

Debating over heterogeneous descriptions

Maxime Morge^a, Jean-Christophe Routier^b

^a *Dipartimento di Informatica - University of Pisa, Largo B. Pontecorvo, 3 I-56127 Pisa, Italy*

E-mail: morge@di.unipi.it

^b *Laboratoire d'Informatique Fondamentale de Lille, F-59655 VILLENEUVE D'ASCQ Cedex FRANCE*

E-mail: routier@lifl.fr

Abstract. A fundamental interoperability problem is caused by the semantic heterogeneity of agents' ontologies in open multi-agent systems. In this paper, we propose a formal framework for agents debating over heterogeneous terminologies. For this purpose, we propose an argumentation-based representation framework to manage conflicting description. Moreover, we propose a model for the reasoning of agents where they justify the description to which they commit and take into account the description of their interlocutors. Finally, we provide a dialectical system allowing agents to participate in a dialogue in order to reach an agreement over heterogeneous descriptions.

Keywords: Artificial Intelligence, Multiagent systems, Dialogue, Argumentation, Ontology, Description logic

1. Introduction

Traditionally, ontologies have been used to achieve semantic interoperability between applications, such as software agents, by providing the definitions of the vocabularies they use to describe the world. In open systems that agents can dynamically join or leave, a fundamental interoperability problem is caused by the semantic heterogeneity of agents at the knowledge level, in particular the discrepancy of the underlying ontologies due to the terminological heterogeneity. The current approaches such as standardization, adopted by Gruber (1995), and ontology alignment, considered by Euzenat & Valtchev (2004), are not suitable in open systems. Since standardization requires that all parties involved reach a consensus on the ontology, the idea of a *great unified world ontology* seems very unlikely. On the other hand, ontology alignment is a technique that enables agents to keep their own individual ontologies by making use of mappings. Alignments are generated by independent trustable alignment services that can be invoked to obtain a mapping between two ontologies and used to translate messages. However, we do not know *a priori* which ontologies should be mapped within an open multi-agent system. As observed by Bailin & Truszkowski (2004), conflicts of representation should not be avoided but resolved.

Argumentation is a promising approach for (1) reasoning with inconsistent information, (2) facilitating rational interaction, and (3) resolving conflicts. In this paper, we aim at using argumentative techniques in order to provide a dialogical mechanism for the agents to reach an agreement on their representations. Agents have their own definitions of concepts and they discover through the dialogue whether or not they share these definitions. If not, they are able to learn the definition of their interlocutor. A valued based mechanism is used to integrate the different and possibly divergent definitions and to resolve the conflict. The debate can finish with an agreement or not in case of misunderstanding on a concept. For this purpose, we extend the formal framework for inter-agents dialogue based upon the argumentative techniques proposed by Morge (2005). (1) We propose here an argumentation-based representation framework, offering a way to manage contradictory concept definitions and assertions. (2) We propose a model of agent reasoning to put forward some representations and take into account the representations of their interlocutors. (3) Finally, we provide a dialectical system in which a protocol enables two agents to reach an agreement about their representations.

Paper overview. Section 2 introduces the example of dialogue that will illustrate our framework. In Section 3, we provide the syntax and the semantics of the description logic which is adopted in this paper. Section 4 presents the argumentation framework that manages interaction between conflicting representa-

tions. In accordance with this background, Section 5 describes our agent model. In Section 6, we define the formal area for agents debate. Section 7 describes the protocol used to reach an agreement. Section 8 presents some related works. Section 9 draws some conclusions and future works.

2. Natural language

Walton & Krabbe (1995) defines a dialogue as a coherent sequence of moves from an initial situation to reach the goal of participants. For instance, the goal of a dialogue may consist in resolving a conflict about a representation. In the initial situation, two participants do not share the same description of a service, either because one of the participants ignores such a service, or because their own descriptions are contradictory. The participants hope to reach an agreement about the description of this service at the end of the dialogue. Inspired by the misunderstanding problem in the natural language, we only consider here dialogue between artificial agents.

Before we start to formalize such dialogues, let us first discuss the following natural language dialogue example between a customer and a service provider:

1. customer: Do you know free software to view my PDF ?
2. provider: acrobat is free software.
3. customer: Why is it a free software ?
4. provider: acrobat is free because it is a freeware.
5. customer: In my humble opinion, acrobat is not a free software.
6. provider: Why is it not free software ?
7. customer: Since acrobat is freeware, it is not free software.
8. provider: OK, however xpdf is free software.
9. customer: Why is it free software ?
10. provider: xpdf is free software because it is opensource.
11. customer: Why is it opensource ?
12. provider: xpdf is opensource because it is copyleft.
13. customer: OK, I will consider xpdf.

In this dialogue, two participants share the concept “free”. However, their definitions are divergent. On one side, the customer considers free software as non-proprietary software. On the other side, the service provider considers free software as a zero price software. This dialogue reveals the conflict in the definitions of this concept and resolves it. Participants argue and challenge the interlocutor’s arguments. In utterance 7, the customer explains to the provider why she is not considering acrobat as a free software, although it was proposed by provider in utterance 2. The service provider considers that the definition of the customer has priority and adjusts her own representation to adopt this definition. Hence, in utterance 8, the provider asserts another solution according to her knowledge. Then the customer challenges this and asks for justification (utterance 9) and the following of the dialogue shows how the provider proposes her definition of free as opensource which is accepted by the customer. Throughout the following we will assume the service provider gives priority to the customer’s concepts.

3. Description Logic

In this section, we provide the syntax and the semantics for the well-known *ALC* language proposed by Schmidt (1991) and which is adopted in the rest of the paper.

The data model of a knowledge base (KBase, for short) can be expressed by means of the Description Logic (DL, for short) which has a precise semantic and effective inference mechanisms. Moreover, most ontologies markup languages (e.g. OWL) are partly founded on DL, although it can be assumed that annotations and conceptual models are expressed using XML-based languages. The syntax of the represen-

tation adopted here is taken from standard constructors proposed in the DL literature. This representation language is sufficiently expressive to support most of the principal constructors of any ontology markup language.

In \mathcal{ALC} , concepts, denoted C, D, \dots are interpreted as unary predicates and primitive roles, denoted R, S, \dots , as binary predicates. We call description a complex concept which can be built using constructors. The syntax of \mathcal{ALC} is defined by the following BNF definition: $C \rightarrow \top | \perp | C | \neg C | C \sqcup D | C \sqcap D | \exists R.C | \forall R.C$.

The semantics is defined by an interpretation $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$, where $\Delta^{\mathcal{I}}$ is the non-empty domain of the interpretation and $\cdot^{\mathcal{I}}$ stands for the interpretation function. The semantics of the constructors are summarized in the table 1.

Table 1
Semantics of the \mathcal{ALC} constructors

Name	Syntax	Semantics
top concept	\top	$\Delta^{\mathcal{I}}$
bottom concept	\perp	\emptyset
concept	C	$C^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$
concept negation	$\neg C$	$\Delta^{\mathcal{I}} - C^{\mathcal{I}}$
concept conjunction	$C_1 \sqcap C_2$	$C_1^{\mathcal{I}} \cap C_2^{\mathcal{I}}$
concept disjunction	$C_1 \sqcup C_2$	$C_1^{\mathcal{I}} \cup C_2^{\mathcal{I}}$
existential restriction	$\exists R.C$	$\{x \in \Delta^{\mathcal{I}}; \exists y \in \Delta^{\mathcal{I}}((x, y) \in R^{\mathcal{I}} \wedge y \in C^{\mathcal{I}})\}$
universal restriction	$\forall R.C$	$\{x \in \Delta^{\mathcal{I}}; \forall y \in \Delta^{\mathcal{I}}((x, y) \in R^{\mathcal{I}} \rightarrow y \in C^{\mathcal{I}})\}$

A KBase $\mathcal{K} = \langle \mathcal{T}, \mathcal{A} \rangle$ contains a T-box \mathcal{T} and an A-box \mathcal{A} . The T-box includes a set of concept definition ($C \equiv D$) where C is the concept name and D is a description given in terms of the language constructors. The A-box contains extensional assertions on concepts and roles. For example, a (resp. (a, b)) is an instance of the concept C (resp. the role R) iff $a^{\mathcal{I}} \in C^{\mathcal{I}}$ (resp. $(a^{\mathcal{I}}, b^{\mathcal{I}}) \in R^{\mathcal{I}}$). We call *claims*, the set of concept definitions and assertions contained in the KBase. A notion of subsumption between concepts is given in terms of the interpretations.

