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DIAGAL: An agent communication language based on dialogue games and sustained by social commitments

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Abstract In recent years, social commitment based approaches have been proposed to solve problems issuing from previous mentalistic based semantics for agent communication languages. This paper follows the same line of thought since it presents the latest version of our dialogue game based agent communication language – DIAlogue-Game based Agent Language (DIAGAL) – which allows agents to manipulate the public layer of social commitments through dialogue, by creating, canceling and updating their social commitments. To make apparent such commitments, we consider here Agent Communication Language (ACL) from the dialectic point of view, where agents "play a game" based on commitments. Such games based on commitments are incorporated in the DIAGAL language, which has been developed having in mind the following questions: (a) What kind of structure does the game have? How are rules specified within the game? (b) What kind of games compositions are allowed? (c) How do participants in conversations reach agreement on the current game? How are games opened or closed? Using such games we show how we can study the commitments dynamic to model agent dialogue and we present metrics that can be used to evaluate the quality of a dialogue between agents. Next, we use an example (summer festival organization) to show how DIAGAL can be used in analyzing and modeling automated conversations in offices. Finally, we present the results and analysis of the summer festival simulations that we realized through our dialogue game simulator (DGS).

Keywords Dialogue games · Agent communication language · Commitments

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1. Introduction

Dialogue games reflect interactions between different participants in dialogues or conversations. In such interactions, each participant intervenes by making utterances according to a pre-defined set of rules. Typically, the rules define how the dialogue may or must start, what statements may or must be uttered in a given context and, how the dialogue may or must terminate. Such games have found many applications in the past. In particular, they have been used for argumentation and more generally, for logical thinking. In modern philosophy, they have been used for argumentation theory related to the contextual analysis of fallacious reasoning.

Dialogue games have also been applied in computational linguistics, computer science and cognitive science. In computational linguistics, they have been introduced to explain sequences of human utterances in conversations. In this context, the pioneering work of Levin and Moore [37] introduced the notion of a dialogue game as a way of initiating an interaction of a specified type, and of controlling it with a partially ordered set of subgoals. This influential work has found subsequent applications in machine-based natural language processing and generation [32,42] and in human-computer interactions [5,50]. Recently, dialogue games have been proposed as the basis for "conversation policies" for autonomous software agent communication [11]. To this end, work has focused on persuasion dialogues [1]; negotiation dialogues [2,59]; agent-team formation dialogues [19]; commitment dialogues [44]; dialogues for rational interactions [48], commitment protocols [40], agent communication and institutional reality [27], etc. However, none has considered an approach entirely based on commitments to specify, design and analyze agents conversations. This paper attempts to fill this gap by proposing (i) a new dialogue game adopting a strict commitment approach within game structure; (ii) a method that studies the commitments dynamic for modeling agents conversations and; (iii) metrics based on commitments to analyze agents conversations.

The remainder of this article is organized as follows. The next section introduces readers to agent communication languages (ACLs) and conversations policies sustained by social commitments. Section 3 gives an overview of formal dialectic sustaining the social commitments on which our approach is based. Section 4 describes in detail our DIAlogue-Game based Agent Language (DIAGAL) language centered around commitment-based games. Section 5 presents the web of commitments concept that allows specifying the agents' dialogical behavior of a multiagent system (MAS). Section 6, follows with a detailed description of a test case devoted to office systems automation that we analyze using a web of commitments. Section 7 presents experiments and results in the case of communication between agents in the summer festival example. Final, Section 8 discusses how our approach addresses (i) flexibility and (ii) specification-analysis.

2. Agent communication language: motivations for a social commitment approach

2.1. From communicating agents using "isolated" speech acts

The two main agent communication languages (ACLs)—both with theoretical and practical use—are KQML [23] and FIPA-ACL [24]. Both borrow from traditional speech act theory [3,61] which views messages of agents as actions with consequences for the environment.

KQML was the first to be developed, in the context of DARPA research. A KQML message is conceptually divided into three levels [36]: (1) *communication level* which specifies the sender and receiver agents; (2) *message level* which mainly specifies the type of message (or performative): affirmation, question, ..., but also the knowledge representation language[1] and the used ontology and finally; (3) the *content level*, which specifies the message content.

KQML was first proposed without any precise semantics, and this gave rise to several criticisms, see e.g. [14]. This led researchers to make another effort to come to a standard ACL through the Foundation for Intelligent Physical Agents (FIPA) initiative. This foundation is a nonprofit association whose objective consists of promoting the success of emerging agent-based technology. FIPA has proposed a new ACL, called FIPA-ACL, which has a precise semantics based on a formal language called SL. This formal language is a quantified, multimodal logic with modal operators for beliefs, desires, uncertain beliefs and persistent goals. In this case, the semantics in each "communicative act" (CA) is specified as a set of SL formulae that describes the act's feasibility conditions and its rational effects. The feasibility conditions describe the necessary conditions for the sender of the CA, whereas the rational effects describe the effects that an agent can expect to occur as result of the CA.

In the same vein, a semantics for KQML messages has been proposed in terms of pre, post, and completion conditions [35]. Since this semantics, as well as the FIPA-ACL one, refer to the mental states of the agents, they are commonly called *mentalistic* [62].

The strictly mentalistic approach considers conversational structures as simple epiphenomena. The idea is merely that, given an ACL with a defined semantics, the structures of conversation will emerge from the succession of communicative acts, and especially from the consequences of these acts on the participants' mental states. Take for instance the well-known question/answer adjacency pair structure[2]: when $Agent_1$ asks $Agent_2$ a question about p, $Agent_2$ will recognize from $Agent_1$ the intention to know whether p is true. Given this, and assuming some cooperative behavior, $Agent_2$ will form the intention to know p himself, and in turn to inform his partner about this point. Thus, the occurrence of this adjacency pair seems to be correctly explained. If this approach is really attractive because of the great flexibility induced by the independence of a particular structural model, it soon appears to be problematic in the context of communicating software agents, both for practical and theoretical reasons.

From a practical point of view, the semantics of speech acts is *so* rich that it is very complex to determine the possible answers by just inferring others' mental states, simply because there are too many semantically coherent dialogue continuations. It appears, therefore, that the necessity to restrict the space of possible answers to a given act in a context of communication is generally a hard problem. This can lead agents to an extensive deductive machinery where they must interpret context, relevance, etc. in order to choose the "right" continuation.

From a theoretical point of view, mentalistic approaches assume two main controversial hypotheses: (i) agents' mental states are "verifiable" and (ii) agents are sincere. Both hypotheses are problematic, especially in an open environment. For the first point, we cannot be sure of the mental state of any other agent and how to access it (since agents are generally heterogenous [62] in open environments). Whether an agent indeed conforms to such semantics (believes or not what he says, for instance) is not verifiable—in the sense that it cannot be determined by an independent observer [69].

For the second point, it is obvious that the hypothesis of sincerity (agents believe what they say, intend what they promise, etc.) cannot hold in several dialogue contexts which are not fully cooperative—like negotiation or persuasion for instance.

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1 Several candidates for such logical languages exist, for instance PROLOG, or KIF (Knowledge Interchange Format), which is proposed as a standard.

2 An adjacency pair is a unit of conversation that contains an exchange of one turn each by two speakers. The turns are functionally related to each other in such a fashion that the first turn requires a certain type or range of types of the second turn.

2.2. . . .TO conversation policies

In light of the above limitations on ACL using "isolated" speech acts, researchers have tried to address the gap between these individual messages and the extended message sequences, or *conversations*, that arise between agents. As part of its program code, every agent must implement tractable decision making procedures that allow it to select and produce ACL messages that are appropriate to its intentions. This is not purely a problem of matching ACL semantics to agent intention; except in the most limited agent systems, these decision procedures must also take into consideration the context of prior ACL messages and other agent events. Paradoxically, taking this context into account can actually *simplify* the computational complexity of ACL message selection for an agent. By engaging in preplanned or stereotypical conversations, much of the search space of possible agent responses can be eliminated, while still being consistent with the ACL semantics. The specification of these conversations has until now been accomplished via *c*onversation policies (CPs).

Conversation policies (CPs) are *"general constraints on the sequences of semantically coherent messages leading to a goal"* [29]. Coherence of the dialogue is thus ensured by these constraints. This greatly facilitates the task of computing the possible answers to a given message.

Usually, one model CPs as finite state machines (FSMs). Carefully designed and highly complex CPs have been proposed using FSMs in the literature, and implemented in real applications, see for instance COOL [4]. Winograd and Flores's example (see Fig. 1) "*A* requests *B* for action" illustrates this [68].

Let us briefly describe the dialogue behavior expected with this latter protocol. Conversation begins in the initial state (1), by the request from agent *A*. In state (2), the dialogue can successfully be followed by the promise from *B* to realize the requested action, or come into a "negotiation cycle" with a counter-proposal from *B*, or fail with a reject leading to state (8). At state (3), the addressee will signal that the task has been achieved, or eventually decide to renege (leading to the final state (7)) and *A* will in turn positively (state(5)) or negatively evaluate this (state (3)). Note that the protocol says nothing about the content of the communicative acts.

Notice that other formalisms can be used to model conversation policies: notably Petri nets, possibly colored [38,46], particularly well-suited to parallelized conversations (with more than two participants in conversation); and Dooley graphs [54], which may offer a compact and precise representation of the conversation.

Let us reconsider as an illustration the previous request for action protocol proposed by Winograd and Flores. Remarks about this protocol are manifold. To start with, as explained

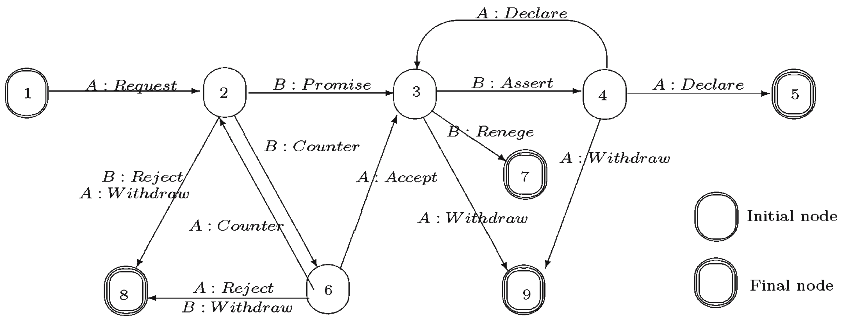

Fig. 1 The request for action protocol

above, the coherence of the conversation is ensured by the constraints imposed by the protocol on all participants—messages not expected in the protocol will simply not be considered. One should note that a large protocol[3] is less flexible for agents and it can cause problems from the computation aspect point of view, particularly in environments with hard time constraints. When considered carefully, the protocol presented in Fig. 1 seems to be composed of different "phases" (or small protocols), not identified as such: firstly, the agents will try to negotiate a task for B to do. Next A and B will discuss the correct achievement of this task. These phases or small protocols are not specific to the particular case of the request for action. In addition, we have no information on how agents have agreed to use such a protocol.

Another limitation of most CPs is that they do not refer to social agency and continue to see a CP as just the sum of mental states of its participants without referring to a social agency more conform to dialogues [62,65,66].

Finally, the use of conversation policies to guide agent communicative behavior engenders a host of practical questions. How should conversation policies be implemented in agent systems? Should CPs be downloaded from a common library, pre-built into the agent's program, or derived from conversational axioms at runtime? How can conversation policies be negotiated, and unfamiliar policies learned? And finally, how can conversation policies be integrated with the other policies, plans, and rules which define an agent's behavior?

2.3. CPs as dialogue games sustained by social commitments

In light of the above considerations and also of the criticisms of [29,30,62,65], we have identified two main issues that the forthcoming generations of CPs must address: flexibility and specification-analysis.

