Strategic Agent Communication: An Argumentation-Driven Approach

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Abstract. This paper proposes a formal framework for agent communication where agents can reason about their goals using strategic reasoning. This reasoning is argumentation-based and enables agents to generate a set of strategic goals depending on a set of constraints. Subgoals are generated using this reasoning and they can be cancelled or substituted for alternatives during the dialogue progress. An original characteristic of this framework is that agents can use this strategic reasoning together with a tactic reasoning to persist in the achievement of their goals by considering alternatives depending on a set of constraints. Tactic reasoning is responsible of selecting the communicative acts to perform in order to realize the strategic goals. Some constraints are fixed when the conversation starts and others during the dialogue progress. The paper also discusses the computational complexity of such a reasoning.

Keywords: Agent Communication, Social Commitments, Argumentation, Strategic Reasoning, Complexity.

1 Introduction

In multi-agent systems, agents are designed to accomplish particular tasks and they should be able to generate, adopt, drop and achieve their goals [22,35,37]. In the modern research into this field, agents are equipped with reasoning capabilities expressed in computational logics [4,15,19,31,33]. These agents often have to interact with each other in order to achieve their goals that are subject to a set of constraints, which can be revised during the dialogue. However, in the most recent approaches of goals modeling (e.g. [1,10,27,28,37]) considering constraints and their dynamics is often neglected.

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The aim of this paper is to take further step toward strategic agent communication using argumentative reasoning. We propose a formal framework for communicating agents that are able to reason about goals using strategic reasoning. These goals, called *strategic goals*, could be achieved by identifying some sub-goals and prospective alternatives. In addition, using a tactic reasoning, agents can select the communicative acts to perform in order to realize the strategic goals considering a set of constraints. This reasoning is based, as for human beings, on psychological and philosophical approaches which are not yet formalized (see for example [5,34]). These approaches suppose that agents use strategic reasoning, which guides their participation in dialogues. Such a reasoning helps agents to create *dialogue strategies*. More precisely, our framework allows agents to generate a set of sub-goals depending on a set of constraints and to find alternatives of these sub-goals if they cannot be achieved. These sub-goals must be justified through argumentation using agents' beliefs and the information made public during the conversation.

The generation of goals and satisfaction of constraints are thus supported by arguments. The motivation behind using argumentation is that this technique has been proven to be efficient when reasoning about incomplete and inconsistent information, which is generally the case in agent communication [6,9,13,32]. Also, argumentation is a kind of non-monotonic reasoning, and when new information arise through conversation, new arguments can be built and some old arguments can become invalid (because attacked by the new arguments and cannot be defended). The idea is to use argumentation in order to give agents the possibility to modify or reject their sub-goals and follow up or revise the strategy they identify. Alternative sub-goals can also be considered using argumentation in order to enable agents to persist in the achievement of their goals, even in the case where some sub-goals are canceled. Although persistence phenomenon is important to ensure the conversation success, such a phenomenon is not addressed by the current communication models (e.g. [1,14,18,26,27,28]). The purpose of this paper is to address this issue.

In this paper, we illustrate our model by an example of negotiating cars between two agents. We suppose that an agent Ag_1 (seller) tries to convince an agent Ag_2 (buyer) to buy a car. In this example, the seller's goal, noted by B, is *the sale of a car*. An example of constraint the seller should consider is: *the price must be higher than* 10.000 *dollars*, and an example of constraint the buyer should satisfy is *the car should not be manufactured in the country* X.

This approach is fundamentally different from hierarchical planning and procedural dynamic and continuous planning approaches such as those proposed in [17,21], which are based on making plans by task decompositions, keeping and incrementally modifying alternative plans during the execution, and switching to an alternative plan when necessary. The main difference is that in our approach the sub-goals are not plans but represent a strategy that agents can follow in order to achieve their goals. This strategy is subject to a set of constraints the agent should satisfy. Also, the mechanism behind generating sub-goals and alternatives and selecting constraints to be satisfied is argumentation-based, which allows agents to reason about the alternatives by considering these constraints. Such an argumentation-based reasoning helps agents to decide about the strategy to be followed and to readapt this strategy when new information arise. This is more flexible than procedural planning-based approaches, and then more suitable for autonomous agents. Our strategic reasoning is close to the *anticipation behavior* [24]. This is similar to *chess game* in which players start by some strategies that determine the first moves to play (generally between 5 and 9 moves), and the upcoming moves are decided by considering the current game situation. Also, although this approach and planning with declarative goals seem to be similar and have many features in common, they are different in the sense that our proposal focuses more on strategy and tactic issues by using argumentation. In our context of agent communication, this is achieved by reasoning on the agent's beliefs and what the addressee made public during the past states of the conversation. In this context, argumentation is a suitable technique as it guides the selection of new sub-goals and new constraints depending on the new available information.

The contributions of this work are:

1. The proposal of a new declarative approach for agent communication allowing agents to reason about the strategies they should follow before and during the conversation. Such a strategic reasoning enables agents to calculate a cognitive representation of the manner of achieving a goal in terms of strategic goals. Also, the approach is argumentation-based, which allows agents to reason about incomplete and inconsistent information and to select *justified* goals and sub-goals.
2. The formalization of the goal persistence and the computing of the initial constraints associated with each goal and the constraints which can be generated during the dialogue. This allows the persistence in achieving the goals by using alternative goals.
3. A complexity analysis of the underlying reasoning.

