

Debating over heterogeneous ontologies

M. Morge* Jean-Christophe Routier†
morge@di.unipi.it routier@lifl.fr

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

† LIFL - USTL
Batiment M3 - F-59655 VILLENEUVE D'ASCQ Cedex FRANCE

Résumé :

L'hétérogénéité sémantique des ontologies est un obstacle majeur à l'interopérabilité dans les systèmes multi-agents ouverts. Nous proposons dans cet article un cadre formel pour que les agents débattent à partir de terminologies hétérogènes. À cette intention, nous proposons un cadre de représentation argumentatif qui permet de gérer des descriptions conflictuelles. Nous présentons également un modèle d'agents qui expliquent les termes qu'ils utilisent et prennent en compte les explications de leurs interlocuteurs. Finalement, nous proposons un système dialectique permettant aux agents de participer à un dialogue pour atteindre un accord sur une terminologie commune.

Mots-clés : Intelligence artificielle, Système Multi-Agents, Dialogue, Argumentation, Ontologie, Logique de Description

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 ontologies.

Keywords: Artificial Intelligence, Multi-agent system, Dialogue, Argumentation, Ontology, Description logic

1 Introduction

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. For this purpose, we extend the formal framework for inter-agents dialogue based upon the argumentative techniques proposed by [9]. (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 representations. 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 draws some conclusions and future works.

2 Natural language

[3] defines a dialogue as a coherent sequence of moves from an initial situation to reach the goal of participants. 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 free software ?
4. *provider* : Acrobat is free because it is freeware.
5. *customer* : In my humble opinion, Acrobat is not 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 open-source.
11. *customer* : Why is it open-source ?
12. *provider* : xpdf is open-source because it is copy-left.
13. *customer* : OK, I will consider xpdf.

In this dialogue, two participants share the concept “free”. 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 divergent definitions of this concept and resolves it. As it will be the case throughout the following, the service provider considers that the definition of the customer has priority and adjusts her own representation to adopt this definition.

3 Description Logic

In this section, we provide the syntax and the semantics for the well-known \mathcal{ALC} language proposed by [2] 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. The syntax of the representation adopted here is taken from standard constructors proposed in the DL literature.

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.

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} its holds that $C^{\mathcal{I}} \supseteq D^{\mathcal{I}}$.

Below we will use \mathcal{ALC} in our argumentation-based representation framework.

4 Argumentation-based representation framework

The seminal work of [1] 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. 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 $\mathcal{U}_A = \{a_1, \dots, a_n\}$). 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 $\{v_1, \dots, v_i\}$;
- $\text{promote} : \mathcal{K} \rightarrow V$ 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 [4], both concrete and abstract values constitute starting points to distinguish different audiences. Values are arranged in hierarchies. 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 bet-

ween 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 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 :

Definition 6 Let $AK_i = \langle \mathcal{K}, V, promote, \ll_i \rangle$ 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 $defeats_i(A, B)$) iff $\forall \Phi_1 \subseteq \Phi, \Psi_2 \subseteq \Psi$, $(\exists \chi \in \mathcal{L}, \Phi_1 \vdash \chi \text{ and } \Psi_2 \vdash \neg \chi) \Rightarrow \neg(level_i(\Phi_1) \ll_i level_i(\Psi_2))$. Similarly, we say that a set S of arguments defeats B if B is defeated by one argument in S .

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

Definition 7 Let $AK_i = \langle \mathcal{K}, V, promote, \ll_i \rangle$ 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 $\forall B \in \mathcal{A}(\mathcal{K}) \quad defeats_i(B, A) \Rightarrow defeats_i(S, B)$.

