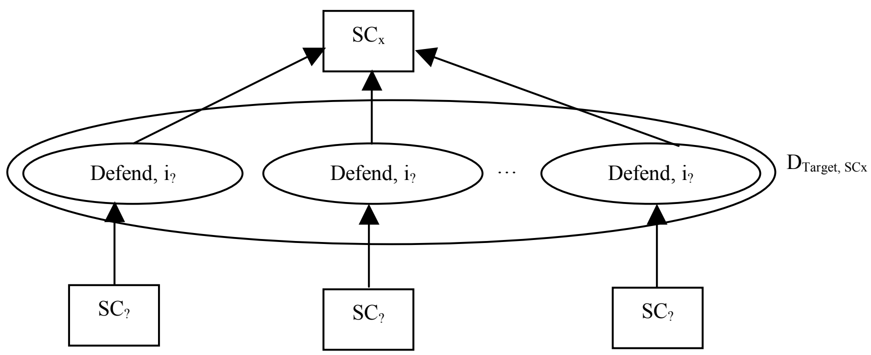

Figure 16: The sets $S_{Defend,\, SCi}$ and $D_{Target,\, SCi}$.

Now, we can specify the rule as follows: if an agent *Ag* withdraws $D_{Target,\, SCx}$, then it withdraws SC_x. Formally:

$\forall x, n\in N,$

R13: $\beta'(Ag, D_{Target,\, SCx})=(Withdraw, i_n)\Rightarrow\alpha(Ag, SC_x)=\alpha(Ag, SC_x)\cup\{Withdraw, i_n\}$

In our example, agent Ag_1 withdraws the relation $(Defend, i_2)$, then it also withdraws the commitment PC_0. The two withdrawal actions are characterized by the same index i_6. In the CAN formalism this is specified by the function:

$$\alpha(Ag_1, PC_0)=\{(Create, i_0), (Withdraw, i_6)\}$$

Thus, the state of PC_0 takes the value "cancelled", and its contents takes the value "refused":

$PC_0(id_0, Ag_1, \{Ag_2\}, t_{pc0}, (Inform, null, null), (active, cancelled), (submitted, refused), p_0, t_{p0})$.

The new network (the saturated network) associated with the dialogue *D1* is the following:

$\langle A, E, PC_0, I, \Omega, \Sigma, \Phi, \Delta, \Pi, \alpha, \beta, \delta, \theta, \gamma, \eta\rangle$ such that:

$A=\{Ag_1, Ag_2\}$

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

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

$\Sigma=\{Defend, Attack\}$

$\Phi=\{Contradict\}$

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

$\alpha(Ag_1, PC_0)=\{(Create, i_0), (Withdraw, i_6)\}$

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

$\alpha(Ag_1, PC_1)=\{(Create, i_2)\}$
$\Delta(PC_1, PC_0)=(Defend, i_2)$
$\beta(Ag_1, Defend, i_2)=\{(Create, i_2), (Withdraw, i_6)\}$
$\beta(Ag_2, Defend, i_2)=\{(Refuse, i_3)\}$
$\alpha(Ag_2, PC_2)=\{(Create, i_3)\}$
$\eta(PC_2, Defend, i_2)=(Contradict, i_3)$
$\alpha(Ag_1, PC_2)=\{(Question, i_4), (Accept, i_6)\}$
$\alpha(Ag_2, PC_3)=\{(Create, i_5)\}$
$\Delta(PC_3, PC_2)=(Defend, i_5)$
$\beta(Ag_2, Defend, i_5)=\{(Create, i_5)\}$
$\Pi(PC_3, Defend, i_2)=(Attack, i_5)$
$\beta(Ag_2, Attack, i_5)=\{(Create, i_5)\}$
$\alpha(Ag_1, PC_3)=\{(Accept, i_6)\}$
$\beta(Ag_1, Attack, i_5)=\{(Accept, i_6)\}$
$\beta(Ag_1, Defend, i_5)=\{(Accept, i_6)\}$

The graphical representation associated with the network is given in Figure 17.