Flexibility. The aim of conversation policies is basically to constrain the conversational behavior of the participants, but there is a delicate equilibrium to be found between this normative aspect and the flexibility expected in most multi-agent communications. Different points may participate in reaching this objective:

1. Adopt a formalism which allows more flexibility than FSMs, being more dependant on the state of the conversation than on the previous messages [63].
2. Consider unexpected (or exceptional) messages within the CPs [62]. The objective is here to give appropriate follow-ups to such messages.
3. Prefer various small CPs, ideally those that we can compose, instead of a single large one [29,63]. The fact that we find recurrent similar structures of dialogue in various CPs is clearly a strong argument for this point. These possibilities of composition should be clearly defined.
4. Study how agents come to an agreement on the CP currently used —this point is crucial if the preceding objective is achieved [65].

Specification-analysis. The specification-analysis of the CPs is the second important challenge that we identify here. Indeed, specification of the CPs often requires ad-hoc formalism and are only semi-formally stated. This does not allow really taking all the profit from the specification, or formally verifying some expected properties of the model. In general, the objectives are the following:

[3] By *large*, we mean a large number of states.

1. Specify CPs at a high level of abstraction. Such specifications should be relatively independent of the specificities of the agents involved in communication, particularly the private mental states of these agents [26,29,55,62,63].
2. Adopt a declarative approach in order to explicitly declare the rules composing the CP [63]. Clarity and expressibility follow from this point.
3. Provide formal properties of the CPs proposed so that we can analyze them from different angles, in particular: (i) Coherency of discourse; (ii) Completeness of discourse; (iii) Coordination within the discourse and (iv) termination of each CP.
4. Try to optimize the CPs. A precise specification might indeed identify shortcuts that the dialogue participants in the CP might take without modifying the meaning of the interaction [63].

We can rely on *social agency* rather than on mental state of agents, to achieve the required high level of abstraction for the specification-analysis as explained early. This promising approach considers communicative acts as part of ongoing social interaction. In this case, even if we cannot determine whether agents have specific mental states, we are sure that communicating agents follow some social laws that sustain conversations. In this specific context of social agency, agent designers have usually assumed that the networks of obligations and power relationships that characterize human social behavior are not relevant to multi-agent systems. In practice however, idiosyncratic social conventions have ended up being embedded in agent architectures and interaction protocols, with the result that different agent systems exhibit significant incompatibilities in this area. More research is needed into characterizing these fundamental communicative concepts in a multi-agent systems context. This includes concepts such as “commitment,” “obligation,” “convention,” “power” (in the sense of hierarchical relations), and so forth. Once these concepts are clarified, it then becomes possible to build a unified ACL semantics and pragmatics that takes these concepts into account.

Recently, researchers have begun to address the issues raised by social agency. Some are working on social issues such as “institutional reality” [60]; an important step has been recently taken in this direction by Colombetti and his team [15,27]. Other researchers have taken the road of formal dialecticians inspired by Hamblin [31] and Walton & Krabbe [66]. This research now forms a real field of dialectical models of interaction, as suggested by some authors [28,58]. We now briefly present in the next section the basics of formal dialectic.

3. Social commitments and dialectic systems

Dialectics is the field of research concerned with the study of the interactive process of argumentation, i.e. the study of the dialectical contexts within which arguments are put forward [31]. In particular, dialectic studies the different kinds of fallacies involved in argumentation—and formal dialectics has introduced formal notions and tools to deal with it. Among these various notions introduced or discussed by formal dialecticians, two have proved to be of first importance for those concerned with communication in multi-agent systems: *social commitments* and *dialectical systems*.

3.1. Social commitments

First of all, social commitment should not be confused with psychological commitment, which commonly captures some persistence of intentions—notably in the theory of rational interaction described in [7,13]. Crucially, social commitments are commitments that *bind* a speaker to a community. This motivates of course, a distinction between the creditor and the debtor of the commitment. Notice that this notion is also clearly different from that of belief or intention and, more generally, social commitments are distinct from the *private* states of the agents.

Amongst social commitments, a classical distinction is also established between propositional or action commitments. Thus, in the following examples (where A stands for the speaker),

A: Ottawa is the capital of Canada. (1)

A: I will visit Ottawa next summer. (2)

We would say that example (1) leads to a propositional commitment which bids the agent A towards the audience (let us say B), while example (2) leads to an action commitment which bids A towards B. Before concluding that A believes what he says, we can express that A is committed to the audience, and there are consequences related to such a commitment. In particular, the audience will certainly penalize A if he makes an ulterior statement contradictory to p (which means *Capital*(*Ottawa,Canada*)). In this case for example, the audience might consider A as a non-credible agent.

In fact, by simply uttering the previous example (1), A is committed in a way that constrains its subsequent actions [66]. Precisely, depending upon context, A may then become committed to a number of things, for example holding that p, defending that p (if challenged), not denying that p, giving evidence that p, arguing that p, proving or establishing that p and so on. Ultimately, A becomes committed to some (sets of) partial strategies. But the reason that we speak of *propositional* commitment here is that all A's commitments (as defined by the strategies he is committed to) center on the proposition p. We shall say in this case that *A is committed to p*, meaning that A is committed to a set of *partial strategies* centering on p [66].

3.2. Dialectical systems

We can trace the notion of dialogue game to the philosophical tradition of Aristotle—a tradition pursued by several philosophers in the Middle Ages, and, more recently, by the work of Lorenzen and Lorenz [39] or the Pragma-Dialectic school of van Eemeren [64]. In formal dialectic, as explained before, the objective is to study fallacious reasoning or argumentation. The work of Hamblin [31] has proposed a popular notion of *dialectical systems* as normative models of persuasive dialogue which mainly consists of (i) a set a moves —e.g. challenge, assertion, question; (ii) one commitment store (CS) for each conversant; (iii) a set of dialogue rules regulating the moves; (iv) a set of commitment rules defining the effect of the moves on the commitment store. The dialogue proceeds correctly when the participants in conversation conform to the dialogue rules, and eventually ends when the proponent has withdrawn his thesis, or (symmetrically) that the opponent has conceded the proponent's claim. These termination conditions might be different for other dialogue types, as proposed by Walton & Krabbe [66] and discussed further below.

3.2.1. Dialogue types

The hypothesis clearly stated in Walton & Krabbe [66] is that dialectical systems can model various types of dialogue. The authors identify six types of dialogue (not exhaustively). This classification is based upon three factors: the information available to the participants, the

Table 1 The six primary types of dialogue

Type of dialogue	Goal of the dialogue	Initial situation
Persuasion	resolution of conflict	conflicting point of view
Negotiation	making a deal	conflict of interest
Deliberation	reaching a decision	need for action
Information-seeking	spreading knowledge	personal ignorance
Inquiry	growth of knowledge	general ignorance
Eristic	accommodation in relationship	antagonism

goal of the dialogue itself, and the individual goals of the participants. Table 1 summarizes these types, and shows the goals (of the dialogue and the participants).

These six types may be refined in subtypes, simply by specifying more elaborate conditions for the dialogues (e.g. the type of conflict, the degree of rigidity of the rules). Thus, for example, a dispute is a subtype of persuasion, where each participant tries to defend its own point of view. Very importantly, Walton and Krabbe argue that *"types of dialogue coincide with particular dialectical systems or dialogue games"* [66], p. 67. In all their types of dialogue, both parties *ideally* have a recorded log of their individual commitments to any given point to which the dialogue has progressed: the commitment store (CS) as previously described.

3.2.2. Dialectical shifts

It is important to note that dialogues are usually not of a single type from beginning to end. For instance, it is common to start an inquiry dialogue, to realize during the dialogue that there is a controversial issue at stake, to enter into a dispute sub-dialogue, and to eventually resume the inquiry dialogue when the issue has been resolved. This means that most dialogue types are complex (i.e. composed of different types). The notion of dialectical shift has been introduced for that aspect [66]. A dialectical shift is a change in the context of dialogue during a conversation from one type of dialogue to another. The shift can be constructive and agreed to by all parties, and it is a licit shift. In this case, the second dialogue may even be functionally related to the goal of the original dialogue: it is an "embedded dialogue". For instance, considering the made-up example (3) below, we could see it as a negotiation sub-dialogue embedded in a request for action dialogue.

S :	Are you finishing the paper in time to submit it to the AAMAS conf.?	begin Request for Action	
H :	No, but we'll extend it.	begin Negotiation	
S :	Can you extend it to the JAAMAS journal ?		
H :	No, may be for another journal, more specific to language.		(3)
S :	OK.	end Negotiation	
H :	We'll send an email when it's finished	return to Request for Action	
S :	Thank you	end Request for Action	

On other occasions, the shift might be canceled or inappropriate because it is an illicit type of shift. Illicit shifts in our context of dialogue based on argumentation are frequently associated with fallacies (a fallacy can be viewed as an argument which *appears to be correct but is not*). In some dialogues, we might have a cascading effect. In this case, there is a sequence of shifts from one type of dialogue to another, and then to yet another, and so forth.

Thus, one can begin with a negotiation, and then shift to a critical discussion and then shift to a negotiation that might shift to a quarrel, etc.

3.3. Discussion

Formal dialectic has developed several carefully designed systems, especially for persuasion and critical discussion. Now, the wide use of the term dialogue games calls for some clarification; the objective of these models clearly varies according to the different disciplines in which they are used. The most significant for our purpose are the models developed in formal dialectic and sustaining the argument-based models of non-monotonic reasoning where agents are supposed to have some minimum argumentative capability (e.g. in general propositions supporting a belief) [8,52,56,57]. This leads to richer interactions between players than just exchanges of unsupported locutions, especially in cases of persuasion or negotiation [51]. For instance, it is possible for an agent to explain why he cannot accept a request from the other agent.

For us, dialogues games are structures reflecting interactions between two or more players, where each player "moves" by making utterances, according to a defined set of rules. More precisely, we view dialogues games as structures regulating the mechanism under which some social commitments are discussed through the dialogue. The next section gives more details on that.

4. DIAGAL: A commitment-based language for software agents

Commitment-based conversations policies aim at defining the semantics of the communicative acts in terms of public notions, as social commitments. A social commitment is a social bind established by an agent called the debtor towards one or several other agents called creditors. It can be viewed a kind of deontic concept as a generalization of obligations as studied in deontic logic. A commitment defines constraints on agents' behavior since they must behave in accordance to it. For instance, by committing towards other agents that a proposition is true, an agent is compelled not to contradict itself during the conversation. It must also be able to explain, argue, justify if the situation requires it.

In this paper we propose a tool, called DIAGAL (*DIAlogue-Game based Agent Language*) which helps to analyze and model conversations between agents. We have developed this tool having in mind the following questions: (i) What kind of structure does the game have? How are rules specified within the game? (ii) What kind of games' compositions are allowed? (iii) How are games grounded (i.e., how do participants in conversation reach agreement on the current game)? How are games opened or closed?

4.1. Commitments

As our approach is based on commitments, we start with details about the notion of commitment. The notion of commitment is a social one, and should not be confused with its other side based on the psychological notion. Crucially, commitments are contracted towards a partner or a group. They are expressed as predicates with an arity of 7. Thus, an action commitment takes the form:

$C(x, y, \alpha, t, s_x, s_y, \texttt{Sta})$

meaning that agent x (the debtor) is committed towards y (the creditor) to do α at time t (creation time), under the sanctions s_x and s_y. These sanctions are considered here as simple scalars similar to scalar reinforcement signals [33] and are directed to society as whole since commitments are themselves social facts. The first sanction s_x specifies what happens if x cancels or violates the commitment, and the second s_y specifies what happens if y tries to withdraw the commitment *once it accepted it*. In fact, in our approach a commitment is created when it is established socially via a contextualisation game (as explained below in Section 4.7). Once the commitment socially established, the sanctions can start to play their role which consists of discouraging disruption. Evidently, in some cases where the situation does not justify it s_y might be equal to zero.