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. 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 :

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

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 :

- $B' = \langle [Freeware(acrobat)], Freeware(acrobat) \rangle$;
- $B'_1 = \langle [Freeware(acrobat), Free(x) \sqsupseteq Freeware(x)], Free(acrobat) \rangle$;
- $B'_2 = \langle [Freeware(acrobat), Nonfree(x) \sqsupseteq Freeware(x)], Nonfree(acrobat) \rangle$;
- $B_1 = \langle [Freeware(acrobat), Free(x) \sqsupseteq Freeware(x), Free(x) \sqcap Nonfree(x) \equiv \perp], \neg Nonfree(acrobat) \rangle$;
- $B_2 = \langle [Freeware(acrobat), Nonfree(x) \sqsupseteq Freeware(x), Free(x) \sqcap Nonfree(x) \equiv \perp], \neg Free(acrobat) \rangle$;

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

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	$\phi_{71} : \text{Freeware}(\text{acrobat})$ $\phi_{72} : \text{Copyleft}(\text{xpdf})$

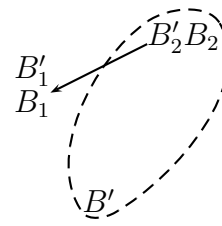
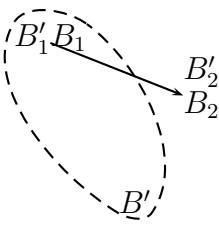


FIG. 2 – The value-based KBase of the second audience

\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	$\phi_{71} : \text{Freeware}(\text{acrobat})$ $\phi_{72} : \text{Copyleft}(\text{xpdf})$



claims and takes into account other claims coming from their interlocutors.

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 [5], agents, which have their own private representations, record their interlocutors commitments. Moreover, agents individually value 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

$$a_i = \langle \mathcal{K}_i, V_i, \ll_i, \text{promote}_i, \cup_{j \neq i} \text{CS}_j^i, \prec_i \rangle$$

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 ;
- $\text{promote}_i : \mathcal{K}_i \rightarrow V_i$ 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} . $\text{CS}_j^i(t)$ 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 :

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

$V_{\Omega_A} \subseteq \bigcap_{a_i \in \mathcal{U}_A} V_i$. The common claims relate to the common values. For every $\phi \in \mathcal{K}_{\Omega_A}$, $\text{promote}_{\Omega_A}(\phi) = v \in V_{\Omega_A}$. The personal KBBase 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 KBBase* the set of claims distributed in the system : $\mathcal{K}_{\mathcal{U}_A} = \bigcup_{a_i \in \mathcal{U}_A} \mathcal{K}_i$. The agent's own claims relate to the agent's own values. For every $\phi \in \mathcal{K}_i - \mathcal{K}_{\Omega_A}$, $\text{promote}_i(\phi) = v \in V_i - V_{\Omega_A}$.

An agent can evaluate her interlocutors commitments either in accordance with a global social order as proposed by [7], or in accordance with a trust model. The different reputation relations, which are transitive, irreflexive, asymmetric, and complete relations on \mathcal{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 KBBase :

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

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

- $\mathcal{K}_i^* = \mathcal{K}_i \cup [\bigcup_{j \neq i} CS_j^i]$ is the agent extended personal KBBase composed of its personal KBBase 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 ;
- $\text{promote}_i^* : \mathcal{K}_i^* \rightarrow V_i^*$ is the extension of the function promote_i mapping claims in the extended personal KBBase 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 : $\forall v_\omega \in V_{\Omega_A} \forall v \in V_1 - V_{\Omega_A} (v_2^1 \ll_1^* v \ll_1^* v_\omega)$. The case where an agent estimates herself less competent than her interlocutor is similar. 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 $a_i \in \mathcal{U}_A$ be an agent associated with the extended KBBase*

$AK_i^* = \langle \mathcal{K}_i^*, V_i^*, \text{promote}_i^*, \ll_i^* \rangle$ 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 a 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 an argumentative semantic, since commitments enrich the extended

KBase of the creditors, and a public 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. 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 non-deterministic situations make agents able to make choices.

The others speech acts 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 `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 : $\forall v_\omega \in V_{\Omega_A} \forall v \in V_{prov} - V_{\Omega_A} (v \ll_{prov}^ v_{cust}^{prov} \ll_{prov}^* v_\omega)$. 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 : $\forall v_\omega \in V_{\Omega_A} \forall v \in V_{cust} - V_{\Omega_A} (v_{prov}^{cust} \ll_{cust}^* v \ll_{cust}^* v_\omega)$.*

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 :

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

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 commitment is related to the reputation value of the customer.