Definition 1 (Subsumption) Let C, D be two concepts. C *subsumes* D (denoted $C \sqsupseteq D$) iff for every interpretation \mathcal{I} it holds that $C^{\mathcal{I}} \supseteq D^{\mathcal{I}}$.

Indeed, $C \equiv D$ amounts to $C \sqsupseteq D$ and $D \sqsupseteq C$. Similarly, $C \sqcap D \equiv \perp$ amounts to $C \equiv \neg D$ and $D \equiv \neg C$. The KBase can contain partial definitions, *i.e.* axioms based on subsumption ($C \sqsupseteq D$). Below we will use \mathcal{ALC} in our argumentation-based representation framework.

4. Argumentation-based representation framework

The seminal work of Dung (1995) formalizes the argumentation reasoning within a framework made of abstract arguments and a contradiction relation to determine their acceptance. Traditionally, the extensions of this framework are built upon a background logic language. Therefore, arguments are not abstract entities but consequence relations between a premise and a conclusion. Recent works such as Amgoud & Cayrol (2002) (or Bench-Capon (2002)) assign one (or different) strength(s) to the arguments. We present in this section, an argumentation framework built around the underlying logic language \mathcal{ALC} , where claims (concept definitions and assertions) can be conflicting and have different relevances depending on the considered audience.

The KBase is a set of sentences in a common language, denoted \mathcal{ALC} , associated with a classical inference, denoted \vdash , and shared by a set of audiences (denoted $\cup_A = \{a_1, \dots, a_n\}$).

The audiences share a value-based KBase, *i.e.* a set of claims promoting values:

Definition 2 Let $\mathcal{U}_A = \{a_1, \dots, a_n\}$ be a set of audiences. The value-based KBase $AK = \langle \mathcal{K}, V, \text{promote} \rangle$ is defined by a triple where:

- $\mathcal{K} = \langle \mathcal{T}, \mathcal{A} \rangle$ is a KBase, i.e. a finite set of claims in \mathcal{ALC} ;
- V is a non-empty finite set of values $\{v_1, \dots, v_t\}$;
- $\text{promote} : \mathcal{K} \rightarrow V$ is a total mapping from the claims to values.

We say that the claim ϕ relates to the value v if ϕ promotes v . For every $\phi \in \mathcal{K}$, $\text{promote}(\phi) \in V$.

According to Perelman & Olbrechts-Tyteca (1958), both concrete and abstract values constitute starting points to distinguish different audiences. Values are arranged in hierarchies. For example, an audience will value both justice and utility, but an argument may require the determination of a strict preference between the two. The relevance of an argument is the value promoted by the most general claims in its premise. Since audiences are distinguished by their hierarchies of values, the values have different priorities for different audiences. Each audience a_i is associated with an *individual value-based KBase* which is a 4-tuple $AK_i = \langle \mathcal{K}, V, \text{promote}, \ll_i \rangle$ where:

- $AK = \langle \mathcal{K}, V, \text{promote} \rangle$ is a value-based KBase as previously defined;
- \ll_i is the priority relation of the audience a_i , i.e. a strict complete ordering relation on V .

A priority relation is a transitive, irreflexive, asymmetric, and complete relation on V . It stratifies the KBase into finite non-overlapping sets. The priority level of a non-empty KBase $K \subseteq \mathcal{K}$ (written $\text{level}_i(K)$) is the most important value promoted by one element in K . On one hand, a priority relation captures the value hierarchy of a particular audience. On the other hand, the KBase contains claims shared by audiences. Arguments, that are consequence relations between a premise and a conclusion, are built on this common KBase.

Definition 3 Let K be a KBase in \mathcal{ALC} . An *argument* is a pair $A = \langle \Phi, \phi \rangle$, where ϕ is a claim and $\Phi \subseteq K$ is a non-empty set of claims such that: Φ is consistent and minimal (for set inclusion), and $\Phi \vdash \phi$. Φ is the premise of A , written $\Phi = \text{premise}(A)$, and ϕ is the conclusion of A , written $\phi = \text{conc}(A)$.

In other words, the premise is a set of claims from which the conclusion can be inferred. A' is a *sub-argument* of A if the premise of A' is included in the premise of A . A' is a *trivial argument* if the premise of A' is a singleton ($\text{premise}(A') = \{\text{conc}(A')\}$). Since the KBase \mathcal{K} can be inconsistent, the set of arguments (denoted $\mathcal{A}(\mathcal{K})$) may contain conflicting arguments.

Definition 4 Let K be a KBase in \mathcal{ALC} and $A = \langle \Phi, \phi \rangle, B = \langle \Psi, \psi \rangle \in \mathcal{A}(K)$ two arguments. A attacks B iff: $\exists \Phi_1 \subseteq \Phi, \Psi_2 \subseteq \Psi$ such that $\exists \chi \in \mathcal{L} \Phi_1 \vdash \chi$ and $\Psi_2 \vdash \neg \chi$.

Because each audience is associated with a particular priority relation, audiences individually evaluate the relevance of arguments.

Definition 5 Let $AK_i = \langle \mathcal{K}, V, \text{promote}, \ll_i \rangle$ be the value-based argumentation KBase of the audience a_i and let $A = \langle \Phi, \phi \rangle \in \mathcal{A}(\mathcal{K})$ be an argument. According to AK_i , the relevance of A (written $\text{relevance}_i(A)$) is the most important value promoted by one claim in the premise Φ .

In other words, the relevance of arguments depends on the priority relation. A fixed ordering is simply assumed, revealing the ordering between claims. In order to give a criterion that will allow an audience to prefer one argument over another, different principles can be considered: the last link principle, as proposed by Simari & Loui Benferhat et al. (1992), the specificity principle, as proposed by Prakken et al. (1997), or the weakest link principle, as proposed by Benferhat et al. (1995). However, these general domain-independent principles of commonsense reasoning are very weak. In the context of ontological arguments, we prefer the arguments built upon the most general claims.

Since audiences individually evaluate arguments' relevance, an audience can ignore that an argument attacks another. According to an audience, an argument defeats another argument if they attack each other and the second argument is not more relevant than the first one:

Fig. 1. The value-based KBase of the first audience

\ll_1	V_1	\mathcal{K}_1
	v_1	$\phi_1(x) : \text{Soft}(x) \sqsupseteq \text{Free}(x) \sqcup \text{Nonfree}(x)$
	v_2	$\phi_2(x) : \text{Nonfree}(x) \sqsupseteq \text{Freeware}(x)$
	v_3	$\phi_3(x) : \text{Free}(x) \sqsupseteq \text{Freeware}(x)$
	v_4	$\phi_4(x) : \text{Free}(x) \sqcap \text{Nonfree}(x) \equiv \perp$
	v_5	$\phi_5(x) : \text{Free}(x) \sqsupseteq \text{Opensource}(x)$
	v_6	$\phi_{61}(x) : \text{Opensource}(x) \sqsupseteq \text{Copyleft}(x)$
	v_7	$\phi_{71} : \text{Freeware}(\text{acrobat})$ $\phi_{72} : \text{Copyleft}(\text{xpdf})$

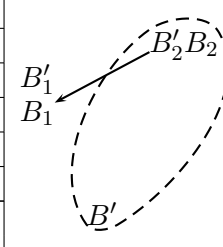
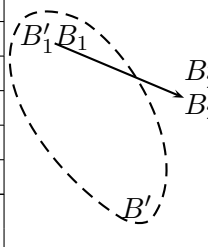