Since a commitment can be in different states, we add the `Sta` parameter to specify the commitment state (the different states of a commitment are explained below). In these conditions, the following commitment

$$c_1 = C(Al, Bob, sing(Al, midnight), now, 10, 20, \texttt{Crt})$$

states that agent *Al* is committed towards agent *Bob* to *sing* at *midnight*. If *Al* eventually decides to cancel his commitment he will pay the penalty 10. If *Bob* decides to withdraw from this commitment, he will pay 20. We concede that this account of penalties is extremely simple in this version. A more complete account could be similar to the one of Excelente-Toledo, Bourne & Jennings [22]. Notice that c_1 is in the commitment state "created" (`Crt`) (see below the details on commitment sates).

This commitment notation is inspired from [63], and allows us to compose the actions or propositions involved in the commitments: $\alpha_1|\alpha_2$ classically stands for the choice, and $\alpha_1 \Rightarrow \alpha_2$ for the conditional statement that the action α_2 will occur in the case of the realization of the action α_1. As examples, let us consider the following:

$$c_2 = C(Al, Bob, sing(Al, midnight)|dance(Al, midnight), t, 10, 20, \texttt{Ina})$$

and

$$c_3 = C(Al, Bob, music(Bob, midnight) \Rightarrow create(c_2), now, 10, 20, \texttt{Crt})$$

The commitment c_2 (which is in the state "inactive") captures the fact that agent *Al* is committed towards *Bob* to *sing* or *dance* at midnight. Similarly, the commitment c_3 (which is in the state "created") captures the following fact: agent *Al* is committed to contract the preceding commitment (c_2) if agent *Bob* plays *music*. The commitment c_3 is a conditional commitment and we will see in Section 4.3 how this kind of commitments allow us to specify the dialogue games rules. All commitments hold from the moment where they were contracted (*now*). From now on, for the sake of readability, we will ignore the *create* operation.

As we said earlier, a commitment can be in different states. In fact, commitments that can exist between the various agents of a MAS evolve: their states change. A commitment can be in one of the following states:

– *Inactive* (`Ina`): By default, a commitment is inactive.
– *Created* (`Crt`): A commitment is in this state if it has been "socially established" in a dialogue game.
– *Canceled* (`Cnl`): A commitment is in this state if it has been withdrawn by the debtor.
– *Released* (`Rel`): A commitment is in this state if it has been withdrawn by the creditor.
– *Fulfilled* (`Ful`): A commitment is in this state if the debtor has satisfied its content.
– *Violated* (`Vio`): A commitment is in this state if the debtor hasn't respected its content.
– *Failed* (`Fal`): A commitment is in this state if an attempt to socially established it has failed.

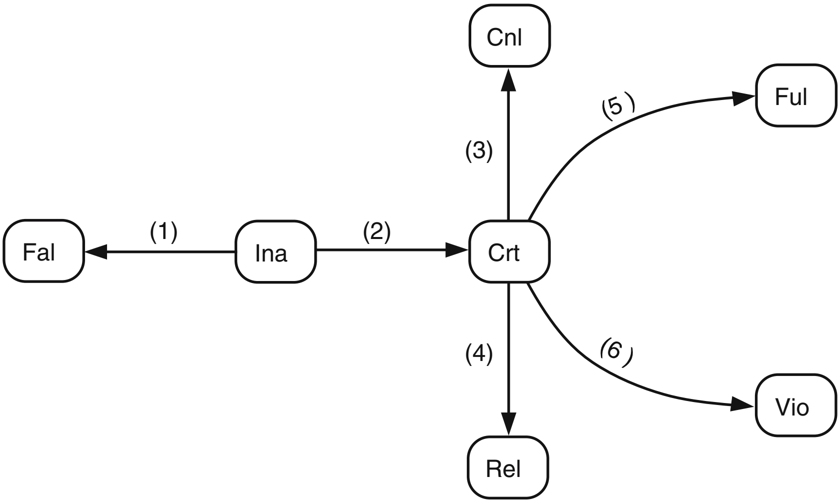

Fig. 2 Commitment state diagram

Table 2 DIAGAL contextualisation game

Move	Operations
$prop.in(x, y, g)$	$create(y, C_g(y, x, acc.in(y, x, g)\|ref.in(y, x, g)\|prop.in(y, x, g')))$
$prop.out(x, y, g)$	$create(y, C_g(y, x, acc.out(y, x, g)\|ref.out(y, x, g)))$
$acc.in(x, y, g)$	create dialogical commitments for game g
$acc.out(x, y, g)$	suppress dialogical commitments for game g
$ref.in(x, y, g)$	no effect on the public layer
$ref.out(x, y, g)$	no effect on the public layer

The various transitions from the possible commitment states are presented in Fig. 2. May be the only state which is difficult to understand is the sate *Failed* (`Fal`). As we said previously a game is created if it is socially established via a contextualization game which regulates the meta-level communication and explained in Section 4.7. In the case where an attempt to achieve such "social establishment" fails, we say that the commitment has failed. For instance, for creating the commitment $C(x, y, \alpha)$, agent x suggests to y to play the dialogue game *Offer* (see Table 2 for details). If y refuses to play this game, then we say that $C(x, y, \alpha)$ is in the state *Failed* (`Fal`).

Obviously, we need to describe the mechanism by which the commitments states are modified during the dialogue. This mechanism is precisely captured within our game structure. In fact, dialogue games allows executing the transitions numbered from 1 to 4 in Fig. 2. Finally, it's important to mention that the agents keep track of each commitment in which they are debtor or creditor in their agendas, which constitutes a kind of distributed "commitment store".

4.2. Dialogue games: Definition and semantics

The main particularity of social commitments is that they must be socially established in order to hold. This means that every change on the social commitment layer should be grounded by the conversing agents. We share with others [16,26,48] the view of dialogue games as structures regulating the mechanism under which some commitments are discussed through the dialogue. Unlike others [16,48] however, we adopt a strict commitment-based approach within game structure and express the dialogue rules in terms of *dialogical commitments* [44]. In our approach, games are considered as bilateral structures defined by:

- *entry conditions* (E_g): expressed in terms of extra-dialogical commitments, entry conditions are conditions which must be respected to enter the game;
- *success conditions* (S_g): success conditions indicate the result (the effect in terms of extra dialogical commitments) of the dialogue game if the modification of the public layer, which was the purpose of the game, has been socially accepted;
- *failure conditions* (F_g): failure conditions indicate the result of the dialogue game if the modification of the public layer has been socially rejected;
- *dialogue rules* (R_g): expressed in terms of dialogical commitments, dialogue rules specify what the conversing agents are "dialogically" committed to do. The fulfillment of those rules will lead to reaching either the success or the failure conditions of the game.

In these conditions, a game is formally defined as follows:

Definition 1 A dialogue game g is defined as a 4-tuple (E_g, S_g, F_g, R_g), where E_g is the set of commitments that specify the entry conditions, S_g the set of commitments that specify the success conditions, F_g the set of commitments that specify the failure conditions and R_g the set of commitments that specify the rules of the dialogue game.

This definition leads us to adopt an axiomatic semantics as a formal model of our dialogue game since an axiomatic semantics generally defines a set of axioms which one should obey, such as preconditions and postconditions. Furthermore, one should distinguish between public and private axiomatic approaches as proposed by [49]. In public axiomatic approaches, the pre-conditions and post-conditions all describe states or conditions of the dialogue which can be observed by all participants. In private axiomatic approaches, at least some of the pre-conditions describe states or conditions which are internal to one or more of the participants, and thus are not directly observable by all participants. In the case of our dialogue games, the axiomatic semantics is *public* and the preconditions are expressed through the *entry conditions* of the game and the postconditions are determined by the *success* and *failure conditions* and all those conditions are expressed in terms of commitments.

We have recently extended this semantics by a denotational semantics where the meaning of messages is based on their use as coordinating devices advancing conversations that advance the state of social commitments and the state of activities in which agents participate [25]. We precisely proposed a model where the meaning of messages is incrementally defined, based on the following levels: a *compositional level*, where the meaning of message is given by the relationship of instances in a message (e.g., agents and the roles they play in a commitment); a *conversational level*, where the meaning of messages is given based on their occurrence as part of a conversation in which agents concur to advance the state of commitments; a *commitment state level* where the meaning of messages is given according to the state of the commitments these messages manipulate; and a *joint activity level*, where the meaning of messages is given according to their use in joint activities.

4.3. Basic dialogue games

Recall that any action commitment can be expressed by a propositional commitment since "is committed to do α" means also "is committed to bring about making α done" and consequently we can express all our commitments in propositional commitments. However both kinds of commitments do not refer to the same dialogue games and that is why we consider both in our context. These two sorts of commitments lead to four directions of fit when we consider two agents x and y:

1. for an attempt to have an action commitment from y toward x accepted, agent x can use a *Request* game (rg);
2. for an attempt to have an action commitment from x toward y accepted, agent x can use an *Offer* game (og);
3. for an attempt to have a propositional commitment from y toward x accepted, agent x can use an *Ask* game (ag).
4. for an attempt to have a propositional commitment from x toward y accepted, agent x can use an *Inform* game (ig);

These four basic dialogue games create the associated social commitments and are exactly those which lead (in case of success) to the four types of commitments which can hold between two agents x and y.

The next subsections detail these games where sanctions were omitted in our games specifications for better readability. The time is expressed using a simple instant theory with < as the precedence relation. Notice that the game rules structure provides an elegant turn-taking mechanism by entailing that $t_j < t_k < t_l < t_f$. To account for the fact that some commitments are established within the context of some games and only make sense within this context, we make explicit the fact that those dialogical commitments are particular to game g (by indicating g as a subscript). This is typically the case of the dialogue rules involved in the games, as we will see below.

4.3.1. Request *game (rg)*

This game captures the idea that the initiator (x) "requests" an action α from the partner (y) who can "accept" or "refuse". The conditions and rules of the *Request* game are presented in Table 3.

4.3.2. Offer *game (og)*

An offer is a promise that is conditional upon the partner's acceptance. To make an offer is to put something forward for another's choice (of acceptance or refusal). To offer then, is to perform a conditional commissive. Precisely, to offer α is to perform a commissive under the condition that the partner accept α. Conditions and rules are presented in Table 4.

Table 3 Conditions and rules for the *Request (rg)* game

	Request game (rg)
E_{rg}	$C(y, x, \alpha, t_c, \texttt{Ina})$ and $C(y, x, \neg\alpha, t_c, \texttt{Ina})$ $\forall\, t_c\,, t_c < t_j$
S_{rg}	$C(y, x, \alpha, t_f, \texttt{Crt})$
F_{rg}	$C(y, x, \alpha, t_f, \texttt{Fal})$
R_{rg}	1) $C_g(x, y, \textit{request}(x, y, \alpha), t_j, \texttt{Crt})$ 2) $C_g(y, x, \textit{request}(x, y, \alpha) \Rightarrow$ $C_g(y, x, \textit{accept}(y, x, \alpha) \vert \textit{refuse}(y, x, \alpha), t_k, \texttt{Crt}), t_j, \texttt{Crt})$ 3) $C_g(y, x, \textit{accept}(y, x, \alpha) \Rightarrow C(y, x, \alpha, t_f, \texttt{Crt}), t_j, \texttt{Crt})$ 4) $C_g(y, x, \textit{refuse}(y, x, \alpha) \Rightarrow C(y, x, \alpha, t_f, \texttt{Fal}), t_j, \texttt{Crt})$

Table 4 Conditions and rules for the *Offer (og)* game

	Offer game (*og*)
E_{og}	$C(x, y, \alpha, t_c, \texttt{Ina})$ and $C(x, y, \neg\alpha, t_c, \texttt{Ina})\ \forall t_c, t_c < t_j$
S_{og}	$C(x, y, \alpha, t_f, \texttt{Crt})$
F_{og}	$C(x, y, \alpha, t_f, \texttt{Fal})$
R_{og}	1) $C_g(x, y, \mathit{offer}(x, y, \alpha), t_j, \texttt{Crt})$
	2) $C_g(y, x, \mathit{offer}(x, y, \alpha) \Rightarrow$
	$C_g(y, x, \mathit{accept}(y, x, \alpha)\vert\mathit{refuse}(y, x, \alpha), t_k, \texttt{Crt}), t_j, \texttt{Crt})$
	3) $C_g(x, y, \mathit{accept}(y, x, \alpha) \Rightarrow C(x, y, \alpha, t_f, \texttt{Crt}), t_j, \texttt{Crt})$
	4) $C_g(x, y, \mathit{refuse}(y, x, \alpha) \Rightarrow C(x, y, \alpha, t_f, \texttt{Fal}), t_j, \texttt{Crt})$

