ALIGNING AGENT COMMUNICATION PROTOCOLS
A Pragmatic Approach

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Abstract: Nowadays, there is a clear trend in using common ontologies for supporting communication interoperability between multiple heterogeneous agents over Internet. An important task that must be solved before implementing ontology-based solutions is the identification of semantic relations to establish alignments between communication primitives. A frequent methodology for aligning different communication primitives consists of processing definitions provided by human developers based on syntactical classification algorithms and semantic enhancement of concepts. We think that the information provided by human developers represents an important source for classification. However, to obtain real semantics, we believe that a better approach would analyze the usage of the primitive in the communication protocol. In this paper we present a pragmatic approach for aligning communication primitives, considering their usage in the protocol. To evaluate our solution we compare the resulting relations and show that our approach provides more accuracy for relating communication primitives.

1 INTRODUCTION

The problem of communication heterogeneity in multi-agent systems (MAS) has become a classical research topic (Furlan 2001, Labrou 1999, Chaib-Draa 2002). Although there are important research communities developing standard agent communication language (ACL) specifications like KQML (Finning, 1994) or FIPA ACL (FIPA, 2003), implementations of such specifications in MAS differ in syntax and semantics, causing heterogeneity. Ontologies have shown good results for supporting communication interoperability among multiple heterogeneous agents over Internet (McGuinness 2000, Noy 2000, Guido 2007), but the design and implementation of ontologies, requires a human expert to analyze and compare among those communication implementations to discover and define relations among primitives. Then research efforts to propose mechanisms for identifying relations among multiple implementations of ACL will benefit the automatic deployment of autonomous agents over Internet.

In this paper we deal with the problem of identifying semantic relations to establish alignments between different implementations of ACL, considering the message representation and the protocol of conversation. Aligning is the task of finding semantic relationships between primitives from two or more communication protocols. Figure 1 shows an example of relations between two sets of primitives, where a dashed line represents a "is similar to" relationship and a continued line represents a "is equal to" relationship.

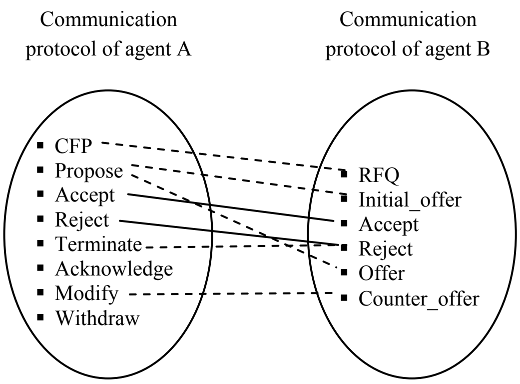

Figure 1: Relations between two sets of primitives.

A frequent methodology for aligning different communication primitives consists of processing definitions provided by human developers, based on classification algorithms and applying semantic enhancement of concepts. We think that the

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information provided by human developers is crucial for classification and enhancement of concepts. However, to obtain real semantics, we believe that a better approach would also consider the pragmatic usage of communication primitives in the communication protocol.

In this paper we present a pragmatic approach for aligning communication primitives, considering their usage in the protocol. To evaluate our solution we compare the resulting relations and show that our approach provides more information for relating communication primitives.

The rest of the paper is organized as follows. In section two we present related work with the subject of this research. In section three we describe the general procedure for aligning communication protocols. In section four we present a case study to show the applicability of our approach. In section five we evaluate the results and finally, in section six we conclude.

2 RELATED WORK

The problem of communication interoperability in MAS represents a common topic, which has been researched from different perspectives. (Guido et al., 2006) presented a common ontology of agent communication languages to bridge the gap between two approaches of defining semantics: mental attitudes and social commitments. (Fourlan de Souza et al., 2001) defined the problem of interoperability and presented Saci (Simple Agent Communication Infrastructure), a tool for programming communication among distributed agents and a CORBA bridge to overcome the interoperability problem. (Labrou et al., 1999) described the interoperability problem between agents. They stated that any solution should take into consideration three aspects: a) various languages, representing different programming paradigms, b) different hardware platforms and operating systems, and c) few assumptions about the internal structure of agents. They also described two possible layers of solutions: translation between languages and guaranteeing that the semantic content is preserved among applications. (Chaib-Draa, 2002) presented the related work and trends on semantics of ACL, he compared the semantics of KQML and FIPA-ACL, and identified that in both cases communicative acts are described in terms of beliefs, intentions, desires and similar mental states. Finally he concluded that agents are almost never programmed using such mental states directly. Therefore it is almost impossible to verify whether the messages are used correctly by the agents and the link between theory and practice in ACL use is still very big.