Fig. 2. The value-based KBase of the second audience

\ll_2	V_2	\mathcal{K}_2
	v_1	$\phi_1(x) : \text{Soft}(x) \sqsupseteq \text{Free}(x) \sqcup \text{Nonfree}(x)$
	v_3	$\phi_3(x) : \text{Free}(x) \sqsupseteq \text{Freeware}(x)$
	v_2	$\phi_2(x) : \text{Nonfree}(x) \sqsupseteq \text{Freeware}(x)$
	v_4	$\phi_4(x) : \text{Free}(x) \sqcap \text{Nonfree}(x) \equiv \perp$
	v_5	$\phi_5(x) : \text{Free}(x) \sqsupseteq \text{Opensource}(x)$
	v_6	$\phi_{61}(x) : \text{Opensource}(x) \sqsupseteq \text{Copyleft}(x)$
	v_7	$\phi_{71} : \text{Freeware}(\text{acrobat})$ $\phi_{72} : \text{Copyleft}(\text{xpdf})$



Definition 6 Let $AK_i = \langle \mathcal{K}, V, \text{promote}, \ll_i \rangle$ be the value-based argumentation KBase of the audience a_i and $A = \langle \Phi, \phi \rangle, B = \langle \Psi, \psi \rangle \in \mathcal{A}(\mathcal{K})$ two arguments. A defeats B for the audience a_i (written $\text{defeats}_i(A, B)$) iff $\forall \Phi_1 \subseteq \Phi, \Psi_2 \subseteq \Psi, (\exists \chi \in \mathcal{L}, \Phi_1 \vdash \chi \text{ and } \Psi_2 \vdash \neg \chi) \Rightarrow \neg(\text{level}_i(\Phi_1) \ll_i \text{level}_i(\Psi_2))$.

Similarly, we say that a set S of arguments defeats B if B is defeated by one argument in S .

By definition, two equally relevant arguments both defeat each other.

Considering each audience own viewpoint, we define the subjective acceptance notion:

Definition 7 Let $AK_i = \langle \mathcal{K}, V, \text{promote}, \ll_i \rangle$ be the value-based KBase of the audience a_i . Let $A \in \mathcal{A}(\mathcal{K})$ be an argument and $S \subseteq \mathcal{A}(\mathcal{K})$ a set of arguments. A is subjectively acceptable by the audience a_i with respect to S iff $\forall B \in \mathcal{A}(\mathcal{K}) \text{ defeats}_i(B, A) \Rightarrow \text{defeats}_i(S, B)$.

The following example illustrates our argumentation-based representation framework.

Example 1 Let us consider the case presented in Section 2. The value-based KBase of two different audiences a_1 and a_2 are represented in the figure 1 and in the figure 2. The different claims $\phi_1(x), \dots, \phi_{72}$ in a KBase relate to the different values v_1, \dots, v_7 . On one side, the claims $\phi_1(x), \dots, \phi_{61}(x)$ are in the T-box. On the other side, ϕ_{71} and ϕ_{72} are in the A-box. The more general the claim is, the higher the promoted value is. According to an audience, a value above another one in a table has priority over it.

In order to decide if *xpdf* is free software, the three following arguments must be considered:

- $A'' = \langle [\text{Copyleft}(\text{xpdf})], \text{Copyleft}(\text{xpdf}) \rangle$;
- $A' = \langle [\text{Copyleft}(\text{xpdf}), \text{Opensource}(x) \sqsupseteq \text{Copyleft}(x)], \text{Opensource}(\text{xpdf}) \rangle$;
- $A = \langle [\text{Copyleft}(\text{xpdf}), \text{Opensource}(x) \sqsupseteq \text{Copyleft}(x), \text{Free}(x) \sqsupseteq \text{Opensource}(x)], \text{Free}(\text{xpdf}) \rangle$.

The trivial argument A'' is a sub-argument of A' , which is a sub-argument of A . In order to decide if *acrobat* is a free software, The five following arguments must be considered:

- $B' = \langle [\text{Freeware}(\text{acrobat})], \text{Freeware}(\text{acrobat}) \rangle$;
- $B'_1 = \langle [\text{Freeware}(\text{acrobat}), \text{Free}(x) \sqsupseteq \text{Freeware}(x)], \text{Free}(\text{acrobat}) \rangle$;

- $B'_2 = \langle [Freeware(acrobat), Nonfree(x) \sqsupseteq Freeware(x)], Nonfree(acrobat) \rangle;$
- $B_1 = \langle [Freeware(acrobat), Free(x) \sqsupseteq Freeware(x), Free(x) \sqcap Nonfree(x) \equiv \perp], \neg Nonfree(acrobat) \rangle;$
- $B_2 = \langle [Freeware(acrobat), Nonfree(x) \sqsupseteq Freeware(x), Free(x) \sqcap Nonfree(x) \equiv \perp], \neg Free(acrobat) \rangle.$

B' is a sub-argument of B'_1 (resp. B'_2) which is a sub-argument of B_1 (resp. B_2). B_1 and B'_2 (resp. B'_1 and B_2) attack each other. The relevance of B_1 and B'_1 is v_3 . The relevance of B_2 and B'_2 is v_2 .

According to the first audience, B'_2 (resp. B_2) defeats B_1 (resp. B'_1) but B_1 (resp. B'_1) does not defeat B'_2 (resp. B_2). Therefore, the set $\{A'', A', A, B', B'_2, B_2\}$ is subjectively acceptable wrt $\mathcal{A}(\mathcal{K})$.

According to the second audience, B_1 (resp. B'_1) defeats B'_2 (resp. B_2) but B'_2 (resp. B_2) does not defeat B_1 (resp. B'_1). Therefore, the set $\{A'', A', A, B, B'_1, B_1\}$ is subjectively acceptable wrt $\mathcal{A}(\mathcal{K})$.

We have defined here the representation framework to manage interactions between conflicting claims. In the next section, we present a model of agents which puts forward claims and takes into account other claims coming from their interlocutors. We shift from the zero-agent notion of acceptability to the one-agent notion of conviction in order to take into account not only representations shared by different audiences but also representations exchanged by agents.

5. Model of agents

In a multi-agent setting it is natural to assume that all the agents do not use exactly the same ontology. Since agents representations can be common, complementary or contradictory, agents have to exchange assumptions and to argue. Our agents individually evaluate the perceived commitments with respect to the estimated reputation of the agents from whom the information is obtained.

As suggested by Fornara & Colombetti (2002), agents, which have their own private representations, record their interlocutors commitments. Moreover, agents individually valueate their interlocutors reputation. Therefore, an agent is defined as follows:

Definition 8 The agent $a_i \in \mathcal{U}_A$ is defined by a 6-tuple $a_i = \langle \mathcal{K}_i, V_i, \ll_i, promote_i, \cup_{j \neq i} CS_j^i, \prec_i \rangle$ where:

- \mathcal{K}_i is a personal KBase, i.e. a set of personal claims in \mathcal{ALC} ;
- V_i is a set of personal values;
- $promote_i : \mathcal{K}_i \rightarrow V_i$ maps from the personal claims to the personal values;
- \ll_i is the priority relation, i.e. a strict complete ordering relation on V_i ;
- CS_j^i is a commitment store, i.e. a set of claims in \mathcal{ALC} . $CS_j^i(t)$ contains propositional commitments taken before or at time t , where agent a_j is the debtor and agent a_i the creditor;
- \prec_i is the reputation relation, i.e. a strict complete ordering relation on \mathcal{U}_A .