Table 5 Conditions and rules for the *Ask (ag)* game

	Ask game (*ag*)
E_{ag}	$C(y, x, p, t_c, \texttt{Ina})$ and $C(y, x, \neg p, t_c, \texttt{Ina})\ \forall t_c, t_c < t_j$
S_{ag}	$C(y, x, p, t_f, \texttt{Crt})$
F_{ag}	$C(y, x, p, t_f, \texttt{Fal})$
R_{ag}	1) $C_g(x, y, \mathit{ask}(x, y, p), t_j, \texttt{Crt})$
	2) $C_g(y, x, \mathit{ask}(x, y, p) \Rightarrow$
	$C_g(y, x, \mathit{agree}(y, x, p)\vert\mathit{disagree}(y, x, p), t_k, \texttt{Crt}), t_j, \texttt{Crt})$
	3) $C_g(y, x, \mathit{agree}(y, x, p) \Rightarrow C(y, x, p, t_f, \texttt{Crt}), t_j, \texttt{Crt})$
	4) $C_g(y, x, \mathit{disagree}(y, x, p) \Rightarrow C(y, x, p, t_f, \texttt{Fal}), t_j, \texttt{Crt})$

Table 6 Conditions and rules for the *Inform (ig)* game

	Inform game (*ig*)
E_{ig}	$C(x, y, p, t_c, \texttt{Ina})$ and $C(x, y, \neg p, t_c, \texttt{Ina})\ \forall t_c, t_c < t_j$
S_{ig}	$C(x, y, p, t_f, \texttt{Crt})$
F_{ig}	$C(x, y, p, t_f, \texttt{Fal})$
R_{ig}	1) $C_g(x, y, \mathit{assert}(x, y, p), t_j, \texttt{Crt})$
	2) $C_g(y, x, \mathit{assert}(x, y, p) \Rightarrow$
	$C_g(y, x, \mathit{agree}(y, x, p)\vert\mathit{disagree}(y, x, p), t_k, \texttt{Crt}), t_j, \texttt{Crt})$
	3) $C_g(x, y, \mathit{agree}(y, x, p) \Rightarrow C(x, y, p, t_f, \texttt{Crt}), t_j, \texttt{Crt})$
	4) $C_g(x, y, \mathit{disagree}(y, x, p) \Rightarrow C(x, y, p, t_f, \texttt{Fal}), t_j, \texttt{Crt})$

4.3.3. Ask *game (ag)*

We use “ask” in the sense of asking a question. More precisely, an agent x can use an Ask game to know the opinion of an agent y on the veracity of a proposition p. The conditions and rules of the Ask game are presented in Table 5.

4.3.4. Inform *game (ig)*

This game corresponds to the following actions: the initiator *asserts* a proposition p and the partner should say if it agrees or disagrees with this assertion. If it agrees, the commitment relative to p is therefore created. The conditions and rules of the $Inform$ game are presented in Table 6.

4.4. Withdrawal dialogue games

We have also defined four other games that allow to retract the four previous types of commitments which can hold between two agents x and y.

1. for an attempt to retract an action commitment from x toward y, agent x can use a *CancelActionC* game (cag);
2. for an attempt to retract an action commitment from y toward x, agent x can use a *ReleaseActionC* game (rag);
3. for an attempt to retract a propositional commitment from x toward y, agent x can use a *CancelPropC* game (cpg).
4. for an attempt to retract a propositional commitment from y toward x, agent x can use a *ReleasePropC* game (rpg);

As games for manipulating propositional commitments are similar to those concerning action commitments, we only present below the games manipulating action commitments. Notice that here also, sanctions are omitted for a better readability.

4.4.1. CancelActionC *game* (*cag*)

This game can be used in order to have an already accepted commitment rejected, i.e. to cancel a commitment. In this game, the debtor (x) of a commitment C_i proposes its cancellation. Then, the creditor can agree or not with the cancellation. If the creditor agrees with the retraction, the debtor will not have to face the sanction attached to the commitment C_i while he will have to do so if he disagrees. According to the creditor's opinion (agree or disagree), the debtor can decide to really cancel the commitment and face the associated sanction or change his mind and keep it (probably to avoid facing the sanction). The conditions and rules of the $CancelActionC$ game are presented in Table 7.

4.4.2. ReleaseActionC *game* (*rag*)

Similar to the *CancelActionC* game, the *ReleaseActionC* game allows retracting an action commitment and negotiating the sanction application, but contrary to the former it allows the creditor instead of the debtor to attempt the cancellation. The rules of the *ReleaseActionC* game are thus similar to the *CancelActionC* game rules and they are presented in Table 8.

Table 7 Conditions and rules for the *CancelActionC* (*cag*) game

	CancelActionC game (*cag*)
E_{cag}	$\exists\, t_c\ , t_c < t_j : C(x, y, \alpha, t_c, \texttt{Crt})$
S_{cag}	$C(x, y, \alpha, t_f, \texttt{Cnl})$
F_{cag}	$C(x, y, \alpha, t_f, \texttt{Crt})$
R_{cag}	1) $C_g(x, y, cancel(x, y, \alpha), t_j, \texttt{Crt})$ 2) $C_g(y, x, cancel(x, y, \alpha) \Rightarrow C_g(y, x, agree(y, x, cancel(x, y, \alpha))$ $\mid disagree(y, x, cancel(x, y, \alpha)), t_k, \texttt{Crt}), t_j, \texttt{Crt})$ 3) $C_g(x, y, disagree(y, x, cancel(x, y, \alpha)) \Rightarrow C_g(x, y, confirm(x, y, cancel(x, y, \alpha))$ $\mid decline(x, y, cancel(x, y, \alpha)), t_l, \texttt{Crt}), t_j, \texttt{Crt})$ 4) $C_g(x, y, agree(y, x, cancel(x, y, \alpha)) \Rightarrow C(x, y, \alpha, t_f, \texttt{Cnl}), t_j, \texttt{Crt})$ 5) $C_g(x, y, confirm(x, y, cancel(x, y, \alpha)) \Rightarrow C(x, y, \alpha, t_f, \texttt{Cnl}), t_j, \texttt{Crt})$ 6) $C_g(x, y, decline(x, y, cancel(x, y, \alpha)) \Rightarrow C(x, y, \alpha, t_f, \texttt{Crt}), t_j, \texttt{Crt})$

Table 8 Conditions and rules for the *ReleaseActionC* (*rag*) game

	ReleaseActionC game (rag)
E_{rag}	$\exists\, t_c\ , t_c < t_j : C(y, x, \alpha, t_c, \texttt{Crt})$
S_{rag}	$C(y, x, \alpha, t_f, \texttt{Rel})$
F_{rag}	$C(y, x, \alpha, t_f, \texttt{Crt})$
R_{rag}	1) $C_g(x, y, release(x, y, \alpha), t_j, \texttt{Crt})$ 2) $C_g(y, x, release(x, y, \alpha) \Rightarrow C_g(y, x, agree(y, x, release(x, y, \alpha))$ $\vert disagree(y, x, release(x, y, \alpha)), t_k, \texttt{Crt}), t_j, \texttt{Crt})$ 3) $C_g(x, y, disagree(y, x, release(x, y, \alpha)) \Rightarrow C_g(x, y, confirm(x, y, release(x, y, \alpha))$ $\vert decline(x, y, release(x, y, \alpha)), t_l, \texttt{Crt}), t_j, \texttt{Crt})$ 4) $C_g(x, y, agree(y, x, release(x, y, \alpha)) \Rightarrow C(y, x, \alpha, t_f, \texttt{Rel}), t_j, \texttt{Crt})$ 5) $C_g(x, y, confirm(x, y, release(x, y, \alpha)) \Rightarrow C(y, x, \alpha, t_f, \texttt{Rel}), t_j, \texttt{Crt})$ 6) $C_g(x, y, decline(x, y, release(x, y, \alpha)) \Rightarrow C(y, x, \alpha, t_f, \texttt{Crt}), t_j, \texttt{Crt})$

Table 9 Conditions and rules for the *UpdateActionC* (*uag*) game

	UpdateActionC game (uag)
E_{uag}	$\exists\, t_c\ , t_c < t_j : C(deb, cre, \alpha, t_c, \texttt{Crt})$
S_{uag}	$C(deb, cre, \alpha, t_c, \texttt{Ina})$ and $C(deb, cre, \alpha', t_f, \texttt{Crt})$
F_{uag}	$C(deb, cre, \alpha, t_f, \texttt{Crt})$
R_{uag}	1) $C_g(x, y, update(x, y, \alpha, \alpha'), t_j, \texttt{Crt})$ 2) $C_g(y, x, update(x, y, \alpha, \alpha') \Rightarrow$ $C_g(y, x, agree(y, x, update(x, y, \alpha, \alpha'))$ $\vert disagree(y, x, update(x, y, \alpha, \alpha')), t_k, crt), t_j, \texttt{Crt})$ 3) $C_g(x, y, agree(y, x, update(x, y, \alpha, \alpha')) \Rightarrow C(deb, cre, \alpha', t_f, \texttt{Crt}), t_j, \texttt{Crt})$ 4) $C_g(x, y, agree(y, x, update(x, y, \alpha, \alpha')) \Rightarrow C(deb, cre, \alpha, t_i, \texttt{Ina}), t_j, \texttt{Crt})$ 5) $C_g(x, y, disagree(y, x, update(x, y, \alpha, \alpha')) \Rightarrow C(deb, cre, \alpha, t_f, \texttt{Crt}), t_j, \texttt{Crt})$

4.5. Update dialogue games

If an agent wants to modify a commitment (change any attribute(s) of the commitment except the debtor or the creditor), he can try to retract the commitment and create a new one with the new attribute(s). However, such a cancellation may result in some undesirable sanctions being applied. This is why, we have defined two more games that allow attempts to update commitments without having to face sanctions. These games are:

1. for an attempt to update an action commitment, agent x or y can use an *UpdateActionC* game (uag);
2. for an attempt to update a propositional commitment, agent x or y can use an *UpdatePropC* game (upg);

In the $UpdateActionC$ game, agent x who initiates the game asks agent y if he agrees to cancel the commitment C_i and replace it with the commitment C_j. Then, y can agree or not to the modification of the commitment. If he agrees, the commitment C_i is withdrawn and a new commitment C_j is created.

The conditions and rules of the $UpdateActionC$ game are indicated in Table 9, assuming that: (1) if the initiator (x) is the creditor then $cre = x$ and $deb = y$ while (2) if the initiator (x) is the debtor then $cre = y$ and $deb = x$.

We don't present here the $UpdatePropC$ game definition since it is really similar to the $UpdateActionC$ game definition.

Table 10 Games that an agent x should use in order to obtain the different commitment states

Commitment Type	Current State	Desired State	Dialogue Game
$C(x, y, \alpha)$	Inactive	Created	*Offer*
	Created	Cancelled	*CancelActionC*
$C(y, x, \alpha)$	Inactive	Created	*Request*
	Created	Released	*ReleaseActionC*
$C(x, y, p)$	Inactive	Created	*Information*
	Created	Cancelled	*CancelPropC*
$C(y, x, p)$	Inactive	Created	*Question*
	Created	Released	*ReleasePropC*

4.6. Completeness and soundness

It is interesting to note that in the assumption that dialogue moves are made sequentially, the set of DIAGAL dialogue games is sound and complete according to our social commitment model. Completeness means that all transitions (creation, cancelation, updating) of the underlying social commitment model can be consumed by our 8 primitive games as specified in Table 10, whereas soundness indicates that nothing other than those permitted transitions is possible. The latter is ensured through entry conditions that prevent, for example, canceling a commitment that has not been created. As a consequence, and as our dialogue games cover all possible commitments that an agent x needs when it is in face of another agent y (see Table 10), any complex game (as for instance the complex request for action protocol of Winograd and Flores depicted in Fig. 1) can be reducible to a combination of our primitive games.