The idea ultimately is to go beyond the current approaches into agent communication focusing more on protocols [3,14]. Our purpose is to advance research in this field by moving from protocol specifications to strategy and tactic reasoning [8,18].

Paper Overview. This paper is organized as follows. In Section 2, we introduce the fundamental ideas of our argumentation-based agent communication approach. In particular, we define the strategic reasoning used by this approach. In Section 3, we present our formal framework allowing reasoning about goals. We present and discuss the notions of constraints, strategic goals and possible alternatives. We also address the complexity issue of this framework. Before concluding, we compare our approach to some related work in Section 4.

2 Agent Communication Approach

In our agent communication approach, we distinguish between the agent model and the dialogue model (or the conversational model). The agent model is mainly based on the agents' mental states. The conversational model is based on the philosophical concept of social commitment (SC) [7,11,29,38] and argumentation. This model enables agents to support their social commitments or to attack those of the other participants using arguments. These two models are illustrated in Fig.1 and are detailed later.

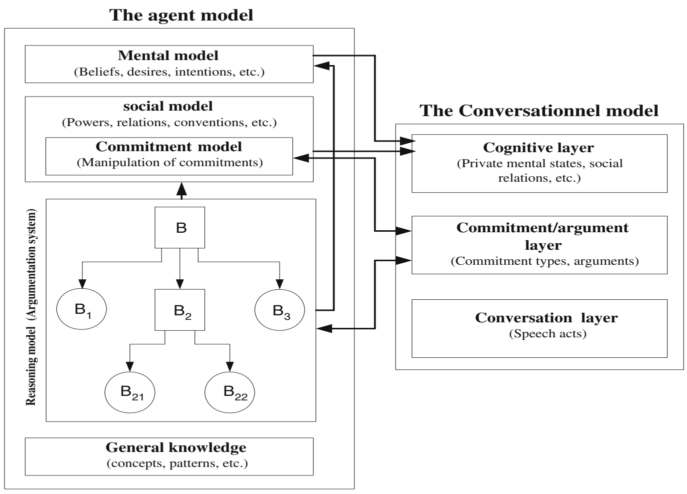

Fig. 1. The links between the agent architecture and communication model

2.1 Agent Model

Based on its mental states and other types of information (coming essentially from the social context and the conversational context), an agent can have a global vision about how to achieve its goals (here we are considering conversation goals, which are goals an agent can achieve by communicating, for example convincing another agent to adopt some opinions). This vision is considered as a strategy. Our work is based on psychological and philosophical approaches which are not yet formalized [5,34]. In philosophy, and according to van Dijk [34], a dialogue strategy is defined as *a global cognitive representation of the manner of achieving some goals*. The strategy concept was also dealt with by Bange [5] who considers that a strategy enables one to associate the intentional element with the cognitive element of the action. In his opinion, *a strategy consists in choosing a certain number of intermediate and subordinate goals whose realization through partial actions may lead in an adequate way to the realization of the final goal*. This notion of intermediate and subordinate goals is similar to the concept of *landmarks* proposed in [30].

Consequently, we define a dialogue strategy as a function associating a goal to a set of sub-goals, which we call *strategic goals*. These sub-goals are selected and arranged in order to achieve the conversation goal. The realization of this goal is thus conditioned by the realization of its strategic sub-goals. Other sub-goals could be determined from the existing goals depending on the current state of conversation. Let us consider our negotiation example introduced in the introduction.

Example 1. The seller agent can choose the strategy of achieving three strategic goals B_1, B_2 and B_3 in order to realize the goal B, which is *selling the car*. These sub-goals can be defined as follows and the method of choosing the strategic goals is detailed in Section 3.

B_1 = *"Know how much the buyer would like to invest in the purchase of a car as well as his preferences".*

B_2 = *"Propose a car which could interest the buyer".*

B_3 = *"Convince the buyer to accept this proposal".*

To achieve the goals B_1 and B_3, the agent strategy consists of trying to achieve the sub-goals B_{11}, B_{12}, B_{31}, and B_{32}. These new sub-goals are defined as follows.

B_{11} = *"Know the model of the car preferred by the buyer".*

B_{12} = *"Know how much the buyer would like to invest".*

B_{31} = *"Convince the buyer that the price of the proposed car is reasonable".*

B_{32} = *"Convince the buyer that the proposed car consumes like small cars on the long distances".*

We represent the set of agent's goals by a tree. The root of the tree represents the main goal (designated by a square), the nodes represent strategic goals (also designated by squares), and the leaves represent elementary goals (designated by circles) which can be reached by performing speech acts. For each defined strategic goal, it might be possible to generate some alternatives. Therefore, an agent might have several strategies to achieve the same goal. In our example, we suppose that the seller is unable to convince the buyer to accept its offer (i.e. the seller is unable to achieve the goal B_3 by using elementary actions) because of a new constraint. In this case, the seller agent can persist in achieving its goal by considering a prospective alternative of the goal B_2. For example, the seller agent may propose another car which could satisfy the new buyer's interest, and this new bid will be an alternative goal for B_2, named B'_2.