By uttering the message M_1 , the customer advances the trivial argument $B_3 = \langle [\neg Free(acrobat)], \neg Free(acrobat) \rangle$. 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 $\neg Free(acrobat)$. The only free software she can propose is `xpdf`.

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

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

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 $\text{CS}_i^k(t) = \text{CS}_i^k(t-1) \cup \{\phi\}$

then the extended KBase of the customer becomes as represented in Table 2. By uttering the message M_3 , the service advanced the trivial argument $A'' = \langle [\text{Free}(xpdf)], \text{Free}(xpdf) \rangle$. Despite this argument is acceptable, the customer cannot concede $\text{Free}(xpdf)$. By uttering the message M_4 , the service provider advances the non-trivial argument A , bearing on the customer own claims. Therefore, $\text{Free}(xpdf)$ can be conceded.

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 [9] 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.

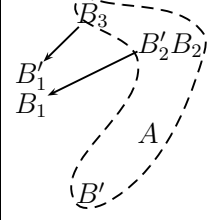
Definition 11 Let

$\text{AK}_{\Omega_A} = \langle \mathcal{K}_{\Omega_A}, V_{\Omega_A}, \text{promote}_{\Omega_A} \rangle$ 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 $\text{DS}_{\Omega_M}(\phi_0, \text{AK}_{\Omega_A}) = \langle N, H, T, \text{protocol}, Z \rangle$ 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

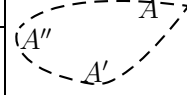
TAB. 1 – The extended KBase of the service provider

$\llcorner_{\text{prov}}^*$	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	$\phi_{71} : \text{Freeware}(\text{acrobat})$ $\phi_{72} : \text{Copyleft}(\text{xpdf})$



TAB. 2 – 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	$\phi_{62}(x) : \text{Free}(x) \sqsupseteq \text{Copyleft}(x)$
	$v_{\text{prov}}^{\text{cust}}$	$\text{CS}_{\text{prov}}^{\text{cust}} = \{ \text{Free}(\text{xpdf}), \text{Free}(\text{xpdf}) \sqsupseteq \text{Opensource}(\text{xpdf}), \text{Opensource}(\text{xpdf}) \sqsupseteq \text{Copyleft}(\text{xpdf}) \}$



- 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. We formalize here the persuasion protocol presented in [6]. We extend and adapt it for debating over ontologies. 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 3). 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 respond can resist or surrender to the previous speech act. For example, the “Assert/Welcome” rule (written $\text{sr}_{A/W}$) specifies authorized moves replying to the previous assertions ($\text{assert}(\Phi)$). Contrary to resisting acts, surrendering acts close the dialogue line.

As pointed in Section 5, an assertion and a proposition have the same argu-

TAB. 3 – 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

mentative/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 : $sr_{R/P}$, $sr_{A/R}$, $sr_{C/A}$, and sr_T . Figure 5 shows a dialogue in the extensive form game representation where nodes are game situations and edges are moves. If the partner has no representation for the topic, she pleads ignorance and closes the dialogue (see game situation 2.1[□]). 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 4 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. At the end of the dialogue, the set of claims explicitly shared increases.*