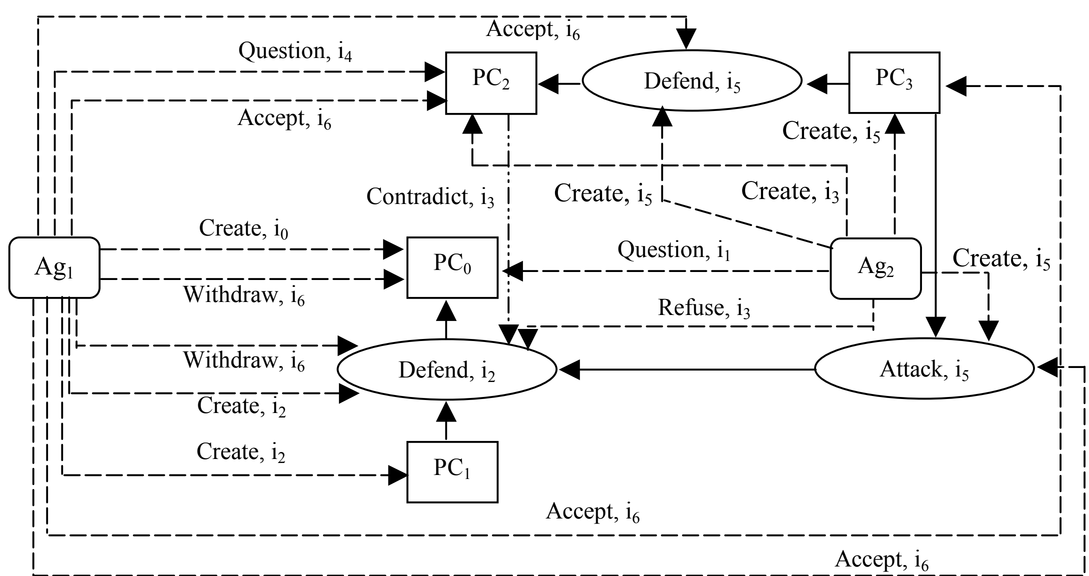

Figure 17: The final network associated with the dialogue *D2*.

5. 4. 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, as well as the information that can be implicitly inferred from what has been stated. In the illustration in 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 all 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 final version of the network is built as the conversation progresses. This process differs from the one illustrated in Figure 15, which is used to analyze a conversation. Therefore, agents use a dynamic process in order to build the network while taking part in the conversation. Following each action (i.e., following each network update), agents must verify if it is possible to complete the network by executing the following algorithm:

```
Considering the current state of the network, find a rule r likely to be applied from
the set of saturation rules
WHILE rule r is found
        DO
                Apply rule r and update the network
                Considering the current state of the network, find a rule r likely to be
                applied from the set of saturation rules
        END
```

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 contents is p_0, i.e.:

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

This corresponds to the speech act identified by i_0.

Then, agent Ag_2 decides to take position on the contents 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 contents of PC_0. Therefore, Ag_2 performs the action corresponding to the speech act identified by i_1:

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

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

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

According to rule R7 of Section 5.3, Ag_1 creates the defense relation at the same time. Therefore, this agent completes the current network by:

$$\beta(Ag_1, Defend, i_2)=\{(Create, i_2)\}$$

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:

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

Thereafter, the two agents seek to infer new information from the current state of the network. By applying rule R2 of Section 5.3, the two agents add the relation:

$$\eta(PC_2, Defend, i_2)=(Contradict, i_3)$$

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

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

The contents 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:

$$\alpha(Ag_2, PC_3)=\{(Create, i_5)\}$$
$$\Delta(SC_3, PC_2)=(Defend, i_5)$$

Ag_2 creates the defense relation at the same time by applying rule R7 of Section 5.3. This agent completes the current network by:

$$\beta(Ag_2, Defend, i_5)=\{(Create, i_5)\}$$

From the current network and according to the above algorithm, the two agents examine the possibility of applying certain rules in order to complete the representation. Thus, they apply rule R5 of Section 5.3 to deduce the action:

$$\Pi(PC_3, Defend, i_2)=(Attack, i_5)$$

Agent Ag_2 must create the relation *(Attack,* i_5*)* according to rule R8 of Section 5.3, i.e.:

$$\beta(Ag_2, Attack, i_5)=\{(Create, i_5)\}$$

Thereafter, agent Ag_1 accepts the contents 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:

$$\beta(Ag_1, Defend, i_5)=\{(Accept, i_6)\}$$
$$\alpha(Ag_1, PC_3)=\{(Accept, i_6)\}$$