Example 2. Moreover, if the seller agent finds during the dialogue progress that the buyer agent is not interested in the fact that the car is economic, then it may suggest an alternative to the strategic goal B_{32}, denoted B'_{32}. For example, the seller will try to convince the buyer that the spare parts for the proposed car are available and not expensive. The strategic goals B'_2 and B'_{32} may be defined as follows.

B'_2 = *"Propose another car which could satisfy a new buyer's interest".*

B'_{32} = *"Convince the buyer that the spare parts of this car are available and not expensive".*

To achieve a same goal, an agent can have several alternative strategies depending on the subset of constraints the agent decide to satisfy. The main goal, sub-goals, and constraints can be expressed in a logical language. The set of constraints may be inconsistent. However, the subset of constraints the agent decide to satisfy should be consistent.

2.2 Dialogue Model

Our communication model is based on the agent architecture suggested in [7]. This model is composed of three layers: mental, social, and reasoning layers. The mental layer includes beliefs, desires, goals, etc. The social layer captures social concepts such as SCs, conventions, roles, etc. Agents use their reasoning capabilities to reason about their mental states and the social concepts. The agent's reasoning capabilities are represented by the reasoning layer using an argumentation system (see Fig.1). Several argumentation theories and frameworks have been proposed in the literature (see for example [9,12,20,25]). However, only few frameworks do consider goals generation and strategic reasoning [2]. An adaptation of these frameworks is needed, particularly in terms of adding sub-goals generation and constraints dynamics. In this paper, we use an argumentation approach based on propositional logic like the one used in [7]. Such an approach allows agents to reason about the internal structure of arguments in terms of premises and conclusion. This approach comprises essentially a logical language, a definition of the argument concept, a definition of the attack relation between arguments, and finally a definition of acceptability [6,13]. In our approach, we distinguish between *internal arguments* and *external arguments*. Internal arguments are used to manage the incoherences of the agent's beliefs. However, external arguments are used to manage the incoherences between the agent's beliefs and the information transmitted by the addressee. Thus, an agent would be able to support the facts on which it is committed and to justify its communicative acts. In this paper, argumentation is used within strategic and tactic reasoning in terms of the generation of sub-goals to be achieved in order to achieve the main goal and in terms of the constraints to be considered.

3 Formal Framework of the Strategic Reasoning and Its Complexity

3.1 Argumentation-Based Strategic Goals

A strategic goal can have one or more alternatives, and the replacement of this strategic goal by one of its alternatives enables agents to achieve the same main goal (the conversation goal), but with different *constraints*. The subset of constraints to be satisfied and the subset of sub-goals to be realized in order to achieve the conversation goal determine the adopted strategy. In our framework, goals and constraints are propositional formulas expresed in some propositional languages. The selection of a set of sub-goals to be achieved must be supported by internal arguments. For this reason, we use the *explanatory argument concept*, inspired by Amgoud and Kaci [1], and we define a new concept: the *realization argument*. A given goal can be supported by these two types of arguments. On one hand, the explanatory arguments justify the choice of the strategic goals in terms of agent's beliefs and the information made public during the conversation. On the other hand, the realization arguments determine the set of strategic goals necessary to achieve a goal. We define in this section an argumentation-driven framework to generate the set of constraints related to a strategic goal. We also define the generation of the strategic goals and their alternatives in order to achieve the conversation goal, while respecting the set of constraints related to this goal. In the rest of the paper, Γ indicates a possibly inconsistent knowledge base (beliefs, goals, ...) with no deductive closure, Δ indicates a possibly inconsistent constraint base with no deductive closure, and $\vdash$ stands for classical inference.

Definition 1 (*Explanatory Argument*). *An explanatory argument of an agent Ag is a pair $(H, G_{Ag}h)$ where $G_{Ag}h$ is an Ag's goal expressed as a formula in a logical language $\mathcal{L}$ and H is a subset of Γ such that: i) H is consistent, and ii) $H \vdash G_{Ag}h$. H is called the support of the argument which justifies the choice of the goal $G_{Ag}h$.*

Definition 2 (*Minimal Explanatory Argument*). *An explanatory argument of an agent Ag $(H, G_{Ag}h)$ is minimal iff H is minimal (i.e. there is no subset of H which satisfies i and ii of Definition 1.*

Definition 3 (*Realization Argument*). *A realization argument of an agent Ag is a triplet $(\Phi_G^{Ag}, G_{Ag}h, C)$ where Φ_G^{Ag} is a finite set of Ag's goals ($\Phi_G^{Ag} \subseteq \Gamma$), $G_{Ag}h$ is an Ag's goal, and $C \subseteq \Delta$ is a finite set of constraints such that: i) all the goals of Φ_G^{Ag} are supported by (minimal) explanatory arguments, ii) $\Phi_G^{Ag} \cup C$ is consistent, and iii) $\Phi_G^{Ag} \cup C \vdash G_{Ag}h$. Φ_G^{Ag} is called the support of the argument (i.e. the set of the strategic goals necessary to the realization of the goal $G_{Ag}h$).*

Definition 4 (*Minimal Realization Argument*). *A realization argument of an agent Ag $(\Phi_G^{Ag}, G_{Ag}h, C)$ is minimal iff $\Phi_G^{Ag} \cup C$ is minimal (i.e. there is no subset of $\Phi_G^{Ag} \cup C$ which satisfies i, ii and iii of Definition 3.*