8 Conclusion

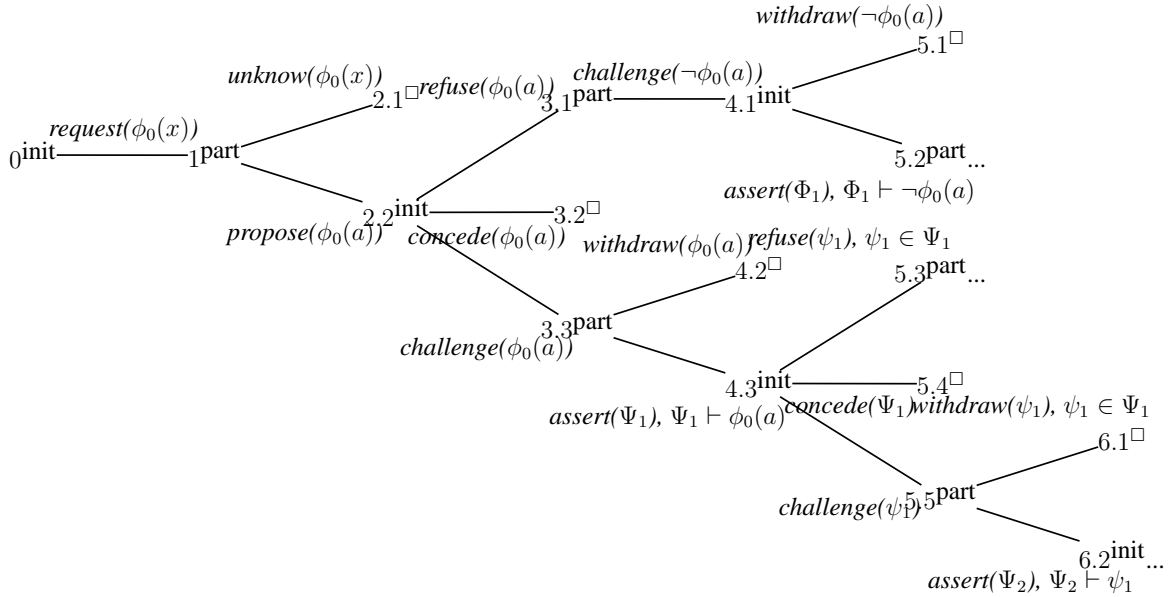
In this paper, we have proposed a framework for inter-agents dialogue to reach an agreement, which formalizes a debate in which divergent representations are discussed. For this purpose, we have proposed an argumentation-based representation framework which manages the conflicts between claims with different 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 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. While this work focuses on single dialogues between two heterogeneous agents, future investigations must explore how this solution 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.

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TAB. 4 – Dialogue to reach an agreement. Natural language sentences are given in association with their dialogue, then the new the commitment stores and the reached game situation (from Fig 5) are given. moves

$\mathcal{K}_{\text{cust}}^* - \mathcal{K}_{\Omega_A}$		\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	\emptyset^{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>				
$\rightarrow \text{move}_1 = \langle \text{cust, prov, request}(\text{Free}(x)), \text{nil}, \text{ReqMultiResPersProto} \rangle \rightarrow$				
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>				
$\rightarrow \text{move}_5 = \langle \text{cust, prov, refuse}(\text{Free}(\text{acrobat})), \text{move}_4, \text{ReqMultiResPersProto} \rangle \rightarrow$				
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>				
$\leftarrow \text{move}_8 = \langle \text{prov, cust, propose}(\text{Free}(\text{xpdf})), \text{move}_7, \text{ReqMultiResPersProto} \rangle \leftarrow$				
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>				
$\leftarrow \text{move}_{12} = \langle \text{prov, cust, assert}(\phi_{72}(\text{xpdf}), \phi_{61}(\text{xpdf})), \text{move}_{11}, \text{ReqMultiResPersProto} \rangle \leftarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf}), \text{Opensource}(\text{xpdf}), \phi_5(\text{xpdf}),$ $\phi_{72}(\text{xpdf}), \phi_{61}(\text{xpdf})$.	6.2^{cust}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$.	idem
<i>OK, I will consider xpdf ?</i>				
$\rightarrow \text{move}_{13} = \langle \text{prov, cust, concede}(\text{Free}(\text{xpdf})), \text{move}_{12}, \text{ReqMultiResPersProto} \rangle \rightarrow$				
idem	$\text{Free}(\text{acrobat}), \phi_3(\text{acrobat}), \phi_{71},$ $\text{Free}(\text{xpdf}), \text{Opensource}(\text{xpdf}), \phi_5(\text{xpdf}),$ $\phi_{72}(\text{xpdf}), \phi_{61}(\text{xpdf})$.	3.2^{\square}	$\neg \text{Free}(\text{acrobat}), \phi_2(\text{acrobat})$,	idem

FIG. 5 – Dialogue in an extensive form game representation. 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 (e.g. 3.2^{\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} .



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