When an agent needs to change a commitment state, he simply uses the right dialogue game among the ten previously presented. For instance, if an agent x wants to create a commitment in action α of which he is the creditor and y is the debtor, then x should propose to y to play a *Request* game concerning α. Table 10 games that an agent x should play relative to the desired operation on commitments.

4.7. Grounding and composing the games

The specific question of how games are grounded through the dialogue is certainly one of the most delicate [44]. *Grounding* refers to the process of reaching mutual belief (or common ground [12]. Following Reed [58], we assume that agents can use some meta-acts of dialogue to handle game structure and thus propose to enter a game, to leave it, and so on. This means that games can have a different status: they can be *open*, *closed*, or simply *proposed*. How this status is discussed in practice is described in a *contextualization* game which regulates this meta-level communication. Table 2 indicates the current contextualisation moves and their effects in terms of commitments. For example, when a proposition to enter a game g ($prop.in(x, y, g)$) is played by agent x, agent y is committed to accept ($acc.in$), to refuse ($ref.in$) or to propose entering another game g' ($prop.in(y, x, g')$).

Concerning the possibility of composing the games, the seminal work of Walton and Krabbe [66] and the follow-up formalisation of Reed [58] have focused on the notions of *embedding*, *iteration* and *sequencing* [48]:

Iteration. If g is a game, then g^n is also a game and it consists of the n repetition of g, where each occurrence being undertaken until closure and then being followed by the next one.

Sequencing. If g_1 and g_2 are both dialogue games, then $g_1; g_2$ is also a game and it represents that game which consists of undertaking g_1 until its closure and then immediately undertaking g_2.

Embedding. Here also if g_1 and g_2 are both dialogue games, then $g_1 \prec g_2$ is also a game and it means g_2 is embedded in g_1. It consists of undertaking $g1$ until a sequence has been executed and then switching immediately to dialogue g_2 which is undertaken until its closure, then dialogue g_1 resumes from immediately after the point where it was interrupted and continues until closure. Our previous example of Section 3.2.2 shows a negotiation sub-dialogue embedded in a request for action dialogue.

4.8. Conversation example

Suppose an agent x wants an agent y to repair its car. Therefore, the agent x proposes to y to enter a request game (the only game whose success conditions is an action commitment as wished by x). When the agent y receives the x's proposition to enter the request game *prop.in(x,y,rg)* (issued from the contextualization game, Table 2) his dialogue manager adds the commitment $C(y, x, acc.in(y, x, rg)|ref.in(y, x, rg)|prop.in(y, x, g'))$ to his agenda. Agent y thus has three choices to fulfill this commitment: accept to play the game, refuse to play the game or propose another game.

For the sake of our example, we assume that y accepts to play a request game, meaning that he has the resources and the will to enter a dialogue with x. The dialogue managers of x and y then add all the request game rules (indicated in Section 4.3.1) to their respective agendas. The first rule expresses that x is committed to make a request $C(x, y, request(x, y, \alpha))$. Agent x thus makes his request in order to fulfill this dialogical commitment. The second rule indicates that if x makes a request, y is committed to accept or reject it. Before answering x's request, y decides to embed another request game to engage x to pay him if he accepts the request and repairs the car. The conversation continues according to the different rules sustaining dialogues games and agent's decisions. Finally, at the end of the conversation, two extra-dialogical commitments remain: $C(y, x, A1)$ and $C(x, y, A1 \Rightarrow A2)$ where *A1* stands for the action "Repair the car" and *A2* stands for the action "Pay for the car repairs". The complete conversation is presented in Fig. 3. The left side of the figure presents the sequence diagram of the conversation between x and y while the right side presents the effects of each message on the contents of their agendas.

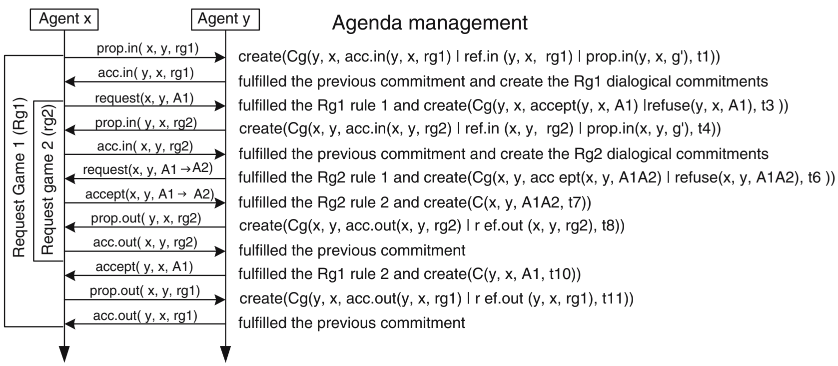

Fig. 3 Conversation example between agents x and y with the management of their respective agendas

5. Web of commitments

As DIAGAL's dialogue games are based on commitments, it would be interesting to look at how one could specify the agents' dialogical behavior of a multiagent system (MAS) using such commitments. In fact, it is interesting to study the links that exist between the different commitments of a MAS. For example, one can wonder when an agent must try to create a particular commitment or try to modify an existing commitment. Usually, it is possible and even probable that an agent attempts to modify the state of a commitment if he notices that the state of another commitment has changed. For example, the cancellation of a commitment C_i can lead an agent to attempt to create another commitment C_j.

Therefore, it is interesting to enumerate the consequences of the commitments states changes in a MAS in order to study the dynamic of the system by the dynamic of the commitments. Moreover, as the dialogue games allow agents to manipulate social commitments, one can see how to specify the dialogical behavior of the agents of a MAS starting from the study of the dynamic of the commitments. Consequently, elaborating a commitment network called here "web of commitments" that enumerates the consequences of all the commitments states changes in a MAS to guide the agents in their conversations is very useful.

5.1. Definitions

Some preliminary concepts should be defined before specifying a web of commitments. Precisely, we need to define the following sets:

- $A = \{a_1, a_2, \ldots, a_k\}$ is the set containing all the agents of a MAS.
- $C = \{c_1, c_2, \ldots, c_n\}$ is the set containing all the commitments that can exist in a MAS.
- $S = \{$ `Ina`, `Crt`, `Cnl`, `Rel`, `Ful`, `Vio`, `Fal`$\}$ is the set containing all the states that a commitment can take. These states have been introduced in Section 4.1

It's also important to define the notions of *commitment state modification cause* and *commitment state modification desire*:

Definition 2

- A commitment state modification cause is represented by a triplet of the type $(a_1, c, s)_{cau}$ where $a_1 \in A$, $c \in C$ and $s \in S$. The triplet $(a_1, c, s)_{cau}$ specifies that the commitment c passes into state s because of agent a_1. The state modification is observed by the debtor and the creditor of the commitment when it occurs.
- A commitment state modification desire is represented by a triplet of the type $(a_1, c, s)_{des}$ where $a_1 \in A$, $c \in C$ and $s \in S$. This triplet specifies that the agent a_1 desires[4] that the commitment c passes into state s if it is possible.

We can now define the web of commitments concept.

Definition 3 A web of commitments $W = (A, C, L)$ is defined by :

- A : a set of agents.
- C : a set of commitments.

[4] High level desires which are specific to the web of commitments. They mean that an agent will try everything which is possible to pass the commitment into state s.

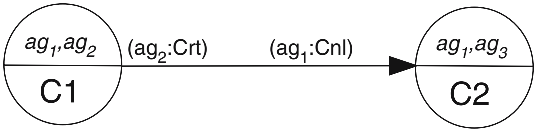

Fig. 4 An example of link between two commitments

– L : a set of couples of the type $((a_1, c_1, s_1)_{cau}, (a_2, c_2, s_2)_{des})$ where $a_1, a_2 \in A$, $c_1, c_2 \in C$ and $s_1, s_2 \in S$. In fact, this set contains all the causality links that exist between all the commitments of the set C. The link $((a_1, c_1, s_1)_{cau}, (a_2, c_2, s_2)_{des})$ specifies that agent a_2 desires that the commitment c_2 passes into state s_2 if he notices that the commitment c_1 passes into state s_1 because of agent a_1.

5.2. Example

Let's suppose that a simple MAS contains three agents (ag_1, ag_2 and ag_3) and that only two commitments can exist in that MAS: $\texttt{C1} = C(ag_1, ag_2, \alpha)$ and $\texttt{C2} = C(ag_1, ag_3, \beta)$. Now, let's suppose that the creation of the commitment C1 by the agent ag_2 causes the cancellation of the commitment C2 by the agent ag_1. Starting from these considerations, we can determine a web of commitments for our MAS. The web of commitments $W_{ex_1} = (A_{ex_1}, C_{ex_1}, L_{ex_1})$ of this example is defined as follows:

1. $A_{ex_1} = \{ag_1, ag_2, ag_3\}$
2. $C_{ex_1} = \{\texttt{C1},\texttt{C2}\}$
3. $L_{ex_1} = \{((ag_2, \texttt{C1}, \texttt{Crt})_{cau}, (ag_1, \texttt{C2}, \texttt{Cnl})_{des})\}$

All agents follow the web of commitments and consequently, when the agent ag_1 notices that the commitment C1 is created by the agent ag_2, he then "attempts" (in the sense of option of desire) to cancel the commitment C2 as indicated by the web of commitments. To achieve such a cancellation, ag_2 should use the game $CancelActionC$ as proposed in Table 10. In these conditions ag_2 proposes to ag_3 to play the game $CancelActionC$ since ag_3 is the creditor of C2.

A web of commitments can also be represented using a graphic method that we developed and which is inspired from the commitments causality diagram of Wan and Singh [67]. At first, a commitment is simply represented by a circle containing the debtor, the creditor and the identifier of the commitment. In addition, a link (arrow) is added between two commitments (circles) if a state modification of the first commitment causes a state modification desire of the second commitment. The graphic version of the web of commitments of the preceding example is presented in Fig. 4. The link between the two commitments means that the creation of the first commitment by ag_2 $(\texttt{ag}_2\texttt{:Crt})$ results in an attempt by the agent ag_1 of canceling $(\texttt{ag}_1\texttt{:Cnl})$ the second commitment.

Thus, we can see how the web of commitments can help MAS designers to specify the dialogical behavior of their agents by studying the dynamic of the commitments.

6. Summer festival example

We are currently studying how we can use the web of commitments and the dialogue games to model offices as systems of communicative actions. Through dialogue games, participants engage in actions by making promises, asking for information, stating facts, etc. and through these actions, they create, modify, cancel, release, ..., fulfill commitments that bind their current and future behavior. The illustrative example on which we focus here concerns the organization of a summer festival. This festival which lasts several days consists of groups of artists coming from various countries. We want all the necessary management of such event to be done by software agents.

With this example, we aim to test the main claims of the paper, in particular: (1) how a multiagent application like the festival example can be specified using a web of commitment? (2) how this web of commitments leads to a dialogical exchange between participants in the festival? (3) how completeness, soundness, coherence and other properties can be respected in the web of commitments and consequently in the dialogical exchange? (4) how evolves in the time the web of commitments and consequently the dialogical exchange?