Definition 5 (*Attack Relation between Explanatory Arguments*). *Let $(H, G_{Ag}h)$ and $(H', G_{Ag'}h')$ be two explanatory arguments of two agents Ag and Ag′ respectively. $(H, G_{Ag}h)$ attacks $(H', G_{Ag'}h')$ iff $H \vdash \neg G_{Ag}h$.*

Definition 6 (*Attack Relation between Realization Arguments*). *Let $(\Phi_G^{Ag}, G_{Ag}h, C)$ and $(\Phi_G'^{Ag'}, G_{Ag'}h', C')$ be two realization arguments of agents Ag and Ag′ respectively. $(\Phi_G^{Ag}, G_{Ag}h, C)$ attacks $(\Phi_G'^{Ag'}, G_{Ag'}h', C')$ iff $\Phi_G^{Ag} \cup C \vdash \neg G_{Ag'}h'$.*

The *acceptability* of these two types of arguments can be defined in the same way as in [13]. Simply put, an argument is *acceptable* w.r.t a set of free-conflict arguments S (i.e. a set of arguments that are not attacking each other) iff if this argument is attacked by another one, there exists an argument in the set S that attacks the attacker. Other acceptability semantics are defined in [13] such as *grounded* and *preferred* semantics, and using them will not change the core of this work.

The set Φ_G^{Ag} represents the sub-goals that Ag can use to achieve the goal $G_{Ag}h$ while satisfying a set of constraints C ($C \subseteq \Delta$). So, the problem is: given an agent goal ($G_{Ag}h$) and a set of constraints C, what are the sub-goals Φ_G^{Ag} to realize in order to achieve this goal. In the following propositions we consider the complexity of this problem. For the concepts of complexity theory, refer to [16,23].

Proposition 1. *Given a subset $H \subseteq \Gamma$ and an Ag's goal $G_{Ag}h$. Deciding whether $(H, G_{Ag}h)$ is a non-necessarily minimal argument is in $P^{\|NP}$ (P with parallel queries to NP).*

Proof. According to Definition 1, $(H, G_{Ag}h)$ is a non-necessarily minimal argument iff H is consistent and $H \vdash h$. Since consistency checking is NP-complete and establishing proof in propositional logic is co-NP-complete, the problem is in Δ_2^P. Because the two conditions are independent, they can be checked in parallel. Consequently the problem is in $P^{\|NP}$. ■

Proposition 2. *Let Γ be a knowledge base and $G_{Ag}h$ a conclusion. Deciding if there is an explanatory argument over Γ $(H, G_{Ag}h)$ is in Σ_2^P.*

Proof. The following algorithm resolves the problem: 1) guess a subset $H \subseteq \Gamma$; 2) check if $(H, G_{Ag}h)$ is an explanatory argument. From Proposition 1, this problem is in Σ_2^P. ■

Proposition 3. *Let $(H, G_{Ag}h)$ be an explanatory argument. Deciding whether $(H, G_{Ag}h)$ is minimal or not is in $P^{\|NP}$.*

Proof. The following algorithm resolves the problem: $\forall$ $subformula$ $x \in H$, check if $H - \{x\}$ is consistent and $H - \{x\} \vdash h$. If H consists of n symbols, then it has no more than n sub-formulae. Thus, from Proposition 1 checking the minimality can be done with a polynomial number of parallel calls to an NP-oracle. It follows that this problem is in $P^{\|NP}$. ■

As a consequence of Proposition 3, the minimality criterion is not an additional source of complexity.

Proposition 4. *Given a finite set of Ag's sub-goals Φ_G^{Ag}, an Ag's goal $G_{Ag}h$, and a finite set of constraints C. Deciding if $(\Phi_G^{Ag}, G_{Ag}h, C)$ is a realization argument is in $P^{\|\Sigma_2^P}$.*

Proof. According to Definition 3, $(\Phi_G^{Ag}, G_{Ag}h, C)$ is a realization argument if All the goals of Φ_G^{Ag} are supported by explanatory arguments. If $|\Phi_G^{Ag}| = n$, then from Proposition 2, n calls to a Σ_2^P-oracle are needed. Because each sub-goal could be checked independently from the others, the n calls could be done in parallel. From Propositions 1, 2, and 3, the other conditions could be checked in $P^{\|NP}$. It follows that the decision problem is in $P^{\|\Sigma_2^P}$. ■

Theorem 1. *Let Γ be a knowledge base, $G_{Ag}h$ a conclusion, and C a set of constraints. Deciding if there is a realization argument over Γ $(\Phi_G^{Ag}, G_{Ag}h, C)$ is in Σ_3^P.*

Proof. The following algorithm resolves the problem: 1) guess a subset $(\Phi_G^{Ag} \subseteq \Gamma$; 2) check if $(\Phi_G^{Ag}, G_{Ag}h, C)$ is a realization argument. From Proposition 4, this problem is in Σ_3^P. ■

By using explanatory and realization arguments, we can define the *strategic goals* and their possible *alternatives* in order to achieve a given goal.