The two agents finish the construction of the final version. By following the algorithm presented above, they successively apply rules: R9, R12 and R13 of Section 5.3. Thus, we have:

$$\alpha(Ag_1, PC_2)=\{(Question, i_4), (Accept, i_6)\}$$
$$\beta(Ag_1, Defend, i_2)=\{(Create, i_2), (Withdraw, i_6)\}$$
$$\alpha(Ag_1, PC_0)=\{(Create, i_0), (Withdraw, i_6)\}$$

5. 5. Other examples

In the following examples, we give the final version of the networks without illustrating the steps that led to their construction. Moreover, for simplification reasons, we do not describe the elements of commitments.

The example presented in Section 5.2 illustrated the case in which an agent takes position on a commitment and on an argumentation relation. The following example of dialogue *D2* (*Example 12*) illustrates the case in which an agent takes position on a creation action.

(Example 12 : dialogue D3)

$SA(i_0, Ag_1, \{Ag_2\}, t_{u0}, U_0)$: I will travel to the Himalayas.
$SA(i_1, Ag_2, \{Ag_1\}, t_{u1}, U_1)$: Why do you tell me that?
$SA(i_2, Ag_1, \{Ag_2\}, t_{u2}, U_2)$: It is only to inform you.
$SA(i_3, Ag_2, \{Ag_1\}, t_{u3}, U_3)$: Ok, thank you.

The network associated with this dialogue is: $<A, E, AC_0, I, \Omega, \Sigma, \Phi, \Delta, \Pi, \alpha, \beta, \delta, \theta, \gamma, \eta>$ such that:

$A=\{Ag_1, Ag_2\}$
$E=\{AC_0, PC_1\}$
$\Omega=\{Create, Question, Accept\}$
$\Sigma=\{Defend\}$
$\Phi=\emptyset$
$I=\{i_0, \ldots, i_3\}$
$\alpha(Ag_1, AC_0)=\{(Create, i_0)\}$
$\delta(Ag_2, Create, i_0)=\{(Question, i_1), (Accept, i_3)\}$
$\alpha(Ag_1, PC_1)=\{(Create, i_2)\}$
$\theta(SC_1, Create, i_0)=(Defend, i_2)$
$\alpha(Ag_2, PC_1)=\{(Accept, i_3)\}$
$\beta(Ag_2, Defend, i_2)=\{(Accept, i_3)\}$

The graphical representation of this network is illustrated by Figure 18.

Agent Ag_1 creates an action commitment AC_0 (it is committed to traveling to the Himalayas) by performing the speech act identified by i_0. Thereafter, agent Ag_2 questions the creation action of this commitment by performing the speech act identified by i_1. To defend its creation action of AC_0, Ag_1 creates a propositional commitment PC_1 by performing the speech act identified by i_2. Finally, Ag_2 accepts of PC_1's contents by performing the speech act identified by i_3.

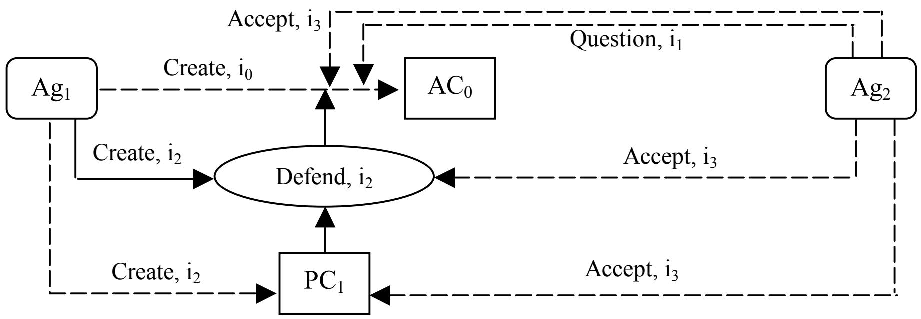

Figure 18: The network associated with the dialogue *D3*.