Our summer festival example is a MAS containing five various types of agents who have different tasks to realize. These agents are as follows:

- $AgArtist$ (ar_i): A type of agent representing an artist in the system. An instance is represented by ar_i where i is used to indicate that potentially several artists will be present in the simulation. Such type of agent can accept or refuse an invitation regarding the requested fee.
- $AgPlanner$ (pl): An instance of $AgPlanner$ is an interface between an agent of type $AgArtist$ and the remainder of the system. He is responsible for finding the artists to be invited, for managing a budget as well as a schedule. He also delegates some tasks to the agent $AgSecretary$.
- $AgSecretary$ (sc): An instance of $AgSecretary$ is an interface between an agent of type $AgPlanner$ and the other resource agents ($AgHotels$ and $AgTravelAgency$). He is responsible for the hotel and flight reservations.
- $AgHotels$ (ht_i): An instance of $AgHotels$ is an agent which represents a conglomerate of hotels.
- $AgTravelAgency$ (ta_i): An instance of $AgTravelAgency$ is an agent which represents a conglomerate of airline companies.

6.1. The summer festival web of commitments

Since the principal task of the summer festival example is the invitation of artists, we have focused on how the planner and the other agents can interact to complete the invitation of an artist. At the beginning of the invitation, the planner and a given artist must try to find an agreement on the date and the time of the artist's performance. Then, the planner and the artist must reach an agreement on the fee for the artist's performance. The planner also has to ask the artist if he wants an airline ticket and an hotel room. Thereafter, the planner must provide the preferences of the artist to the secretary agent so that he can carry out the reservations correctly. Then, the secretary has to contact the hotels and the travel agencies to make the reservation requested by the artist. Finally, the secretary agent must contact the artist and request him to pay the various services (i.e., airline ticket and hotel room) that he asked for.

To specify the web of commitments of such interactions, we must find the commitments that are hidden in the description of the invitation of an artist. Initially, the planner must try to *commit* the artist to come to the festival. If the artist commits himself and accepts the invitation, the planner must *commit* himself to pay the artist for his performance at the festival. The planner also *commits* himself reserving the airline ticket and the hotel room if the artist accepts. The secretary also has to *commit* himself reserving the airline ticket and the hotel room if the planner asks for it and so on.... In fact, the invitation of an artist can lead to the creation of ten different commitments which are presented in Table 11.

Table 11 An analysis of the festival example in terms of commitments

Id	Commitment	Description
Planner and Artists Commitments		
C1	$C(ar_i, pl, ComeToFestival(ar_i, date, time))$	The artist commitment toward the planner to come to the festival.
C2	$C(pl, ar_i, PayFee(pl, ar_i, fee))$	The planner commitment toward the artist to pay her fees.
C3	$C(ar_i, pl, WantARoom)$	The artist commitment toward the planner to want a (hotel) room.
C4	$C(ar_i, pl, WantATicket)$	The artist commitment toward the planner to want a (flight) ticket.
Planner and Secretary Commitments		
C5	$C(sc, pl, ReserveRoom(sc, ar_i, date))$	The secretary commitment toward the planner to reserve a room for the artist.
C6	$C(sc, pl, ReserveTicket(sc, ar_i, date))$	The secretary commitment toward the planner to book a flight ticket for the artist.
Secretary and Hotel Commitments		
C7	$C(ht, sc_i, ReserveRoom(ht, ar_i, date))$	The hotel commitment toward the secretary to reserve a room for the artist.
Travel Agency and Secretary Commitments		
C8	$C(ta, sc_i, ReserveTicket(ta, ar_i, date))$	The travel agency commitment toward the secretary to book a flight ticket for the artist.
Secretary and Artists Commitments		
C9	$C(ar_i, sc, PayRoom(ar_i, sc, price))$	The artist commitment toward the secretary to pay her room.
C10	$C(ar_i, sc, PayTicket(ar_i, sc, price))$	The artist commitment toward the secretary to pay her flight ticket.

After inventorying the commitments of the summer festival example, we can now elaborate a web of commitments of the artist's invitation. All we have to do is to determine the causality links that exist between the commitments. In our case, the links emerge from the description of the invitation of an artist and from the commitments of Table 11. The web of commitments of the invitation of an artist $W_{fes} = (A_{fes}, E_{fes}, L_{fes})$ is defined as follows:

1. The agents set $A_{fes} = \{pl, sc\} \cup \{ar_1, ar_2, \ldots, ar_n\} \cup \{ht_1, ht_2, \ldots, ht_m\} \cup \{av_1, av_2, \ldots, av_k\}$.

2. The commitments set $C_{fes} = \{\texttt{C1}, \texttt{C2}, \ldots, \texttt{C10}\}$.
3. The causality links set
$L_{fes} = \{\ ((-, -, -)_{cau}, (pl, \texttt{C1}, \texttt{Crt})_{des}),$

$((pl, \texttt{C1}, \texttt{Crt})_{cau}, (pl, \texttt{C2}, \texttt{Crt})_{des}),$ $((pl, \texttt{C1}, \texttt{Rel})_{cau}, (pl, \texttt{C5}, \texttt{Rel})_{des}),$
$((ar_i, \texttt{C1}, \texttt{Cnl})_{cau}, (pl, \texttt{C5}, \texttt{Rel})_{des}),$ $((pl, \texttt{C1}, \texttt{Rel})_{cau}, (pl, \texttt{C6}, \texttt{Rel})_{des}),$
$((ar_i, \texttt{C1}, \texttt{Cnl})_{cau}, (pl, \texttt{C6}, \texttt{Rel})_{des}),$ $((pl, \texttt{C1}, \texttt{Rel})_{cau}, (pl, \texttt{C2}, \texttt{Cnl})_{des}),$
$((ar_i, \texttt{C1}, \texttt{Cnl})_{cau}, (pl, \texttt{C2}, \texttt{Cnl})_{des}),$ $((pl, \texttt{C2}, \texttt{Fal})_{cau}, (ar_i, \texttt{C1}, \texttt{Cnl})_{des}),$
$((pl, \texttt{C2}, \texttt{Crt})_{cau}, (pl, \texttt{C3}, \texttt{Crt})_{des}),$ $((pl, \texttt{C2}, \texttt{Crt})_{cau}, (pl, \texttt{C4}, \texttt{Crt})_{des}),$
$((pl, \texttt{C3}, \texttt{Crt})_{cau}, (pl, \texttt{C5}, \texttt{Crt})_{des}),$ $((ar_i, \texttt{C3}, \texttt{Rel})_{cau}, (pl, \texttt{C5}, \texttt{Rel})_{des}),$
$((pl, \texttt{C4}, \texttt{Crt})_{cau}, (pl, \texttt{C6}, \texttt{Crt})_{des}),$ $((ar_i, \texttt{C4}, \texttt{Rel})_{cau}, (pl, \texttt{C6}, \texttt{Rel})_{des}),$
$((pl, \texttt{C5}, \texttt{Crt})_{cau}, (sc, \texttt{C7}, \texttt{Crt})_{des}),$ $((pl, \texttt{C5}, \texttt{Rel})_{cau}, (sc, \texttt{C7}, \texttt{Rel})_{des}),$
$((pl, \texttt{C5}, \texttt{Rel})_{cau}, (sc, \texttt{C9}, \texttt{Rel})_{des}),$ $((pl, \texttt{C6}, \texttt{Crt})_{cau}, (sc, \texttt{C8}, \texttt{Crt})_{des}),$
$((pl, \texttt{C6}, \texttt{Rel})_{cau}, (sc, \texttt{C8}, \texttt{Rel})_{des}),$ $((pl, \texttt{C6}, \texttt{Rel})_{cau}, (sc, \texttt{C10}, \texttt{Rel})_{des}),$
$((sc, \texttt{C7}, \texttt{Crt})_{cau}, (sc, \texttt{C9}, \texttt{Crt})_{des}),$ $((sc, \texttt{C7}, \texttt{Fal})_{cau}, (sc, \texttt{C7}, \texttt{Crt})_{des}),$
$((ht_i, \texttt{C7}, \texttt{Cnl})_{cau}, (sc, \texttt{C7}, \texttt{Crt})_{des}),$ $((sc, \texttt{C8}, \texttt{Crt})_{cau}, (sc, \texttt{C10}, \texttt{Crt})_{des}),$
$((sc, \texttt{C8}, \texttt{Fal})_{cau}, (sc, \texttt{C8}, \texttt{Crt})_{des}),$ $((av_i, \texttt{C8}, \texttt{Cnl})_{cau}, (sc, \texttt{C8}, \texttt{Crt})_{des}),$
$((sc, \texttt{C9}, \texttt{Fal})_{cau}, (sc, \texttt{C7}, \texttt{Rel})_{des}),$ $((ar_i, \texttt{C9}, \texttt{Cnl})_{cau}, (sc, \texttt{C7}, \texttt{Rel})_{des}),$
$((sc, \texttt{C10}, \texttt{Fal})_{cau}, (sc, \texttt{C8}, \texttt{Rel})_{des}),$ $((ar_i, \texttt{C10}, \texttt{Cnl})_{cau}, (sc, \texttt{C8}, \texttt{Rel})_{des})$

$\}.$

A graphic version of the web of commitments is also given in Fig. 5. With this web, we can for instance see that the establishment of the commitment C1 (which commits the artist to come to the festival) leads (under some conditions) to the creation of C2 (which commits the planner to pay the artist fees).

Therefore, the web of commitments allows us to identify all the commitment states changes that have a consequence on the invitation of an artist. If a commitment state modification is not included in the web of commitments, it means that this modification has no consequences. In these conditions, the dialogical behavior of the agents is implicitly specified through the web of commitments. An agent can easily follow this web of commitments and determine the dialogue game to use according to the desired modification of the social layer. In fact, an agent can find the game to use according to the desired commitment type and the state wanted for this commitment as previously indicated in Table 10. For example, the planner can easily determine that he has to use a *Request* game to create the commitment C1. He has to use a *Request* game because he is the creditor of C1 and C1 is an action commitment.

7. Simulation and results

We have developed a tool (called Dialogue Game Simulator, DGS) which allows us to simulate conversations between agents who use dialogue games to communicate. In fact, the DGS is an implementation of the DIAGAL's theoretical concepts and allows us to study several aspects of the communication between software agents. DGS aims to be an effective tool of validation as well as a means of analyzing dialogues, diagrams and structures concerning the various games.

The main component of the DGS is the agenda of agents. This structure contains action commitments as well as propositional commitments deduced from dialogue rules when an action is played. With it, users can follow the effects of the agents' actions i.e., check the creation, cancellation, fulfillment, …of commitments between the agents. In fact, an agenda is a kind of distributed *commitment store* where commitments are classified according to

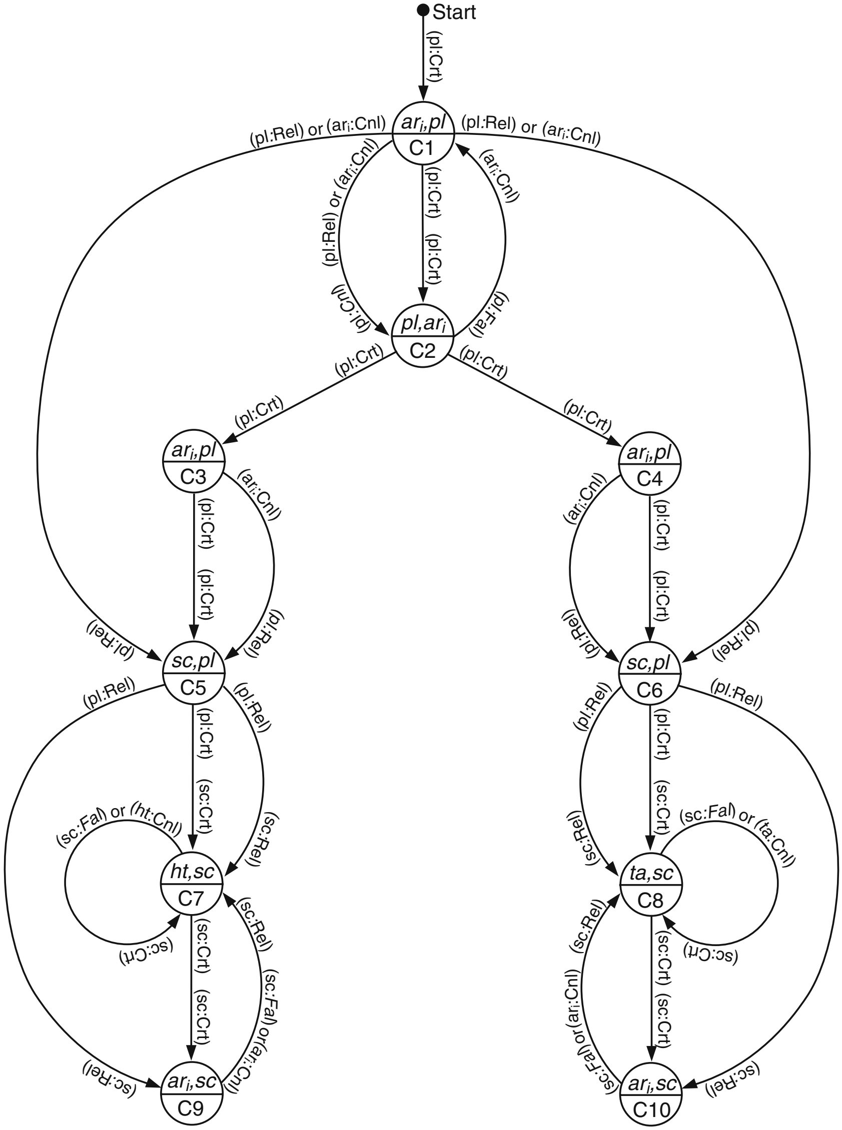

Fig. 5 The web commitments of the invitation of an artist

the time they were contracted. In addition, the DGS contains an action board that offers the possibility of observing the exchange of messages between agents (UML sequence diagram). Such a board acts as a visual component for the simulator user, to help him understand and analyze what occurred in a dialogue between two agents.