Definition 7 (*Strategic Goal*). *Let Φ_G^{Ag} be a finite set of Ag's goals, C be a finite set of constraints, and $StrG(G_{Ag}h)$ be a set of strategic goals (i.e. sub-goals) necessary to realize a given goal $G_{Ag}h$. $G_{Ag}h'$ is a strategic goal of $G_{Ag}h$ $(G_{Ag}h' \in StrG(G_{Ag}h))$ iff there is an acceptable realization argument $(\Phi_G^{Ag}, G_{Ag}h, C)$ such that: $G_{Ag}h' \in \Phi_G^{Ag}$.*

The fact that Φ_G^{Ag} is minimal makes $G_{Ag}h'$ necessary for the realization of $G_{Ag}h$. However, $G_{Ag}h'$ could be substituted for another sub-goal called alternative goal.

Definition 8 (*Alternative Goal*). *Let Φ_G^{Ag} be a finite set of Ag's goals, C be a finite set of constraints, and $AltG(G_{Ag}h_i/G_{Ag}h)$ be a set of alternative goals of a strategic goal $G_{Ag}h_i$ relative to a given goal $G_{Ag}h$. $G_{Ag}h_j$ is an alternative goal of $G_{Ag}h_i$ $(G_{Ag}h_j \in AltG(G_{Ag}h_i/G_{Ag}h))$ iff:*

1. *$(\Phi_G^{Ag}, G_{Ag}h, C)$ is an acceptable realization argument such that $G_{Ag}h_i \in \Phi_G^{Ag}$.*
2. *$(\Phi_G^{Ag} - \{G_{Ag}h_i\} \cup \{G_{Ag}h_j\}, G_{Ag}h, C)$ is also an acceptable realization argument of $G_{Ag}h$.*

Proposition 5. *Let $G_{Ag}h_j$ be an alternative goal of a strategic goal $G_{Ag}h_i$ relative to a given goal $G_{Ag}h$. $G_{Ag}h_j$ is also a strategic goal of $G_{Ag}h$.*

Proof. According to the second condition of Definition 8, there is realization argument $(\Phi_G^{Ag}, G_{Ag}h, C)$ of $G_{Ag}h$ such that $G_{Ag}h_j \in \Phi_G^{Ag}$. Consequently and according to Definition 7, $G_{Ag}h_j$ is a strategic goal of $G_{Ag}h$. ■

Proposition 6. *Deciding if there are strategic goals to achieve a given goal is in Σ_3^P.*

Proof. This result is a straightforward consequence of Theorem 1. ■

Theorem 2. *Deciding if there is an alternative goal of a given strategic goal is in $P^{\|\Sigma_P^2}$.*

Proof. Let $\Psi_G^{Ag} = \Gamma - \Phi_G^{Ag}$ be the set of Ag's goals not used in the realization argument of the given strategic goal $G_{Ag}h$. The following algorithm decides the problem: For each goal $G_{Ag}h_j \in \Psi_G^{Ag}$, decides if $(\Phi_G^{Ag} - \{G_{Ag}h_i\} \cup \{G_{Ag}h_j\}, G_{Ag}h, C)$ is a realization argument. By Proposition 4, this can be done with a polynomial number of calls to an Σ_2^P-oracle. Because these verifications could be done in parallel, we are done. ■

3.2 Generation and Satisfaction of Goals and Constraints

The argumentation-based strategic reasoning presented above enables agents to generate the strategic goals that ensure the realization of the conversation goal while respecting, in each dialogue step, the set of constraints related to this goal. The idea is that when the dialogue progresses, before adapting a new set of strategic goals, agents should find an acceptable explanatory argument to justify the selection of this set. Thereafter, they should find an acceptable realization argument so that the new constraints associated to the identified strategic goals along with the previous constraints are satisfied. As defined in Definition 3, realization arguments need explanatory arguments. These acceptable arguments should be built from the agent's beliefs and the public information conveyed by the addressee during the previous dialogue steps. Before discussing some formal properties and the argumentative reasoning algorithm for generating and satisfying goals and constraints, let us define the following notions:

Definition 9 (*Elementary Goal*). *A goal ϕ is elementary iff it cannot be decomposed into strategic goals.*

Definition 10 (*Super-Goal*). *Let $(\Phi_G^{Ag}, G_{Ag}h, C)$ be an acceptable realization argument. $G_{Ag}h$ is the super-goal of a strategic goal ϕ iff $\phi \in \Phi_G^{Ag}$.*

We have the following proposition:

Proposition 7. *Let ϕ, C_ϕ, and C be a new strategic goal, the associated constraints, and the previous constraints respectively. The consistency of C_ϕ and C is a sufficient condition, but not a necessary one for the realization of ϕ.*

Proof. Let ϕ' be a goal. According to Definition 7, ϕ is a strategic goal of ϕ' iff there is a realization argument (Φ_G^{Ag}, ϕ', C) such that $\phi \in \Phi_G^{Ag}$. Consequently, and according to Definition 3, ϕ and C are consistent. If ϕ is elementary, it could be realized. Otherwise, strategic goals of ϕ should be found. This means that a new realization argument$(\Phi_G'^{Ag}, \phi, C \cup C_\phi)$ should be built. According to Definition 3, the consistency of $\Phi_G'^{Ag}$ and $C \cup C_\phi$ is only one condition, the second condition is the logical entailment of ϕ. Therefore, the consistency of C and C_ϕ is necessary but not sufficient for the realization of ϕ. ■