The CAN formalism also allows us to manage commitment attempts. *Examples 13* and *14* illustrate the acceptance and the refusal of a commitment attempt.

(Example 13 : dialogue D4)

$SA(i_0, Ag_1, \{Ag_2\}, t_{u0}, U_0)$: Can you drive me to the airport at 5PM?
$SA(i_1, Ag_2, \{Ag_1\}, t_{u1}, U_1)$: Yes, I can.
$SA(i_2, Ag_2, \{Ag_1\}, t_{u2}, U_2)$: I will be available at 5PM.

The network associated with this dialogue is: $<A, E, CT_0, I, \Omega, \Sigma, \Phi, \Delta, \Pi, \alpha, \beta, \delta, \theta, \gamma, \eta>$ such that:

$A=\{Ag_1, Ag_2\}$
$E=\{TC_0, AC_1, AC_2\}$
Ω={Create, Question, Accept}
Σ={Defend}
Φ={Fulfill}
$I=\{i_0, i_1, i_2\}$
$\alpha(Ag_1, TC_0)=\{(\text{Create}, i_0)\}$
$\alpha(Ag_2, TC_0)=\{(\text{Accept}, i_1)\}$
$\alpha(Ag_2, AC_1)=\{(\text{Create}, i_1)\}$
$\alpha(Ag_2, SC_2)=\{(\text{Create}, i_2)\}$
$\Delta(SC_2, SC_1)=(\text{Defend}, i_2)$
$\gamma(SC_1, TC_0)= (\text{Fulfill}, i_1)$

The graphical representation of this network is illustrated by Figure 19.

Agent Ag_2 accepts the commitment attempt CT_0 by performing the speech act identified by i_1. Therefore, it creates the action commitment AC_1 (it is committed to driving agent Ag_1 to the airport at 5PM). Thereafter, Ag_2 creates the action commitment AC_2 that supports the AC_1's contents by performing the speech act identified by i_2,

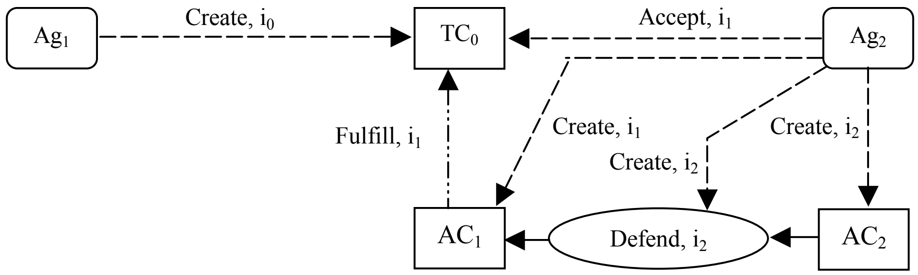

Figure 19: The network associated with the dialogue *D4*.

(Example 14 : dialogue D5)

$SA(i_0, Ag_1, \{Ag_2\}, t_{u0}, U_0)$: Can you drive me to the airport at 5PM?
$SA(i_1, Ag_2, \{Ag_1\}, t_{u1}, U_1)$: No, I cannot.
$SA(i_2, Ag_1, \{Ag_2\}, t_{u2}, U_2)$: Why not?
$SA(i_3, Ag_2, \{Ag_1\}, t_{u3}, U_3)$: Because I have a meeting at 5PM.
$SA(i_4, Ag_1, \{Ag_2\}, t_{u4}, U_4)$: Ok, thank you.