The personal KBases are not necessarily disjoint. The commonsense claims are explicitly shared by all the agents. We call *common KBase* the set of commonsense claims explicitly shared by the agents¹: $\mathcal{K}_{\Omega_A} \subseteq \cap_{a_i \in \mathcal{U}_A} \mathcal{K}_i$. Similarly, we call *common values* the values explicitly shared by the agents: $V_{\Omega_A} \subseteq \cap_{a_i \in \mathcal{U}_A} V_i$. The common claims relate to the common values. For every $\phi \in \mathcal{K}_{\Omega_A}$, $promote_{\Omega_A}(\phi) = v \in V_{\Omega_A}$. The personal KBase can be complementary or contradictory. Some claims can be shared without the agents being aware of it. These similarities between agents will be discovered during the dialogue. We call *joint KBase* the set of claims distributed in the system: $\mathcal{K}_{\mathcal{U}_A} = \cup_{a_i \in \mathcal{U}_A} \mathcal{K}_i$. The agent's own claims relate to the agent's own values. For every $\phi \in \mathcal{K}_i - \mathcal{K}_{\Omega_A}$, $promote_i(\phi) = v \in V_i - V_{\Omega_A}$.

We can distinguish two ways for an agent to evaluate her interlocutor's commitments: either in accordance with a global social order as proposed by Amgoud & Parsons (2001), or in accordance with a trust model. Obviously, the latter is more flexible. According to Castelfranchi (1998), reputation is a local perception of the interlocutor, a social concept that links an agent to her interlocutors, and a leveled relation. The different reputation relations, which are transitive, irreflexive, asymmetric, and complete relations on

¹We qualify with Ω_A a value obtained through an intersection over \mathcal{U}_A

\bar{U}_A , preserve these properties. $a_j \prec_i a_k$ denotes that an agent a_i trusts an agent a_k more than another agent a_j . In order to take into account the claims notified in the commitment stores, each agent is associated with the following extended KBase:

Definition 9 *The extended KBase of the agent a_i is the value-based KBase*

$AK_i^* = \langle \mathcal{K}_i^*, V_i^*, promote_i^*, \ll_i^* \rangle$ where:

- $\mathcal{K}_i^* = \mathcal{K}_i \cup [\bigcup_{j \neq i} CS_j^i]$ is the agent extended personal KBase composed of its personal KBase and the set of perceived commitments;
- $V_i^* = V_i \cup [\bigcup_{j \neq i} \{v_j^i\}]$ is the agent extended set of personal values composed of the set of personal values and the reputation values associated with her interlocutors;
- $promote_i^* : \mathcal{K}_i^* \rightarrow V_i^*$ is the extension of the function $promote_i$, mapping claims in the extended personal KBase to the extended set of personal values. On the one hand, personal claims relate to personal values. On the other hand, claims in the commitment store CS_j^i relate to the reputation value v_j^i ;
- \ll_i^* is the agent extended priority relation, i.e. an ordered relation on V_i^* .

Since the debate is a collaborative social process, agents share common claims of prime importance. That is the reason why we consider that the common values have priority over the other values.

An agent a_1 may estimate herself more competent than her interlocutor a_2 and her personal values have priority over v_2^1 , i.e. the reputation value of the agent a_2 . In this case, the extended priority relation of the agent a_1 is constrained as follows: $\forall v_\omega \in V_{\Omega_A} \forall v \in V_1 - V_{\Omega_A} (v_2^1 \ll_1^* v \ll_1^* v_\omega)$. Alternatively, an agent a_1 may estimate herself less competent than her interlocutor a_2 and v_1^2 , i.e. the reputation value of the agent a_2 , has priority over her personal values. In this case, the extended priority relation of the agent a_1 is constrained as follows: $\forall v_\omega \in V_{\Omega_A} \forall v \in V_1 - V_{\Omega_A} (v \ll_1^* v_1^2 \ll_1^* v_\omega)$.

In both cases, we can easily demonstrate that the extended priority relation is a strict complete ordering relation. The one-agent notion of conviction is then defined as follows:

Definition 10 *Let $a_i \in \bar{U}_A$ be an agent associated with the extended KBase*

$AK_i^* = \langle \mathcal{K}_i^*, V_i^*, promote_i^*, \ll_i^* \rangle$ and let $\phi \in \mathcal{ALC}$ be a claim. The agent a_i is convinced by the claim ϕ iff ϕ is the conclusion of an acceptable argument for the audience a_i with respect to $\mathcal{A}(\mathcal{K}_i^*)$. The set of acceptable arguments for the audience a_i with respect to $\mathcal{A}(\mathcal{K}_i^*)$ is denoted by \mathcal{S}_i^* .

Let us now consider how claims are produced. Agents utter messages to exchange their representations. The syntax of messages is in conformance with the common *communication language*, \mathcal{CL} . A message $M_k = \langle S_k, H_k, A_k \rangle \in \mathcal{CL}$ has an identifier M_k . It is uttered by a speaker ($S_k = \text{speaker}(M_k)$) and addressed to an hearer ($H_k = \text{hearer}(M_k)$). $A_k = \text{act}(M_k)$, the message speech act, is composed of a locution and a content. The locution is one of the following: *question*, *request*, *assert*, *propose*, *refuse*, *reject*, *unknow*, *concede*, *challenge*, *withdraw*. The content, also called *assumption*, is a claim or a set of claims in \mathcal{ALC} .

Speech acts have a public semantic, since commitments enrich the extended KBase of the creditors, and an argumentative semantic, since commitments are justified by the extended KBase of the debtor.

For example, Figure 3 shows the semantics associated with the assertion of an assumption. An agent can propose an hypothesis if she has an argument for it. The corresponding commitments stores are updated. Obviously, claims already known by an agent are not notified in her commitments store. The speech act *propose* has the same argumentative/public semantics. *reject*(ϕ) and *refuse*(ϕ) are both equivalent to *assert*($\neg\phi$). As we will see in Section 7, these latter do not have the same place in the sequence.

In a similar way, Figure 4 shows the semantics associated with the concession of an assumption. The rational conditions for the assertion and for the concession of the same assumption by the same agent are different. Agents can assert an assumption whether they are supported by a trivial argument or not. By contrast, agents do not concede all the assumptions they hear in spite of all assumptions are supported by a trivial argument.

Fig. 3. Semantics for asserting an assumption ϕ at time t

- MESSAGE: $M_l = \langle a_i, a_j, \text{assert}(\phi) \rangle$
- ARGUMENTATIVE SEMANTICS:
 $\exists A \in \mathcal{A}(\mathcal{K}_i^*) \text{conc}(A) = \phi$
- PUBLIC SEMANTICS: For any agent a_k in the audience
 if $\phi \notin \mathcal{A}(\mathcal{K}_k^*)$ then $\text{CS}_i^k(t) = \text{CS}_i^k(t-1) \cup \{\phi\}$

Fig. 4. Semantics for conceding an assumption ϕ at time t

- MESSAGE: $M_l = \langle a_i, a_j, \text{concede}(\phi) \rangle$
- ARGUMENTATIVE SEMANTICS:
 $\exists A \in \mathcal{A}(\mathcal{K}_i^*) \text{conc}(A) = \phi$ with $(\text{premise}(A) \neq \{\phi\} \wedge \text{premise}(A) \not\subseteq \cup_{j \neq i} \text{CS}_j^i)$
- PUBLIC SEMANTICS: For any agent a_k in the audience
 if $\phi \notin \mathcal{A}(\mathcal{K}_k^*)$ then $\text{CS}_i^k(t) = \text{CS}_i^k(t-1) \cup \{\phi\}$

It is worth noting that the rational conditions for the assertion of an assumption and for the assertion its explicit negation are not necessary mutually exclusive. These nondeterministic situations make agents able to make choices. If an agent is *thoughtful*, she can assert only assumptions for which she has an acceptable argument. Otherwise, she is *confident*. If an agent is *skeptical*, she can concede only assumption for which she has an acceptable argument. Otherwise, she is *credulous*. Because arguing agents exchange their convictions, they are thoughtful and skeptical.

The others speech acts (question, request, unknow, challenge, and withdraw) are used to manage the sequence of moves (see Section 7). They have no particular effects on commitments stores, neither particular rational conditions of utterance. We assume that the commitments stores are cumulative, *i.e.* no commitment can be retracted. This is the reason why the speech act $\text{withdraw}(h)$ has no effect on the commitments stores.