Figure 6 presents a snapshot of the DGS, where at the top left we have the "created agents" (1) and below it, the "loaded games" (2) and the "dialogue games stack" (3). The big window at right reflects the agenda (4) of the current selected agent and below it, another window which reflects the action board (5).

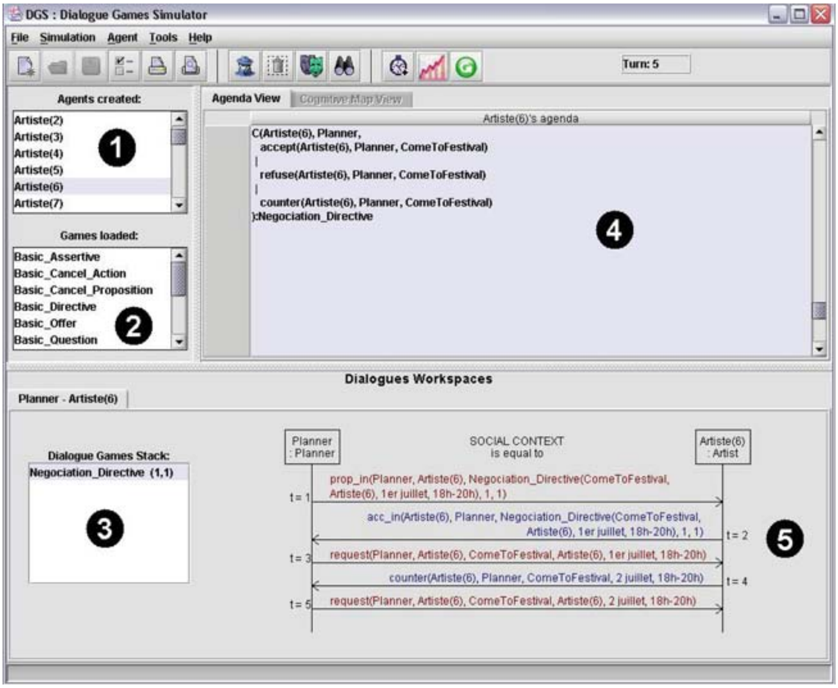

Fig. 6 A snapshot of the DGS

We also have defined several metrics to evaluate and analyze the quality of the conversations which take place into the DGS. These metrics make it possible to check and validate the dialogical behavior of the agents of a MAS and are defined on three levels:

– Metrics for the entire MAS.
– Metrics for a dialogue between two agents.
– Metrics for an agent.

Moreover, for each of these levels, we defined three types of metrics: metrics concerning commitments, metrics concerning dialogue games and general metrics. For instance, the metrics we have defined for the entire MAS are presented in Table 12.

7.1. Summer festival agents

The agents of the summer festival example have been implemented using the JACK^{TM} language which is an agent-oriented programming language using practical-reasoning based on beliefs–desires–intentions (BDI). We used however a simplified version of decision-making mechanism for agents and not a complete one which can refer to preferences, utilities, etc. The reason for that is that our main objective was to test DIAGAL as a communication tool and not to focus on distribution reasoning mechanism. As simplified mechanism, we precisely used behavior files to model the decision-making mechanism of the summer festival agents. In the behavior files we specify if an agent has a tendency to cancel his commitments, if he respects his commitments and if he often commits himself. For example, an agent can cancel some commitments with a probability of 0.5, respect some commitments with a probability of 0.8 and accept to commit himself to realize an action α with a probability of 0.9.

Table 12 Metrics for the entire MAS

Type	Metrics
Commitment	Number of commitments in action Number of commitments in prop. Number of fulfilled commitments Number of withdrawn commitments
Dialogue game	Number of dialogue games used Proportion of dialogues games used
General	Number of agents in the MAS. Number of dialogues in the MAS Avg number of dialogues per agents Total number of dialogues turn

It is important to mention that the behavior files are private to the agent and that the agents negotiate the content (salary of the artist for example) of their commitments even if their decisions are random. The behavior file of a given agent only specifies if he is predisposed to commit himself. For example, the agent artist will negotiate his fee if he plans to commit himself to come to the festival, but will refuse to commit himself if he does not obtain an appropriate fee.

In addition, the summer festival agents must determine which agents to interact with to organize the festival effectively. For example, the planner must try to invite artists who respect and do not cancel their commitments. Consequently, the planner must try to learn the behavior of the artists if he wants to organize the festival more effectively. To this end, we have used the concepts of trust and agreement degrees. In the case of trust, we used the notation $T_x(y)$ (with $-1 \leq T_x(y) \leq 1$) to specify the degree of trust that an agent x has in agent y [41]. This trust degree is fixed at the beginning (generally at 0) and evolves according to the actions of the agents (fulfill commitment, cancel commitment, …). We also used the notation $A_x(y)$ (with $-1 \leq A_x(y) \leq 1$) to specify the agreement degree that agent x has toward agent y. This agreement degree reflects some harmony of opinions between agents and the higher it is between them, the less they need to negotiate. This degree is also fixed at the beginning and evolves according to the agents' actions. Consequently, the planner must make a good compromise between the trust and agreement degrees to determine which artists he should invite. If A stands for the artist set, then the planner (pl) will choose to interact with the agent y who is such as:

$$y = \arg \max_{a \in A}(\gamma \ T_{pl}(a) + \mu \ A_{pl}(a))$$

The γ and μ parameters balance the importance allocated to the two degrees (trust and agreement). Finally, the summer festival agents use a web of commitments to guide their conversations. The web of commitments itself is specified in an XML file which is loaded when the simulation starts.

7.2. Experiments

We simulated 500 summer festival organizations to analyze the evolution of the agents from one simulation to the other. We focused particularly on the interactions between the planner and the artists. The planner has to find 9 artists out of a group of 25 artists who have different behaviors and preferences (salary, availability, …). We used our metrics to analyze

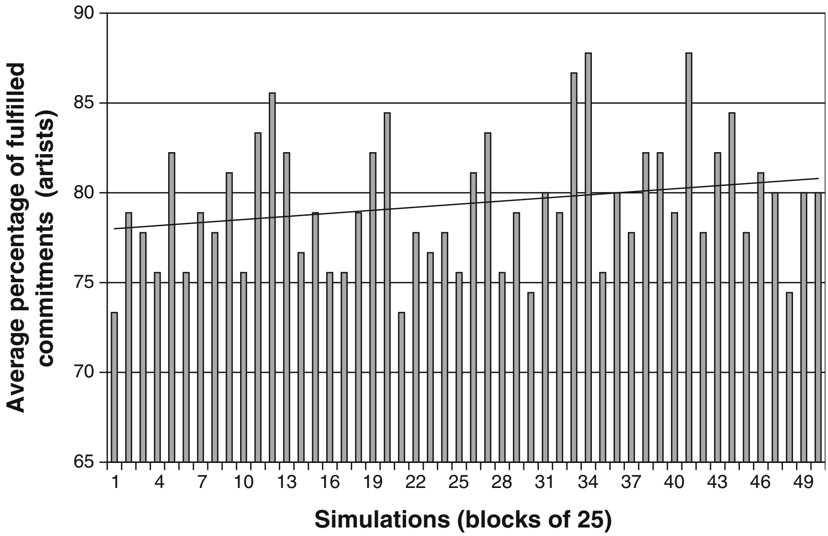

Fig. 7 Average percentage of commitments fulfilled by the artists

the summer festival simulations and the work of the planner. We show here the results of the analysis of two metrics that we find significant to evaluate the quality of the planner's work: the percentage of fulfilled commitments by the artists and the number of commitments canceled by the artists.

The graph in Fig. 7 presents the average percentage of fulfilled commitments by the artists for each block of 25 simulations. Hence, the graphic contains the average percentage of fulfilled commitments for 50 blocks of 25 simulations. The graph in Fig. 8 presents the average number of commitments cancelled by the artists for each block of 25 simulations.

We add the linear regression line of the data on both graphs to show that the planner learns to organise the festival more effectively. In fact, the planner learns to find better artists for the festival (artists who generally respect their commitments). The erratic variation between the results of simulations is attributable to the random behavior of the agents. Indeed, even if the planner invites artists who respect their commitments with a very strong probability, it is possible that several of these agents do not respect their commitments.

We also present the result of the analysis of two dialogue metrics to show how the planner improvement affects the communication. The first metric is the number of dialogue turns that take place between the planner and the artists. The second metric is the number of dialogue games used by the artists and the planner. The graph in Figs. 9, 10 presents this two metrics for each block of 25 simulations.

These two graphs show that the festival organization requires less communication from one simulation to another. The number of dialogue turns and dialogue games decrease because the planner invites artists who rarely cancel their commitments (trust degree) and artists who are predisposed to commit themselves (agreement degree). After all, when an artist cancels a commitment or refuse to commit himself, the planner has to start a new dialogue with a new artist to organize the festival correctly. All things considered, the summer festival example shows us that the metrics are efficient to analyze agents conversations.