The network associated with this dialogue is: $<A, E, CT_0, I, \Omega, \Sigma, \Phi, \Delta, \Pi, \alpha, \beta, \delta, \theta, \gamma, \eta>$ such that:

$A=\{Ag_1, Ag_2\}$
$E=\{TC_0, PC_1, PC_2\}$
$\Omega=\{Create, Question, Refuse, \}$
$\Sigma=\{Defend\}$
$\Phi=\{Not\ fulfill\}$
$I=\{i_0, \ldots, i_3\}$
$\alpha(Ag_1, CT_0)=\{(Create, i_0)\}$
$\alpha(Ag_2, CT_0)=\{(Refuse, i_1)\}$
$\alpha(Ag_2, PC_1)=\{(Create, i_1)\}$
$\alpha(Ag_1, PC_1)=\{(Question, i_2), (Accept, i_4)\}$
$\alpha(Ag_2, PC_2)=\{(Create, i_3)\}$
$\Delta(SC_2, PC_1)=(Defend, i_3)$
$\gamma(PC_1, CT_0)=(Not\ fulfill, i_1)$

The graphical representation of this network is illustrated by Figure 20.
As a result of refusing the commitment attempt CT_0 by performing the speech act identified by i_1, agent Ag_2 creates the propositional commitment PC_1 (it is committed not to drive the agent Ag_2 to the airport at 5h). By performing the speech act identified by i_2, agent Ag_1 questions PC_1's contents. Therefore, Ag_2 creates the propositional commitment PC_2, by performing the speech act identified by i_3, in order to defend the refusal of CT_0, i.e. to defend PC_1.

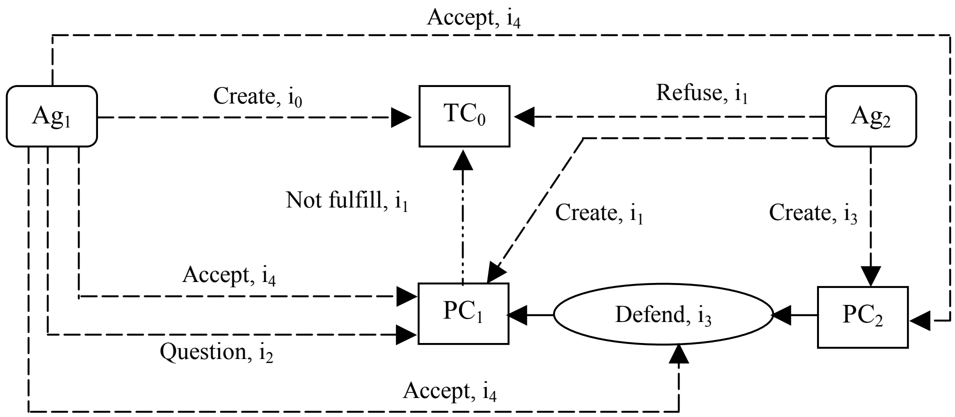

Figure 20: The network associated with the dialogue *D5*.

6. Related works

KQML (knowledge query and manipulation language) was the first standard proposed to specify communications between agents (Finin et al., 1995). More recently, FIPA (1997, 1999, 2000) (foundation for intelligent physical agents) proposed a new standard called FIPA-ACL. KQML and FIPA-ACL are both based on the mental approach (see Section 1). These two languages use protocols like those proposed by Pitt and Mamdani (2000). These protocols define, in a fixed way, which sequences of moves are conventionally expected in a conversation. Protocols are often technically modeled as finite state machines and are usually too rigid to be used to model natural conversations. They do not leave room for agents' autonomy. In this context, the CAN formalism can reflect the action sequences described by a protocol, but in a more flexible way. Contrary to the protocols, the agents using the CAN system do not follow a pre-planned sequence, but they reason in terms of commitments, arguments and relations between these two types of elements. Several researchers proposed dialogue games in order to offer more flexibility (Maudet and Chaib-draa, 2002) (Dastani et al., 200) (McBurney et al., 2002). The CAN formalism can be used to represent these dialogue games and to illustrate how various games can be combined in order to build a coherent conversation.