As a direct result of this proposition, if the new constraints are not consistent with the previous ones, the identified strategic goal should be dropped, and an alternative should be found. This sheds the light on two possible scenarios when identifying strategic goals depending on the satisfaction of associated constraints. The first scenario is *following up the strategy*, and the second one is *changing the strategy*. The first scenario takes place when all the identified strategic goals can be satisfied, which means that an acceptable realization argument $(\Phi_G^{Ag}, \phi, C \cup C_\phi)$ can be built for each strategic goal ϕ considering previous and new constraints $C \cup C_\phi$. The second scenario takes place when at least one of the strategic goals cannot be realized because the new constraints are not consistent with the previous constraints or because the new constraints cannot be satisfied even if they are consistent with the previous constraints. In this case an alternative should be identified. Our solution is to reconsider the super-goal of the non-realized strategic goal and try to find new strategic goals of this super-goal using the same argumentative reasoning. This means that building a new realization argument of the super-goal considering the new constraints. This process is sketched in Algorithm 1. In this algorithm, the function *SuperGoal*(ϕ) returns the super-goal of a given strategic goal ϕ.

Algorithm 1. Strategic goals identification

Input: The conversation goal $G_{Ag}h$ and the associated constraints C
Initialization: Q: an empty FIFO queue

```
Given G_Ag h and C, compute Φ_G^Ag by building an acceptable realization
  argument (Φ_G^Ag, G_Ag h, C)
∀φ ∈ Φ_G^Ag, put φ in Q
while Q is not empty do
  φ ← First(Q)    % the first element of Q
  Remove φ from Q
  if φ is not elementary, then
    C ← C ∪ C_φ      % C_φ are the constraints associated to φ
    Given φ and C, if ∃(Φ_G^Ag, φ, C) an acceptable realization argument
      then ∀φ ∈ Φ_G^Ag, put φ in Q    % Follow up the strategy
    else    % Change the strategy
      while φ is different from the conversation goal do
        φ ← SuperGoal(φ)
        Remove from Q the sub-goals of φ previously computed
        Given φ and C, if ∃(Φ_G^Ag, φ, C) an acceptable realization argument
        then ∀φ ∈ Φ_G^Ag, put φ in Q
          exit()    % exit second while
      end while
        if φ is equal to the conversation goal then return false
end while
return true
```

We have the following two theorems about the termination, soundness and completeness of Algorithm 1:

Theorem 3. *Algorithm 1 terminates either by identifying the elementary strategic goals for the realization of the conversation goal or by identifying the case where this goal cannot be realized.*

Proof. Algorithm 1 includes two embedded whiles. The second while always terminates since its condition becomes true when *SuperGoal* function returns the conversation goal. This is always possible because the number of strategic goals is finite. In this case there is at least a strategic goal of the conversation goal that can not be realized. The algorithm terminates by returning false. If the termination of this second while is forced by exit(), the first while always terminates since the number of strategic goals is finite and each time a strategic goal is dealt with, this goal is get removed from the queue. In this case, the algorithm successfully terminates by identifying the elementary strategic goals. ■

Theorem 4. *The conversation goal $G_{Ag}h$ can be realized iff Algorithm 1 terminates by identifying a set of elementary strategic goals for the realization of $G_{Ag}h$.*

Proof. On one hand, let us suppose that Algorithm 1 terminates by identifying a set of elementary strategic goals. Therefore, the algorithm terminates when the queue is empty. This means that all the strategic goals are supported by acceptable realization arguments. Because the constraints related to the new strategic goals are considered, building these acceptable realization arguments means that the whole constraints are satisfied. Therefore, the conversation goal can be realized by realizing the identified elementary goals.

On the other hand, let us suppose that the conversation goal $G_{Ag}h$ which is the input of Algorithm 1 can be realized. Therefore, it can be composed into a set of elementary strategic goals that can be realized. However, this set is not necessarily unique. Algorithm 1 will identify a possible set since many alternatives are tried until this set is identified. This is possible thanks to the backtracking processed in the second while using the *SuperGoal* function. Algorithm 1 will then terminate when elementary strategic goals are identified. ■

As indicated in Section 2, the set of the agent's goals are represented by a tree in which the root represents the conversation goal, the nodes represent decomposable strategic goals, and the leaves represent *elementary* strategic goals (i.e. strategic goals that cannot be decomposed). This tree is built progressively while the dialogue progresses. To simplify the notation, an agent's conversation goal will be denoted by B and its strategic goals will be denoted by B_{ij}. The principal idea of the goals decomposition is that for each conversation or strategic goal we have:

1. If the goal is elementary, then the agent tries to satisfy it by using a tactical reasoning. This reasoning enables agents to choose the most relevant communicative act in order to achieve this goal. More details about this type of reasoning can be found in [8].
2. If the goal is decomposable, then the agent must calculate, using the argumentative process described above, the sub-goals to achieve in order to realize the initial goal. For each sub-goal, the agent can have several alternatives. The achievement of these alternatives can provide the same result as that provided by the initial sub-goals. An alternative is identified when the associated realization argument is built. However, if many alternatives are possible, deciding which one is the best is out of the paper scope. Here, an alternative is adopted once it is identified. The set of the strategic goals which can be used to achieve the same goal are connected by a concave arc, as indicated in Fig.2. In this figure, the goal B may be decomposed into two goals B_{11} and B_{21}. For the goal B_{11}, we can have several alternatives $(B_{12}, \ldots, B_{1n})$ and realizing B requires the achievement of B_{11} or one