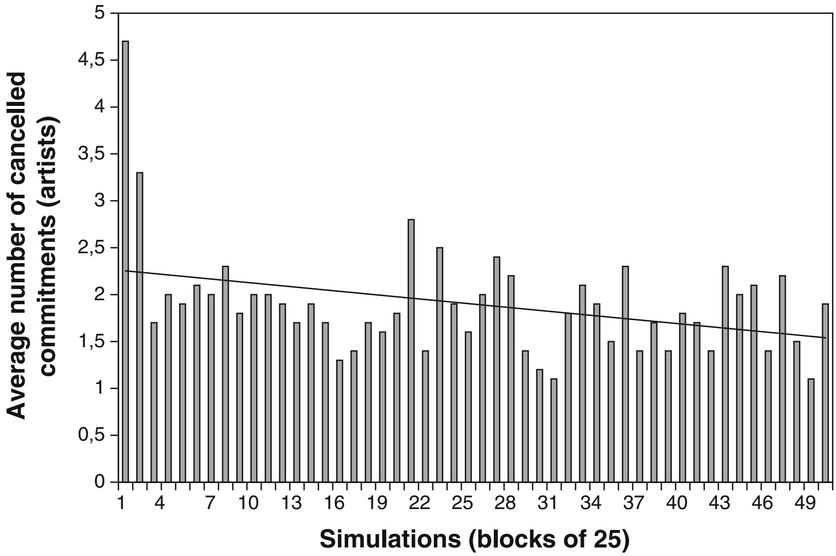

Fig. 8 Average number of commitments cancelled by the artists

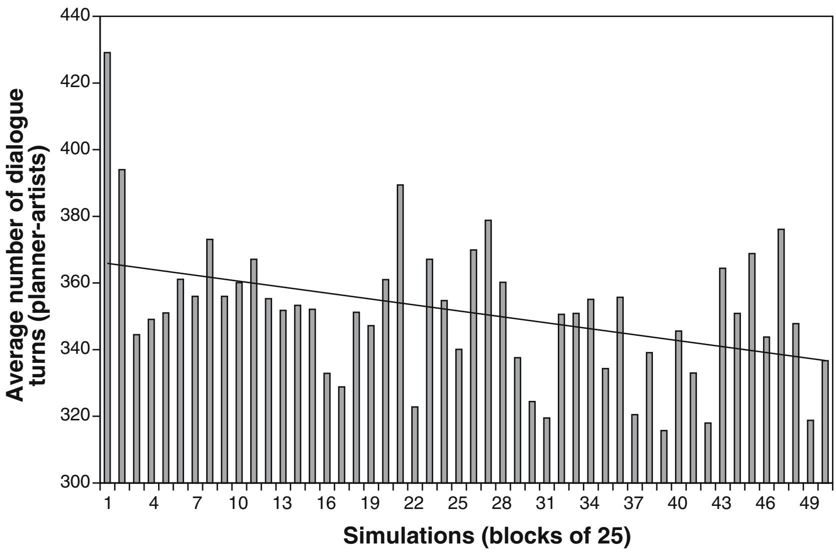

Fig. 9 Average number of dialogue turns that take place between the planner and the artists

8. How DIAGAL addresses flexibility and specification-analysis

Let us now return to the problems of flexibility and specification as described in Section 2.3, and explain how commitment-based games as described here can (or not) solve them.

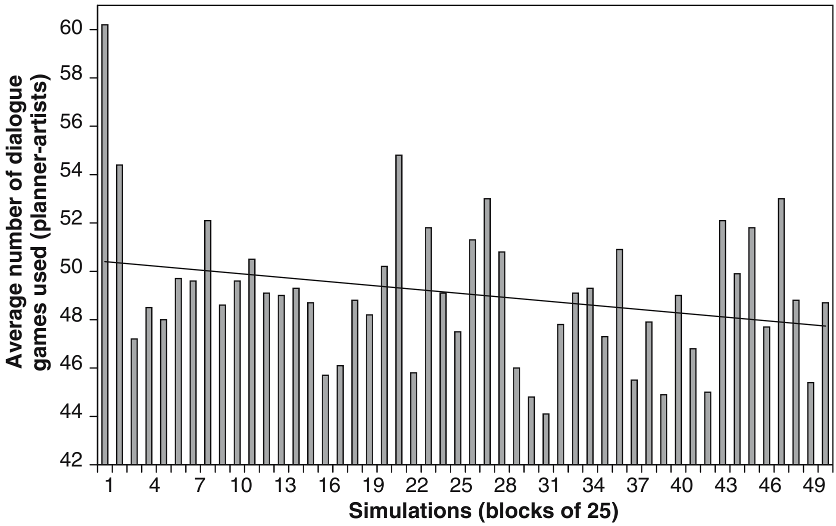

Fig. 10 Average number number of dialogue games used by the artists and the planner

8.1. DIAGAL and flexibility

8.1.1. DIAGAL adopts a formalism which allows more flexibility than classical states-based protocols

Keeping track of the state of the dialogue, as proposed in the dialectical literature and therefore in our approach, is a key point in making the conversation between agents more flexible. For instance, recording the commitments of the participants in an agenda, as in DIAGAL, makes possible ulterior references to these commitments instead of just on the previous move of the dialogue (e.g., backtracking replies). Notice that in DIAGAL and more generally in dialectic approaches, the basic structure is just a set of commitments, but it may be useful to also store the questions currently challenged, or under discussion —see e.g., Gordon, [28]. In these cases, it may be necessary to use some notion of relevance [16,56] to ensure the focus of the dialogue. We should also note that DIAGAL is non-cumulative, in the sense that it allows (under some conditions) the retraction of commitments. This is important to enable the *self-transformation* [48] of the participants through the dialogue: changing their point of view, preferences, and so forth.

8.1.2. DIAGAL permits unexpected messages within conversations

Classical states-based protocols require agents to conform to the expected transitions. Conversely commitments motivate agents to conform to some expected behavior [22], discourage disruption [48] and thus facilitate the coordination between agents. However, software agents remain autonomous and can act in a different manner if they have reason to do so [18]. This is a strong argument supporting the definition of the conversational rules of DIAGAL in terms of commitments. DIAGAL's rules describes the expected conversational behaviors, but participants have the possibility of not following these rules. This raises the delicate question of the system policy on normative compliance and control. An elegant solution is to admit norm violation as long as nobody objects [8].

8.1.3. Like other commitment approaches, DIAGAL allows games' combinations

Note that different possibilities on games' combinations have been carefully studied in literature. DIAGAL permits as combinations : embedding, sequencing and iteration. It is on the verge of being extended to some others such as: *choice* where participants undertake either g_1 or g_2 non-deterministically; *parallelization* where participants undertake both g_1 and g_2 simultaneously, until each is closed. Among these combinations, the embedding combination is the cornerstone since it allows us to consider different embedding games like for instance: negotiation within deliberation (the picture hanging case of Parsons and Jennings [51]), info-seeking within deliberation, expert-consultation within persuasion, deliberation within critical discussion, negotiation within persuasion (the car sales case of McBurney et al. [48] or the team formation case of Dignum, Morley, Sonenberg, & Cavedon [21], or inquiry within persuasion (the party case of Maudet & Evrard [45]).

8.1.4. DIAGAL allows agents to come to an agreement on the current game

Reaching a common ground in the sense of reaching mutual belief [12] is very important for conversations between agents. In DIAGAL, we have opted for the contextualization game of Maudet [43] which is also based on participants' commitments and therefore on public notions and not on "mutual mental states" which are not verifiable. Although this sort of meta-game allows agents to come to an agreement on the current game, the mechanisms underlying it are still ongoing research, in particular for taking into account some considerations from the desiderata proposed in McBurney et al. [48].

8.2. DIAGAL and specification-analysis

8.2.1. DIAGAL adopts public specifications

Firstly, DIAGAL is based on public conversational principles, independent of agents' internal specificities. In fact, in DIAGAL all games including the contextualization one are based on commitments and consequently the specification process goes through the determination of public commitments. Thus, the specification process itself can be considered as public, in particular if we consider the *dialogue purpose*, *the dialogue rules*, the *underlying argumentation theory*—all these ensure some sort of *fairness* of the system [47].

8.2.2. DIAGAL adopts a declarative approach

In DIAGAL, the commitment rules are expressed under a declarative form and this facilitates the task of designing games, and improves clarity and expressiveness. This makes possible the definition of conversations in some standard explicit language, e.g., XML, as is the case in our DIAGAL simulator.

8.2.3. DIAGAL allows constructing a coherent web of commitments

Using DIAGAL, a designer of a multiagent system might clarify what the necessary and sufficient conditions are for each dialogue game to obtain its purpose. To this end, he can use a data base where such conditions are stored. For example, when we receive a request, one must clarify under what conditions it is acceptable to "accept" or to "refuse" the request. In the case where the request is refused, one should go further and see under what conditions it can make a "counteroffer" or to "ask" for clarification. By doing so, one can show how the utterances in a discourse logically connect to each other. Therefore, a coherent web of commitments emerges and a coherent discourse with only successful illocutions.

8.2.4. With DIAGAL we can analyze the discourse termination

The study of discourse termination analyzes ways of terminating a discourse or some of its parts. To test for termination, we transform our web of commitment into a reachability tree which shows possible terminating discourse processes associated with the application. In our festival example, the reachability tree ends either with the refusal of an invitation, withdrawal of the artist, or with the completion of the hotel and flight reservations and their announcement to the artist. In the case of termination we can check which fulfilled commitments (with their characteristics such as : debtors, creditors, time, etc.) have caused that. Conversely, when the discourse is not complete, similar analysis can inform agents and also designers why such or such process is not terminated. This can lead agents to find another way (if any) to terminate the process. In our example, agents can, for instance, "insist", "increase fee", etc.

8.2.5. With DIAGAL, we can coordinate agents through the web of commitments

With the web of commitments proposed here, we can check what sorts of commitments bind different parties, how these commitments evolve, and by whom, and when the commitments are fulfilled. In our festival example, the planner is interested in the creation of a final program. In this context, it is important to see how different parties' commitments and their fulfillment relate to this final program. Designers of a multiagent system can elaborate a mechanism (doing the same job than our DGS) allowing them to observe some features of the dynamic evolution of our web of commitments.

For instance, upon accepting the invitation by an artist, the DGS (i) removes a planner's commitment to have another artist; (ii) removes the planner's commitment to invite an artist; (iii) adds a commitment for a show in the final program; (iv) adds a commitment to pay; (v) adds a commitment to arrange a flight (sometimes), etc. If all partners are to successfully coordinate preparing and realizing the festival, they must know the state of all their commitments. To achieve that, they should report back, since keeping all agents informed about the evolution is an important decision that can be achieved by reporting about the fulfilled and unfilled commitments. Evidently, the timelessness of this information is crucial and consequently agents should report the status of their commitments in real-time.

9. Conclusion and perspectives

In this article, we have presented our commitment-based approach for the agent communication language by explaining (i) what a game is in our approach and how it is structured, what are the rules specified within the game; (ii) the kind of games' compositions which are allowed; (iii) the ways that participants in conversation reach agreement on the current game and how games are opened or closed. At the syntactic level, the DIAGAL's dialogue games appear to be a good alternative between strictly "mentalistic" or "social" approaches and protocols. At the semantic level, dialogue games are defined in terms of entry conditions, success conditions and failure conditions expressed in terms of verifiable extra-dialogical social commitments. Moreover, the conventional part of pragmatics is expressed in terms of conditional dialogical social commitments specifying the rules of the games. Besides, the contextualization game ensures the grounding of dialogue games (taking into account the attentional level of agents) while dialogue games ensure the grounding of each modification in the social commitments layer. Consequently, DIAGAL is a complete language to manipulate the social commitments layer.

Thereafter, we introduced the web of commitments which allows specifying the dialogical behavior of the agents of a MAS by studying the dynamic of the commitments. Comparatively to others [67] that use commitments causality to analyze conversations examples, we propose to use commitments causality to specify the dialogical behavior of the agents of a MAS. In addition, we have shown how we can use metrics based on commitments to analyze agents conversations. In fact, we have shown through DIAGAL and DGS how commitments can be used to specify, design and analyze dialogues between agents.

Finally, we would like to raise the difficult question of the *agent architecture* which should fit a new language of communication as presented here. In other words, how should we design agents to allow them to dialogue with the languages of communication described here? Although not unique, the approach of normative/deliberative agents seems promising [34] Lesperance. In their deliberative process, such agents take into account their own intentions, beliefs and goals (following the classical theories of rational agency) but also the normative notions which motivate them to act as they are committed to (follow the rules of the dialogue, conform to the conversation policy). This supposes of course, the use of a private mentalistic semantics in addition to the public notions described so far—see also the notion of layered semantics [55]. For instance, Amgoud et al. defines particular rationality rules for each move, i.e., the conditions under which the moves may be played during the dialogue, w.r.t. to the private argumentation system of each agent—see [53] for a generalization of this work.

But how should these different levels be combined? In fact, allowing the agents to reason about their social and private attitudes involves complex architectures. Different works have explored this aspect: the BDOING (Belief, Desire, Obligations, Intentions, Norms and Goals) architecture [10], the BOID (Belief, Obligations, Intentions, Desires) architecture [9,17], the normative/deliberative model of agency [6]. These numerous works make us confident as to the future development of these models.

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