Singh and Colombetti propose a commitment-based approach that emphasizes the importance of the social aspect of communication (Singh, 1998, 2000) (Colombetti, 2000). Singh's and Colombetti's works were focused on the definition of a semantics for speech acts. When considering the conversational aspect, Singh simply proposed the enhancement of the classical protocols (like those used in KQML and FIPA-ACL) by using commitments in order to ensure the compliance of the agents' behavior with the protocol. A participating agent can maintain a record of the commitments being created and modified. From these, the agent can determine the compliance of the other agents according to the given protocol. However, this approach is still not flexible. Colombetti proposed general conversational principles from which the structure of well-formed conversations should be derived. However, the way to implement these principles is not specified. The management of commitments is only partially addressed in this approach. Our approach illustrates explicitly how agents handle their commitments and how they take positions on others' commitments by using arguments. Consequently, our approach allows agents to take part in coherent conversations.

Amgoud and her colleagues (Amgoud et al., 2000) proposed to model dialogues using an argumentative approach and formal dialectics. Using MacKenzie's dialectical system (MacKenzie, 1979), they define a certain number of dialogue rules and update rules for the different types of locutions supported by their dialogue model. Dialogue rules define the protocol, while update rules capture the effect of the speech acts on the state of the dialogue. To reflect the dialogue dynamics, they use the concept of a *commitment store*. Each agent has its own commitment store accessible by all the other agents. These commitment stores contain only the moves which were performed. Therefore, they reflect only the dialogue history. In our approach, dynamics is reflected not only by the connectedness of the commitments resulting from the performed speech acts, but also by the concepts of the commitment state and the commitment contents state. The CAN formalism more clearly illustrates this dynamics in terms of actions on commitments and arguments. Moreover, contrary to the CAN formalism, the notion of commitment store does not make it possible to distinguish the argumentation phases from the other phases and does not allow us to illustrate the positioning of an agent on an another agent's action as shown by *Example 12* (dialogue *D3*) of Section 5.5.

Reed (1998) introduced the notion of dialogue frame as a model of inter-agent communication. He used this notion to present the dialogue types defined by (Walton and Krabbe, 1995): persuasion, negotiation, investigation, deliberation and information seeking. Formally, a dialogue frame is a 4-uple:

$$F = \langle\langle t, \Delta\rangle \in D,\ \tau \in \Delta,\ \{u^0_{x0\rightarrow y0}, \ldots, u^n_{xn\rightarrow yn}\}$$

where t is the type of the dialogue frame, τ is the topic of the dialogue frame, x_0 and y_0 are the interlocutors and $u^j_{xj\rightarrow yj}$ refers to the jth utterance occurring in a dialogue between agents x_j and y_j such that ($x_j=y_{j+1}$ and $y_j=x_{j+1}$). A dialogue frame is of a particular type ($\langle t, \Delta\rangle \in D$), and focused on a particular topic ($\tau \in \Delta$). For instance, a persuasion dialogue will be focused on a particular belief, a deliberation on a plan, and so on. Reed's approach makes it possible to illustrate the conversation dynamics only in terms of sequences of utterances. As an external representation, the CAN formalism is more complete than the concept of dialogue frame. In the CAN formalism, the dynamics is reflected by the actions that the agents perform on commitments and arguments and by the argumentation relations and the connection relations existing between these commitments and arguments. In addition to being a means to analyze conversations, the CAN formalism provides agents with a means that enables them to participate in coherent conversations and to select their future moves.

7. Conclusion

In this paper, we proposed 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 and the reasoning aspect. We also proposed a formalism in order to represent the dynamics of these conversations. The formalism offers an external representation of the conversational activity. It reflects not only the interpretation of the performed speech acts and their connectedness, but also the information that can be indirectly inferred from the conversation. 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.

As an extension to our work, we intend to demonstrate in a formal way that any dialogue can be represented using the CAN formalism. We also intend to show how the formalism can support the different types of dialogue according to the classification proposed by (Walton and Krabbe, 1995). We finally consider extending and validating the rules that will enable agents to build a saturated network. Using these rules, we can build a detailed algorithm that will allow agents to properly and dynamically build the networks corresponding to their conversations.

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