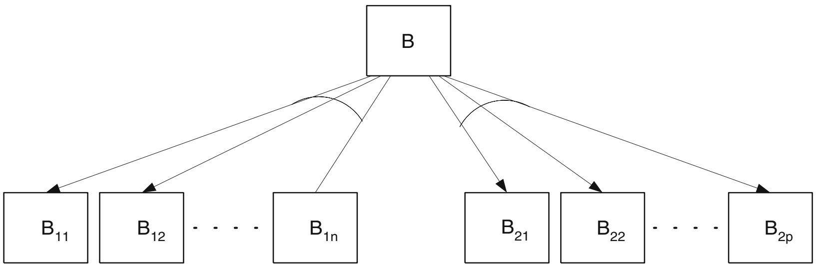

Fig. 2. Example of decomposition of a conversation or strategic goal

of its alternatives (there is thus a disjunction). In the same way, the realization of B requires achieving B_{21} or one of its alternatives: $B_{22}, \ldots, B_{2p}$. The realization of B requires then the achievement of a goal from the set $\{B_{11}, B_{12}, \ldots, B_{1n}\}$ and a goal from the set $\{B_{21}, B_{22}, \ldots, B_{2p}\}$ (there is thus a conjunction).

In a general way, the definition of the set of constraints related to a set of strategic goals is defined as follows:

Definition 11 (*Constraint Definition*). *Let B be a conversation or strategic goal and $\mathcal{E}$ be a function associating elementary goals to a set of constraints. The constraints associated with the set of the strategic goals ($StrG(B)$) of the goal B is given by the function $\mathcal{C}$ which is defined in Table 1.*

In Definition 11, the function $\mathcal{C}$ takes as argument a set of goals (or a set of graphs) and gives us a set of subsets of constraints representing the set of possible scenarios (i.e. each subset represents a scenario). In the practice, this function is implemented using the argumentation machinery explained above. α and β are two sets of constraints. $B(1)$ represents the set composed by the strategic goal B_1 of the goal B and its possible alternatives. $\overline{B(1)}$ represents the remaining goals in the tree representing the goal B. In a general way, $B(i)$ represents the set including the i^{th} strategic goal of the goal B and its possible alternatives and $\overline{B(i)}$ represents the remaining goals of the tree representing the goal B. For example, in Fig.2 we have: $B(1) = \{B_{11}, B_{12}, \ldots, B_{1n}\}$ and $\overline{B(1)} = \{B_{21}, B_{22}, \ldots, B_{2p}\}$. Furthermore, we consider that the constraints related to an elementary goal are generated from the speech act performed to achieve this goal. For example, for

Table 1. Constraint Generation Function

$\mathcal{C}(\emptyset)$	$= \{\emptyset\}$
$\mathcal{C}(\{B\})$	$= \mathcal{E}(B)$ if B is elementary
$\mathcal{C}(\{B_i\})$	$= \bigcup_{\alpha \in \mathcal{C}(\{B(i)\})} \bigcup_{\beta \in \mathcal{C}(\{\overline{B(i)}\})} \{\alpha \cup \beta\}$ if B is not elementary
$\mathcal{C}(\{B_1, B_2, \ldots, B_n\})$	$= \mathcal{C}(\{B_1\}) \cup \mathcal{C}(\{B_2\}) \cup \ldots \cup \mathcal{C}(\{B_n\})$

the speech act: "*I sell you my watch for 5 dollars*", the function $\mathcal{E}$ gives us the set which contains the constraint: "*the price is equal to 5 dollars*". We have the following proposition and its proof is straightforward.

Proposition 8 (*Constraints Satisfaction*). *Let B be a conversation goal and $Ctr(B)$ be the set of its initial constraints. The set of constraints $Ctr(B)$ is satisfied if there is a set $C_i \in \mathcal{C}(\{B\})$ such that: $Ctr(B) \cup C_i$ is consistent.*

As a result of this proposition, a conversation goal B cannot be achieved if there is no set of constraints in the set $\mathcal{C}(\{B\})$ which is consistent with the set $Ctr(B)$ (set of constraints associated with the agent's conversation goal). In other words, an agent that is able to satisfy the constraints which appear during the dialogue would be able to achieve its conversation goal. The reason is that this agent will be able to build an acceptable realization argument supporting the strategic goals of the conversation goal by considering the new constraints.