The assumptions which are received must be valued. For this purpose, commitments will be individually considered in accordance with the speaker estimated reputation. The following example illustrates this principle.

Example 2 Let us consider two agents, a service provider (denoted *prov*) and a customer (denoted *cust*). It is worth recalling that the service provider considers that customer's claims make authority and adjust her own representation to adopt these claims. Since a service provider considers that customer's claims are more relevant than her own ones, her interlocutor reputation values have priority over her personal values: $\forall v_\omega \in V_{\Omega_A} \forall v \in V_{\text{prov}} - V_{\Omega_A} (v \ll_{\text{prov}}^* v_{\text{cust}}^{\text{prov}} \ll_{\text{prov}}^* v_\omega)$. Since a customer considers that her own claims are more relevant than the service provider ones, her own values have priority over her interlocutor reputation values: $\forall v_\omega \in V_{\Omega_A} \forall v \in V_{\text{cust}} - V_{\Omega_A} (v_{\text{prov}}^{\text{cust}} \ll_{\text{cust}}^* v \ll_{\text{cust}}^* v_\omega)$.

The initial personal KBase of the service provider is the set $\{\phi_1(x), \phi_3(x), \phi_4(x), \phi_5(x), \phi_{61}(x), \phi_{71}, \phi_{72}\}$ and the personal KBase of the customer is the set $\{\phi_1(x), \phi_2(x), \phi_4(x), \phi_{62}(x)\}$. If the customer utters the two following messages:

- $M_1 = \langle \text{cust}, \text{prov}, \text{assert}(\neg \text{Free}(\text{acrobat})) \rangle$,
- $M_2 = \langle \text{cust}, \text{prov}, \text{assert}(\phi_2(\text{acrobat}), \phi_4(\text{acrobat}), \phi_{71}) \rangle$.

then the extended KBase of the service provider is represented as in Table 2. The extended KBase of the service provider is composed of her personal claims and the claims advanced by the customer. The extended set of personal values is composed of the set of personal values and the reputation value of the customer. The common claim $\phi_1(x)$ is related to the common value v_1 . The claims in the commitments is related to the reputation value of the customer.

Table 2
The extended KBase of the service provider

$\llcorner_{\text{prov}}^*$	V_{prov}^*	$\mathcal{K}_{\text{prov}}^*$
	v_1	$\phi_1(x) : \text{Soft}(x) \sqsupseteq \text{Free}(x) \sqcup \text{Nonfree}(x)$
	$v_{\text{cust}}^{\text{prov}}$	$\text{CS}_{\text{cust}}^{\text{prov}} = \{ \neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat}) : \text{Nonfree}(\text{acrobat}) \sqsupseteq \text{Freeware}(\text{acrobat}) \}$
	v_3	$\phi_3(x) : \text{Free}(x) \sqsupseteq \text{Freeware}(x)$
	v_4	$\phi_4(x) : \text{Free}(x) \sqcap \text{Nonfree}(x) \equiv \perp$
	v_5	$\phi_5(x) : \text{Free}(x) \sqsupseteq \text{Opensource}(x)$
	v_6	$\phi_{61}(x) : \text{Opensource}(x) \sqsupseteq \text{Copyleft}(x)$
	v_7	$\phi_{71} : \text{Freeware}(\text{acrobat})$ $\phi_{72} : \text{Copyleft}(\text{xpdf})$

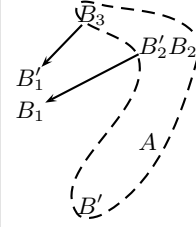
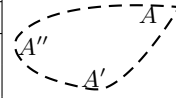


Table 3
The extended KBase of the customer

$\llcorner_{\text{cust}}^*$	V_{cust}^*	$\mathcal{K}_{\text{cust}}^*$
	v_1	$\phi_1(x) : \text{Soft}(x) \sqsupseteq \text{Free}(x) \sqcup \text{Nonfree}(x)$
	v_2	$\phi_2(x) : \text{Nonfree}(x) \sqsupseteq \text{Freeware}(x)$
	v_4	$\phi_4(x) : \text{Free}(x) \sqcap \text{Nonfree}(x) \equiv \perp$
	v_6	$\phi_{62}(x) : \text{Free}(x) \sqsupseteq \text{Copyleft}(x)$
	$v_{\text{prov}}^{\text{cust}}$	$\text{CS}_{\text{prov}}^{\text{cust}} = \{ \text{Free}(\text{xpdf}), \text{Copyleft}(\text{xpdf}), \text{Free}(\text{xpdf}) \sqsupseteq \text{Opensource}(\text{xpdf}), \text{Opensource}(\text{xpdf}) \sqsupseteq \text{Copyleft}(\text{xpdf}) \}$



By uttering the message M_1 , the customer advances the trivial argument $B_3 = \langle [\neg \text{Free}(\text{acrobat})], \neg \text{Free}(\text{acrobat}) \rangle$. Despite the service provider is convinced by this assumption, she cannot concede it. Indeed, this assumption is only supported by a trivial argument in the commitment stores. By uttering the message M_2 , the customer advances the non-trivial argument B_2 bearing on the service provider own claims. Therefore, this last one can concede $\neg \text{Free}(\text{acrobat})$. The only free software she can propose is xpdf.

Now, if the service provider utters the two following messages:

- $M_3 = \langle \text{prov}, \text{cust}, \text{assert}(\text{Free}(\text{xpdf})) \rangle$,
- $M_4 = \langle \text{prov}, \text{cust}, \text{assert}(\phi_5(\text{xpdf}), \phi_{61}(\text{xpdf}), \phi_{72}) \rangle$.

then the extended KBase of the customer becomes as represented in Table 3. By uttering the message M_3 , the service advanced the trivial argument $A'' = \langle [\text{Free}(\text{xpdf})], \text{Free}(\text{xpdf}) \rangle$. Despite this argument is acceptable, the customer cannot concede $\text{Free}(\text{xpdf})$. By uttering the message M_4 , the service provider advances the non-trivial argument A , bearing on the customer own claims. Therefore, $\text{Free}(\text{xpdf})$ can be conceded since M_4 includes the claim ϕ_{72} that can be combined by the customer with ϕ_{62} to reach the conclusion.

We have presented here a model of agents who exchange assumptions and argue. In the next section, we provide a dialectical system where debates take place.

6. Dialectical system

When a set of social and autonomous agents argue, they reply to each other in order to reach the goal of the interaction. We provide a dialectical system, which is inspired by Morge (2005) and adapted to the dialogue on representations.

During exchanges, the speech acts are not isolated but they respond each other. The syntax of moves is in conformance with the common *moves language*: \mathcal{ML} defined as follows: a move $\text{move}_k = \langle M_k, R_k, P_k \rangle \in \mathcal{ML}$ has an identifier move_k . It contains a message M_k as defined before. The moves are

messages with some attributes to control the sequence. $R_k = \text{reply}(\text{move}_k)$ is the identifier of the move to which move_k responds. A move (move_k) is either an initial move ($\text{reply}(\text{move}_k) = \text{nil}$) or a replying move ($\text{reply}(\text{move}_k) \neq \text{nil}$). $P_k = \text{protocol}(\text{move}_k)$ is the name of the protocol which is used during the dialogue.

A dialectical system is composed of two agents. In this formal area, two agents play moves to check an initial assumption, *i.e.* the topic.