To solve the problem, the most common solution reported in literature consists of defining and using a shared ontology and a translation approach between the different ACL implementations. But the implementation of such a solution requires a human expert to analyze and compare among those ACL implementations to discover and define relations among primitives. In this specific task many authors have presented different techniques and algorithms for aligning and matching vocabularies in various research areas, such as data base schema integration, knowledge engineering, natural language processing and information systems integration. In data base research (Rahm, 2001) argues that “match” is a fundamental operation to manipulate data schemas, which takes two schemas as input and produces a mapping between elements that correspond semantically each other. (Batini, 1986) presented various data base schema integration methods and established three integration phases: schema comparison, schema conforming and schema merging. In the area of knowledge engineering various methods have been proposed. Chimaera (McGuinness, 2000) is a semi-automatic merging and diagnosis tool developed by the Stanford University Knowledge Systems Laboratory. It provides assistance in the task of merging knowledge bases produced by multiple authors in multiple scenarios. PROMPT (Noy, 2000) is an algorithm that provides a semi-automatic approach to ontology merging and alignment. PROMPT determines possible inconsistencies in the ontology, which result from the user actions, and suggests ways to remedy these inconsistencies.

In the above related works we can see a common concern in the problem of communication heterogeneity in MAS. We can appreciate also that there are many aspects in communications that can cause heterogeneity. Various authors have reported solutions based on the incorporation of ontologies, and the need for aligning concepts from different sources. Aligning is a task that depends on the provided semantics of communication primitives, but due to different implementations of agents, such semantics may differ from one agent to another. In this work we are dealing with communication protocols, where documentation of primitives is generated during development time. We take as input those descriptions and extract keywords to generate classifications according to the type of primitive. After classification we compare such classifications with the pragmatic usage of the primitive in the communication protocol. In contrast to reported works, in this paper we present a combined approach, which considers the information included in protocols.

3 ALIGNING COMMUNICATION PROTOCOLS

Aligning is the task of finding semantic relations among different concepts, in this work we are dealing with different ACL implementations, an ACL implementation consists of descriptions of communication primitives and definitions of protocols (sequences of messages). To find semantic relations among those communication primitives, most aligning solutions consider only the descriptions provided by human developers of agents; on the contrary, in this work we obtain the meaning of a communication primitive by analyzing its usage in the communication protocol. Therefore, we evaluate the moment when the primitive is issued in the communication protocol.

Figure 2 shows the general architecture for aligning communication primitives. The solution is a semi-automatic approach; it has an automatic extraction and classification of primitives, based on the use of a Bayesian-based classification, and a pragmatic analysis of primitives in protocols, based on the use of Finite State Machines (FSM). The overall process for helping agent developers and system integrators in the task of deploying multiple software agents over Internet is described next:

a). *Extraction of Communication Primitives*. The first step consists of obtaining the communication primitives and their descriptions. This process is executed by extracting the natural language descriptions of communication primitives from the agent communication interface. Currently we are getting this information through a Web-based environment.

b). *Classification of Primitives*. Once communication primitives have been acquired and their descriptions preprocessed, the next step consists of classifying the primitives. According to the classification scheme proposed by (Müller, 1996), communication messages are divided into three groups: *starters*, if they initiate a communication, *reactors*, if they react on a given statement and *completers*, whether they complete a communication. We took this classification because it considers the moment in the sequence of messages exchanged. We use a previously implemented ontology, which defines classes, subclasses and attributes. We apply a Bayes classifier to identify to which class each communication primitive belongs to.