4 Discussion and Related Work

The framework proposed in this paper has many advantages. First, it provides a technique for reasoning about communication strategies. Also, it enables agents to reason about strategic goals and the dynamics of the associated constraints. In fact, unlike existing frameworks [1,10,27,28,37]), our proposal allows agents to adjust their strategies by considering the new constraints and identifying possible alternatives using argumentation reasoning. In our negotiation example (Examples 1 and 2), the existing frameworks do not guarantee the realization of the conversation goal B (selling the car), if the goal B_{32} (convincing the buyer by the fact that the car is economic), cannot be achieved. In our approach, the goal B can still be achieved by reconsidering the decomposition of the goal B when new constraints appear. For instance, let us assume that during the dialogue the seller learns that the buyer does not need an economic car (for example because he is currently working close to home). In this case, the seller is unable to convince the buyer by achieving the goal B_{32}, that the proposed car is economic. Thereafter, the seller will give up the goal B_{32} and will try to persist in the realization of his conversation goal which is selling the proposed car by using the alternative goal B'_{32}. This goal aims at trying to convince the buyer that the spare parts for the proposed car are available and not expensive.

Formalizing goals has attracted a special attention in the last decade within multi-agent systems. Winikoff et al. [37] discuss the two aspects of goals: declarative (a description of the state sought), and procedural (a set of plans for achieving the goal). A framework integrating these two aspects is proposed. Nigam and Leite [22] use dynamic logic programming to represent the agent's goals and their evolution. van Riemsdijk et al. [35,36] investigate the dynamics of declarative goals in agent programming. In these proposals internal and external motivations such as norms, obligations, and impositions about adopting and dropping goals are considered. Our work is inline with these proposals by considering declarative goals, but the context, motivations and underlying techniques are different. Also, some interesting frameworks in the context of agent communication have been proposed by Amgoud and Kaci [1], Shapiro and Brewka [27], Shapiro et al. [28], Sardina et al. [26], and Caelen [10].

The approach proposed by Amgoud and Kaci [1] considers the realization of a goal as the realization of a plan which is composed of a set of sub-goals, called conditions. In this approach, an initial goal is subject to some conditions (in terms of agent's beliefs) so that it is adopted or followed by the agent. Consequently, this approach is interested in the generation of the initial goals (followed by the agent) and of the conditional goals which compose the plans of the initial goals. In fact, this approach considers the conditional goals as constraints to be satisfied in order to achieve an initial goal. However, it is different from ours in which we distinguish between the agents' constraints and the goals. The agent's goals reflect its objectives, whereas the constraints reflect the limits encountered to realize these objectives. Another fundamental difference is that our approach considers strategic reasoning and strategic goals which are different from conversation goals. Indeed, a strategic goal may be achieved, substituted for one of its alternatives, or rejected if the strategy is being changed, (i.e. if one of its constraints is not satisfied). In contrast, a conversation goal can only be realized or failed. To achieve a conversation goal, the agent must have a strategic reasoning which enables it to follow strategic sub-goals. The realization of a conversation or strategic goal is conditioned mainly by the capability of the agent to convince its addressee by using an argumentative process. More precisely, in our approach we are interested in realizing a conversation goal in terms of the performance of its strategic sub-goals by respecting the constraints (imposed beforehand on the agent or generated by the agent for each goal according to its beliefs).

In the approach proposed by Shapiro and his colleagues [28], an agent adopts a goal with reference to a request on behalf of another agent. An agent maintains its goal as long as it did not receive a request for cancellation of this goal. Furthermore, in [27], if an agent believes a goal is impossible to achieve, it is dropped. However, if the agent later believes that it was mistaken about the impossibility of achieving the goal, the agent might readopt the goal. Contrary to this approach, we do not consider in this paper the problem of goal change, but rather we deal with the problem of achieving conversation goals in terms of sub-goals and constraints that should be satisfied. In other words, our approach does not address goal change, but it tackles the realization of conversation goals in terms of strategic sequences of actions and constraints. Readopting goals is a form of persistence which is completely different from ours in which we consider other strategies to achieve the same goal.

Goals and dialogue strategy concepts were also dealt with by Caelen [10]. He presents an approach for the logical modeling of dialogues in which each interlocutor looks for achieving his goal by using the best possible strategies. The author models a kind of interaction between the goals of each agent and the dialogue strategy without considering agent reasoning. However, in our approach we model strategic reasoning for each agent implied in the conversation using argumentation. This reasoning, which is non-monotonic, takes into account the nature of dialogue which is a dynamic and a joint activity.

Finally, Sardina and his colleagues [26] propose an approach for the formalization of goals based on the planning which is static in nature. However, dialogue is purely a dynamic activity. Therefore, dialogues cannot be modelled by plans to follow. Our proposal is different because it is based upon argumentation-driven reasoning about strategic goals and constraints. Sub-goals are generated and substituted for alternatives dynamically while the dialogue progresses. The strategy can also be adjusted when other information becomes available.

5 Conclusion

In this paper, we proposed an argumentation-driven approach for interacting agents in a multi-agent setting allowing them to reason about goals. This formalism is based on a strategic reasoning which provides a mechanism to calculate a cognitive representation of the manner of achieving a conversation goal in terms of strategic goals. Agents' strategic goals are supported by two types of arguments: explanatory arguments to justify the choice of the goals and realization arguments which provide the set of sub-goals necessary to achieve these goals given a set of constraints. The formalism also allows agents to persist in achieving their conversation goals by using alternative goals.

As future work, we plan to address the relevance issue within strategic reasoning. Since an agent can have several dialogue strategies for the same conversation goal, we are interested in proposing a method enabling agents to select the most relevant and efficient strategy.

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