Definition 11 Let $AK_{\Omega_A} = \langle \mathcal{K}_{\Omega_A}, V_{\Omega_A}, \text{promote}_{\Omega_A} \rangle$ be a common value-based KBase and ϕ_0 a claim in \mathcal{ALC} . The **dialectical system** on the topic ϕ_0 is a quintuple $DS_{\Omega_M}(\phi_0, AK_{\Omega_A}) = \langle N, H, T, \text{protocol}, Z \rangle$ where:

- $N = \{\text{init}, \text{part}\} \subset \mathcal{U}_A$ is a set of two agents called players: the initiator and the partner;
- H is the set of histories, *i.e.* the sequences of well-formed moves *s.t.* the speaker of a move is determined at each stage by a turn-taking function and the moves agree with a protocol;
- $T : H \rightarrow N$ is the turn-taking function determining the speaker of a move. If $|h| = 2n$ then $T(h) = \text{init}$ else $T(h) = \text{part}$;
- $\text{protocol} : H \rightarrow \Omega_M$ is the function determining the moves which are allowed or not to expand an history, where $\Omega_M \subseteq \mathcal{ML}$ is the set of all well-formed moves;
- Z is the set of dialogue, *i.e.* terminal histories.

In order to be well-formed, the initial move is a question about the topic from the initiator to the partner and a replying move from a player always references an earlier move uttered by the other player. In this way, backtracking are allowed. We call dialogue line the sub-sequence of moves where all backtracks are ignored. In order to avoid loops, assumptions redundancy is forbidden within assertions. Obviously, all moves should contain the same parameter protocol value.

We have bound here the area in which dialogues take place. We formalize in the next section a particular protocol to reach a representation agreement.

7. Protocol

When two agents have a dialogue, they collaborate to reconcile their representations. For this purpose, we propose in this section a protocol.

Walton & Krabbe (1995) have proposed an influential classification of dialogues into six types according to their goal. While persuasion aims to resolve a difference of opinion, negotiation tries to resolve a conflict of interest by reaching a deal, information seeking aims at transferring information, deliberation wants to reach a decision on a course of actions, inquiry aims at increasing knowledge, and quarrel is the verbal substitute of a fight. This classification is not meant to be exhaustive and leaves room for dialogues of mixed type. Parsons & Wooldridge (2002) have investigated how these different types of dialogue can be captured using a formal model of argumentation. We formalize here their persuasion protocol. Moreover, this protocol is extended and adapted for debating over ontologies.

As observed by Prakken (2001), protocols can vary in several ways. In a unique-response protocols, players can reply just once to the other player's moves. Otherwise, the protocol is multi-response. We consider here a multi-response protocol which, unlike a unique-response protocol, improves the quality of the outcome but decreases the time spent.

A protocol is determined by a set of sequence rules (see Table 4). Each rule specifies authorized replying moves. According to the "Question/Answer" rule ($\text{sr}_{Q/A}$), the hearer of a question ($\text{question}(\phi)$) is allowed to respond with a confirmation ($\text{assert}(\phi)$), or with an invalidation ($\text{assert}(\neg\phi)$), or with a plea of ignorance ($\text{unknow}(\phi)$). The "Request/Propose" rule ($\text{sr}_{R/P}$) is quite similar. The hearer of a request ($\text{request}(\phi(x))$) is allowed to respond either by asserting an instantiation of this assumption ($\text{assert}(\phi(a))$), or with a plea of ignorance ($\text{unknow}(\phi(x))$). The respond can resist or surrender to the previous speech act. For example, the "Assert/Welcome" rule (written $\text{sr}_{A/W}$) specifies authorized

Table 4
Set of speech acts and their potential answers.

Sequences rules	Speech acts	Resisting replies	Surrendering replies
$sr_{Q/A}$	$question(\phi)$	$assert(\phi)$ $assert(\neg\phi)$	$unknow(\phi)$
$sr_{R/P}$	$request(\phi(x))$	$propose(\phi(a))$	$unknow(\phi(x))$
$sr_{A/W}$	$assert(\Phi)$	$challenge(\phi), \phi \in \Phi$ $refuse(\phi), \phi \in \Phi$	$concede(\Phi)$
$sr_{A/R}$	$assert(\Phi)$	$challenge(\phi), \phi \in \Phi$	$concede(\Phi)$ $reject(\phi), \phi \in \Phi$
$sr_{C/A}$	$challenge(\phi)$	$assert(\Phi), \Phi \vdash \phi$	$withdraw(\phi)$
sr_T	$unknow(\Phi)$	\emptyset	\emptyset
	$concede(\Phi)$	\emptyset	\emptyset
	$refuse(\Phi)$	\emptyset	\emptyset
	$withdraw(\Phi)$	\emptyset	\emptyset

moves replying to the previous assertions ($assert(\Phi)$). Contrary to resisting acts, surrendering acts close the dialogue line. A concession ($concede(\Phi)$) surrenders to the previous proposition. A challenge ($challenge(\phi)$) and a refuse ($refuse(\phi)$) resist to the previous proposition. By contrast, denying one of the assumptions previously asserted ($reject(\phi)$) closes the dialogue line in the “Assert/Reject” rules.

As pointed in Section 5, an assertion and a proposition have the same argumentative/public semantics. Moreover, $refuse(\phi)$ and $reject(\phi)$ are equivalent to $assert(\neg\phi)$. However, these speech acts do not have the same place in the sequence of moves.

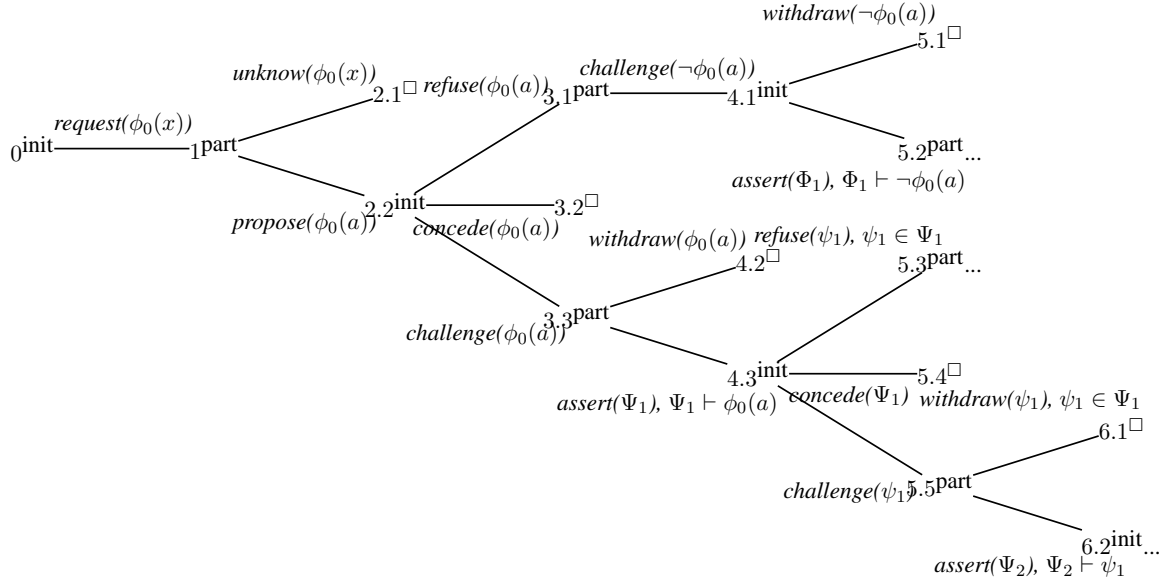
We consider here the requesting multi-response persuasion protocol (denoted ReqMultiResPersProto) using the following rules: $sr_{R/P}$, $sr_{A/W}$, $sr_{C/A}$, and sr_T . Figure 5 shows a dialogue in the extensive form game representation where nodes are game situations and edges are moves. For example, 2.2^{init} denotes a game situation where the exponent indicates that the initiator is the next move speaker. The exponent of game-over situations are boxes (3.2^{\square} , 4.2^{\square} , 5.1^{\square} , 5.4^{\square} , and 6.1^{\square}). To improve clarity, the games that follow situations 5.2^{part} , 5.3^{part} , and 6.2^{init} are not represented. In order to enrich her representation with a partner, an initiator begins a dialogue with a request in the game situation 0^{init} . If the partner has no representation for the topic, she pleads ignorance and closes the dialogue (see game situation 2.1^{\square}). The goal of the dialogue is to reach an agreement over representations by verbal means. The following example illustrates such a dialogue.