c). *Align Primitives*. The next step consists of aligning primitives using a pragmatic approach, based on the use of finite state machines (FSM), in order to compare the primitive's real usage in the communication protocol. We believe that a combined strategy based on the analysis of syntactical description and protocol pragmatics provides more information of the relatedness of the communication primitives.

d). *Establish Relationships*. Based on the previous classification and aligning steps we can proceed to define semantic relationships between communication primitives, according to the following rules:

- Two communication primitives are ***equal (EQ)*** if they belong to the same class, and if they have the same usage in the FSM.
- Two communication primitives are ***similar_pragmatic (SP)*** if they do not belong to the same class, but they have the same usage in the FSM.
- Two communication primitives are ***similar_semantic (SS)*** if they belong to the same class, but they do not have the same usage in the FSM.
- Two communication primitives are ***different (DF)*** if they do not belong to the same class, and if they do not have the same usage in the FSM.

4 A CASE STUDY

In this section we present a case study to show the applicability of our approach. The objective of this case is to align a set of communication primitives from three different agents using their natural language descriptions and applying the process described in Section 3.

1. *Extraction of Communication Primitives.* Let *A*, *B* and *C* be the names of the agents that will participate in bilateral communication processes.

In table 1 we present the set of communication primitives and descriptions that agents use for formulating messages.

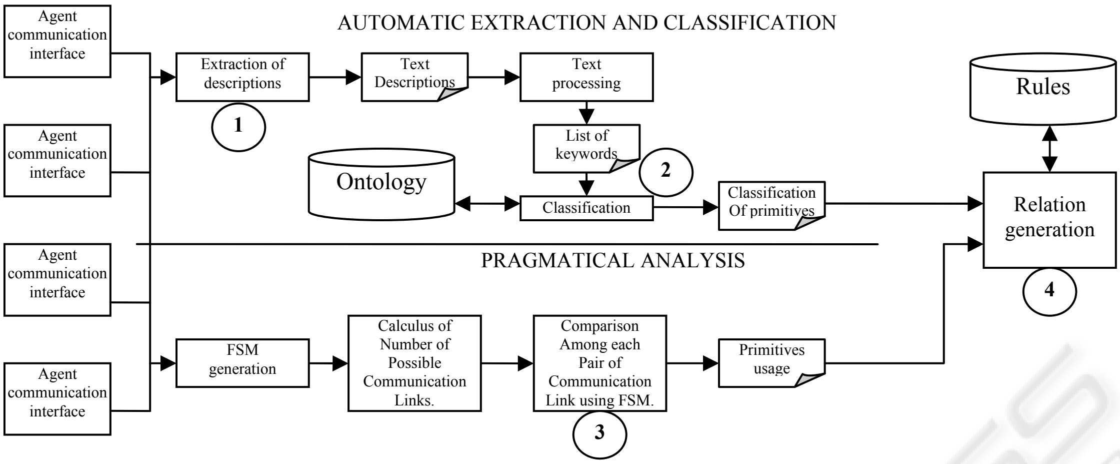

Figure 2: Architecture for classification and relation generation.

Table 1: Descriptions of communication primitives.

A	Communication primitives
	{(CFP, "Initiate a communication process by calling for proposals"), (Propose, "Issue a proposal or a counterproposal"), (Accept, "Accept the terms specified in a proposal without further modifications"), (Terminate, "Unilaterally terminate the current communication process"), (Reject, "Reject the current proposal with or without an attached explanation"), (Acknowledge, "Acknowledge the receipt of a message"), (Modify, "Modify the proposal that was sent last"), (Withdraw, "Withdraw the last proposal")}
B	Communication primitives
	{(Initial_offer, "Send initial offer"), (RFQ, "Send request for quote"), (Accept, "Accept offer"), (Reject, "Reject offer"), (Offer, "Send offer"), (Counter-offer, "Send counter offer")}
C	Communication primitives
	{(Call for proposal, "Initiate a call-for-proposal"), (Propose proposal, "Send a proposal or a counterproposal"), (Reject proposal, "Reject the received proposal with or without an attached explanation"), (Withdraw proposal, "Withdraw the previous proposal that was sent"), (Accept proposal, "Accept the terms and conditions specified in a proposal without further modifications") (Change proposal, "Change the proposal that was sent") (Inform proposal, "Inform the receipt of a proposal") (Terminate communication, "Unilaterally terminate the communication process")}