Example 3 *Let us consider again the dialogue presented in Section 2. Table 5 shows how, using the protocol, the two agents play the dialogue. This table details the different moves corresponding to the claims of the natural language dialogue. We can see that the commitments stores are the results of moves. At the beginning of the dialogue, ϕ_1 is the only claims explicitly shared by the agents (\mathcal{K}_{Ω_A}). During exchanges, the service provider detects that she shares ϕ_4 with the customer. Since the provider does not share the whole knowledge of the customer, the sequence of moves guides her to the claim which is the source of the consensus. Due to the polysemy of the concept *Free*, the provider must deploy her own argumentation to establish *Free(xpdf)*. Hence, this is the reason why she utters ϕ_5 and ϕ_{61} (in $move_{10}$ and $move_{12}$) in order to try to convince the customer. However the sole claim that effectively convinces the customer is ϕ_{72} , that she combines with ϕ_{62} , but she does not need nor use the two previous ones. Had the provider known the customer definition of *Free* (by ϕ_{62}), she could have immediately used the convincing claims ϕ_{72} . At the end of the dialogue, the set of claims explicitly shared increases. In other terms, the agents co-build a common ontology during the dialogue.*

8. Related works

Laera et al. (2006) provides a framework for agents to reach an agreement over ontology alignment. Argumentation is used to select a correspondence among candidate correspondences, according to the

Fig. 5. Dialogue in an extensive form game representation



ontological knowledge and the agents' preferences. This approach is static because alignments have been achieved off-line. By contrast, we solve the semantic heterogeneity during the dialogical process.

Van Digglen et al. (2006) proposes the ANEMONE approach for solving semantic integration problems. Instead of trying to solve ontology problems at design time, ANEMONE provides agents with tools to overcome ontology problems at agent interaction time. This work tackles semantic integration problems when needed and only when needed by focusing on the layered communication mechanism. By contrast, our work is not restricted to the communication issues, but it provides a model of reasoning as well as a model of agents.

Valencia & Sansonnet (2004) proposes a framework to solve on-line the semantic heterogeneity by exploiting the topological properties of the representation. This work considers one-shot interaction steps, which are simply requests and responses to the requests, to reformulate concepts from a heterogeneous terminology into a terminology semantically shared *a priori* between the agents. In this paper, we use a protocol to detect concepts shared implicitly and to build a common ontology.

As we have already said, we have extended the formal framework for inter-agents dialogue based upon the argumentative techniques proposed by Morge (2005). Since the denotational semantics of the description logic is adapted to the knowledge representation, the background logic has shifted from the first order logic program to the description logic. Therefore agents are equipped with a KBase, *i.e.* a TBox and a ABox and utter speech acts such as `request` and `propose`. To improve the quality of the outcome, we have shifted from a unique-respond protocol to a multi-respond protocol. Finally, we provide a multi-agent interaction framework to reach an agreement over heterogeneous representations.

9. Conclusion

In this paper, we have proposed a framework for inter-agents dialogue to reach an agreement, which formalizes a debate in which divergent representations are discussed. For this purpose, we have proposed an argumentation-based representation framework which manages the conflicts between claims with different relevances for different audiences to compute their acceptance. Moreover, we have proposed a model for the reasoning of agents where they justify the claims to which they commit and take into account the

Table 5

Dialogue to reach an agreement. Natural language sentences, corresponding to the dialogue presented in 2, are given in association with their dialogue, then the new the commitment stores and the reached game situation (from Fig 5) are given.

$\mathcal{K}_{\text{cust}}^* - \mathcal{K}_{\Omega_A}$		\mathcal{K}_{Ω_A}	$\mathcal{K}_{\text{prov}}^* - \mathcal{K}_{\Omega_A}$	
		ϕ_1		
$\mathcal{K}_{\text{cust}}$	$\text{CS}_{\text{prov}}^{\text{cust}}$	Game situation	$\text{CS}_{\text{cust}}^{\text{prov}}$	$\mathcal{K}_{\text{prov}}^*$
$\phi_2(x), \phi_4(x)$ $\phi_{62}(x)$	\emptyset	0^{cust}	\emptyset	$\phi_3(x), \phi_4(x), \phi_5(x),$ $\phi_{61}(x), \phi_{71}, \phi_{72}$.
<i>Do you know free software to view my PDF ?</i>				
$\rightarrow \text{move}_1 = \langle \text{cust, prov, request}(\text{Free}(x)), \text{nil, ReqMultiResPersProto} \rangle \rightarrow$				
idem	\emptyset	1^{prov}	\emptyset	idem
<i>acrobat is free software.</i>				
$\leftarrow \text{move}_2 = \langle \text{prov, cust, propose}(\text{Free}(\text{acrobat})), \text{move}_1, \text{ReqMultiResPersProto} \rangle \leftarrow$				
idem	$\text{Free}(\text{acrobat})$	2.2^{cust}	\emptyset	idem
<i>Why is it free software ?</i>				
$\rightarrow \text{move}_3 = \langle \text{cust, prov, challenge}(\text{Free}(\text{acrobat})), \text{move}_2, \text{ReqMultiResPersProto} \rangle \rightarrow$				
idem	$\text{Free}(\text{acrobat})$	3.3^{prov}	\emptyset	idem
<i>acrobat is free because this is freeware.</i>				
$\leftarrow \text{move}_4 = \langle \text{prov, cust, assert}(\phi_3(\text{acrobat}), \phi_{71}), \text{move}_3, \text{ReqMultiResPersProto} \rangle \leftarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71}$	4.3^{cust}	\emptyset	idem
<i>In my humble opinion, acrobat is not free software.</i>				
$\rightarrow \text{move}_5 = \langle \text{cust, prov, refuse}(\text{Free}(\text{acrobat})), \text{move}_2, \text{ReqMultiResPersProto} \rangle \rightarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71}$	3.1^{prov}	$\neg \text{Free}(\text{acrobat})$	idem
<i>Why is it not free software ?</i>				
$\leftarrow \text{move}_6 = \langle \text{prov, cust, challenge}(\neg \text{Free}(\text{acrobat})), \text{move}_5, \text{ReqMultiResPersProto} \rangle \leftarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71}$	4.1^{cust}	$\neg \text{Free}(\text{acrobat})$	idem
<i>Since acrobat is freeware, this is not free software.</i>				
$\rightarrow \text{move}_7 = \langle \text{assert}(\phi_2(\text{acrobat}), \phi_4(\text{acrobat}), \phi_{71}), \text{move}_6, \text{ReqMultiResPersProto} \rangle \rightarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71}$	5.2^{prov}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$	idem
<i>OK, however xpdf is free software.</i>				
$\leftarrow \text{move}_8 = \langle \text{prov, cust, propose}(\text{Free}(\text{xpdf})), \text{move}_1, \text{ReqMultiResPersProto} \rangle \leftarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf})$	2.2^{cust}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$	idem
<i>Why is it free software ?</i>				
$\rightarrow \text{move}_9 = \langle \text{cust, prov, challenge}(\text{Free}(\text{xpdf})), \text{move}_8, \text{ReqMultiResPersProto} \rangle \rightarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf})$	3.3^{prov}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$	idem
<i>xpdf is free software because it is opensource.</i>				
$\leftarrow \text{move}_{10} = \langle \text{prov, cust, assert}(\text{Opensource}(\text{xpdf}), \phi_5(\text{xpdf})), \text{move}_9, \text{ReqMultiResPersProto} \rangle \leftarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf}), \text{Opensource}(\text{xpdf}), \phi_5(\text{xpdf})$	4.3^{cust}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$	idem
<i>Why is it opensource ?</i>				
$\rightarrow \text{move}_{11} = \langle \text{prov, cust, challenge}(\text{Opensource}(\text{xpdf})), \text{move}_{10}, \text{ReqMultiResPersProto} \rangle \rightarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf}), \text{Opensource}(\text{xpdf}), \phi_5(\text{xpdf})$	5.5^{prov}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$	idem
<i>xpdf is opensource because it is copyleft.</i>				
$\leftarrow \text{move}_{12} = \langle \text{prov, cust, assert}(\phi_{72}, \phi_{61}(\text{xpdf})), \text{move}_{11}, \text{ReqMultiResPersProto} \rangle \leftarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf}), \text{Opensource}(\text{xpdf}), \phi_5(\text{xpdf}),$ $\phi_{72}, \phi_{61}(\text{xpdf})$	6.2^{cust}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$	idem
<i>OK, I will consider xpdf ?</i>				
$\rightarrow \text{move}_{13} = \langle \text{prov, cust, concede}(\text{Free}(\text{xpdf})), \text{move}_8, \text{ReqMultiResPersProto} \rangle \rightarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf}), \text{Opensource}(\text{xpdf}), \phi_5(\text{xpdf}),$ $\phi_{72}, \phi_{61}(\text{xpdf})$	3.2^{L}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$	idem

claims of their interlocutors. We provide a dialectical system in which two agents participate in a dialogue to reach an agreement about a conflict in representations.

The implementation of this formal framework is a work in progress. The representation framework will be computed through a simple logic-based knowledge representation wrapper built upon the dialectical proof procedure proposed in Dung (2007). Since we develop from scratch the reasoning and communicating capabilities of the agents, any MAS platform could be used to implement the whole framework. Obviously, the soundness and completeness of both framework and implementation should be studied.

In this work, we have focused on multi-agent systems but, as suggested by the example, our approach is also relevant to the Web and its proposed extension, the Semantic Web, where different services performing the same tasks may advertise their capabilities differently, or where service requests, and service offers may be expressed by using different ontologies, and thus need to be reconciled dynamically at run time.

While this work focuses on single dialogues between two heterogeneous agents, future investigations

must explore how this solution, when it will be implemented, scales to multi-agent systems where dialogues are amongst multiple parties and sequenced. In particular, we must explore how the shared claims discovered and the result of dialogues will impact on the ontologies and the reputation of agents in the following dialogues.

Acknowledgements

The authors like to thank Yann Secq, Jean-Paul Sansonnet, and Philippe Mathieu for their willingness to discuss this issue with us. Thanks are also due to Fariba Sadri and Paolo Mancarella for their advice to improve the English of this paper. We would like to thank the reviewers for their detailed comments on this paper. The first author is supported by the Sixth Framework IST programme of the EC, under the 035200 ARGUGRID project. The second author is supported by the CPER TAC of the region Nord-Pas de calais and the european fund FEDER.

References

- Leila Amgoud and Simon Parsons. *Agent dialogues with conflicting preferences* in Intelligent Agent VIII. Revised papers of the International Workshop on Agent Theories, Architectures and Languages, Vol. 2333 of Lecture Notes in Artificial Intelligence, pages. 190-205, Springer-Verlag (2001).
- Leila Amgoud and Claudette Cayrol. *A reasoning model based on the production of acceptable arguments*. Annals of Maths and AI, **34**(1-3), pages 197–215, Springer-Verlag (2002).
- Leila Amgoud, Nicolas Maudet, and Simon Parsons. *An argumentation-based semantics for agent communication languages*. In Proceedings of the 15th European Conference on Artificial Intelligence, pages 38–42. IOS Press (2002).
- Sidney Bailin and Walt Truszkowski. *Ontology negotiation between intelligent information agents* Knowledge Engineering Review, **17**(1), pages 7–19, Cambridge University Press (2002).
- Trevor J.M. Bench-Capon. *Value based argumentation frameworks*. In Proceedings of Non Monotonic Reasoning, pages 444–453, Toulouse, France (2002).
- Salem Benferhat, Didier Dubois, and Henry Prade. *A local approach to reasoning under inconsistency in stratified knowledge bases*. In Proc. of the european conference on Symbolic and Quantitative Approaches to Reasoning and Uncertainty (ECSQARU'95), volume 946 of Lecture Notes in Artificial Intelligence, pages 36-43. Springer-Verlag, 195.
- Cristiano Castelfranchi and Rino Falcone. *Principles of trust in mas: Cognitive anatomy, social importance, and quantification* in Proceedings of the third international conference on multi-agent systems, pages 72–79, ACM press (1998).
- Phan Minh Dung. *On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games* Artificial Intelligence, **77**(2), pages 321–357, Springer-Verlag (1995).
- Phan Minh Dung and Paolo Mancarella and Francesca Toni. *Computing ideal sceptical argumentation* Artificial Intelligence, Special Issue on Argumentation in Artificial Intelligence, Springer-Verlag, To appear (2007).
- Jérôme Euzenat and Petko Valtchev. *Similarity-Based Ontology Alignment in OWL-Lite* in Proceedings of the 16th European Conference on Artificial Intelligence, pages 333-337, IOS Press (2004).
- Nicolletta Fornara and Marco Colombetti. *Operational specification of a commitment-based agent communication language*, in Proceedings of the 1st international joint conference on autonomous agent and multi-agent systems, pages 535–542. ACM press (2002).
- Thomas R. Gruber. *Toward principles for the design of ontologies used for knowledge sharing* International Journal of Human-Computer Studies, special issue on Formal Ontology in Conceptual Analysis and Knowledge Representation, **43**(5-6), pages 907–928, Academic Press (1995).
- Carl Hewitt. *Offices are open systems* ACM Transactions on Information Systems, **4**(3), pages 271–287, ACM Press (1986).
- Loredana Laera, Valentina Tamma, Jérôme Euzenat, Trevor Bench-Capon, and Terry Payne. *Reaching agreement over ontology alignments*. In Proceedings of the 5th International Semantic Web Conference, Vol. 4273 of Lecture Notes in Artificial Intelligence, pages 371-384, Springer-Verlag (2006).
- Maxime Morge. *Collective decision making process to compose divergent interests and perspectives* Artificial Intelligence and Law, **13**(1), pages 75-92, Springer-Verlag, (2005).
- Simon Parsons and Michael Wooldridge. *An analysis of formal inter-agent dialogues* in Proceedings of the first international joint conference on autonomous agent and multi-agent systems, pages 394–401, ACM press (2002).
- Chaim Perelman and Lucie Olbrechts-Tyteca. *Traité de l'Argumentation - La Nouvelle Rhétorique*. Presses Universitaires de France (1958).
- Henry Prakken and Giovanni Sator. *Argument-based logic programming with defeasible priorities*. Journal of Applied Non-classical Logics, **7**:25-75, 1997.
- Henry Prakken. *Relating Protocols for Dynamic Dispute with Logics for Defeasible Argumentation* Synthese **127**(1-2), pages 187-219, Springer-Verlag, (2005).
- Manfred Schmidt-Schauß and Gert Smolka. *Attributive concept descriptions with complements* Artificial Intelligence, **48**(1), pages 1–26, Springer-Verlag (1991).

- Guillermo Ricardo Simari and Ronald Prescott Loui. *A mathematical treatment of defeasible reasoning and its implementation* Artificial Intelligence, **53**(2-3):125-157, 1992.
- Erika Valencia and Jean-Paul Sansonnet. *Building Semantic Channels between Heterogeneous Agents with Topological Tools* In Proceedings of the 2nd European Workshop on Multi-Agent Systems, Barcelona, Spain (2004).
- Jurriaan Van Digglen, Robbert-Jan Beun, Frank Dignum, Rogier Van Eijk, and John-Jules Meyer. *Anemone: An effective minimal ontology negotiation environment* In Proceedings of the 5th International Conference on Autonomous Agents and Multi-agent Systems, pages 899–906, ACM Press (2006).
- Douglas N. Walton and Eric C. W. Krabbe. *Commitment in Dialogue*, SUNY Press (1995).