2. Classification of Primitives

According to the classes in the Ontology described in section 3, any communication primitive can be a *starter*, a *reactor* or a *completer*, depending on the time during the communication protocol, when it occurs. We preprocessed the descriptions of the primitives to extract keywords, and then using the definitions from the Ontology we applied a Bayes classifier to identify to which class each communication primitive belongs to. Table 2 presents the resulting classification of communication primitives of agents *A*, *B* and *C*.

Table 2: Resulting classification of primitives.

Starter	Reactor	Completer
CFP	Propose Modify Withdraw Acknowledge	Accept Reject Terminate
RFQ Initial_Offer	Offer Counter_Offer	Accept Reject
Call for proposal	Propose proposal Withdraw proposal Change proposal Inform proposal	Accept proposal Reject proposal Terminate communication

3. Align Primitives

To align communication protocols we need first to calculate the total number of communication links and identify the pairs of agents that may participate.

a) Number of Communication links

Considering a set of ***n*** agents, the possible number of peer to peer communication links among them is $\boldsymbol{n}^2$. However, as we are evaluating heterogeneity, we need to extract the number of communication links where agents are equal, which is $\boldsymbol{n}$. We also considered that a communication link between agents (a, b) has the same heterogeneity as a communication link of agents (b, a), thus we reduced the number of different communication links dividing by 2.

$$CL = (n^2 - n)/2$$
$$CL = (3^2 - 3)/2 = 3 \qquad (1)$$

B) Set of Different Communication links

Considering a set of agents, the set of different communication links is given by:

$$\boldsymbol{DCL} = \{ (a_1, a_2), (a_1, a_3), \ldots , (a_i, a_j) \}$$
$$\boldsymbol{DCL} = \{ (A, B), (A, C), (B, C) \} \qquad (2)$$

For each different communication link, we used a FSM to compare the real implementation of the primitives in the communication protocol. Figure 3 shows the aligned protocols of the different communication links:

a). FSM of communication protocol between agents A and B, which share the neccessary communication primitives to support interoperability;

b). FSM of communication protocol between agents A and C, both protocols share the three classes of communication primitives and other specific primitives: Terminate, Acknowledge and Inform that both agents use; and

c). FSM of communication protocol between agents B and C, with the neccessary communication primitives to support interoperability.

4. Establish Relationships

Taking the classification of primitives shown in Table 4 and the aligment of protocols shown in Figure 2, we finally established semantical relationships between primitives following the set of rules presented in Section 3. We defined only equal and similar relations for primitives that are syntactically different.

We did not established differences, because this kind of relations will not support communication interoperability. However, they are important to measure heterogeneity and to propose another solution based on a learning approach. Results of this process are shown in Table 3. To define relations we used the form:

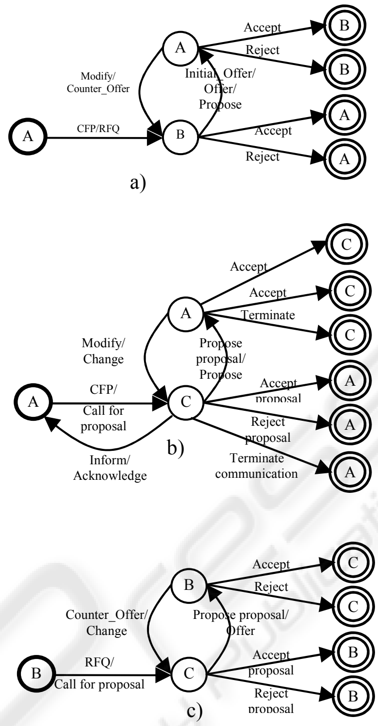

Figure 3: Relations between two sets of primitives.

Table 3: Semantic relations primitives.

CL(A, B)	CL(A, C)	CL(B, C)
EQ(A, CFP, B, RFQ)	*EQ*(A, CFP, C, Call for proposals)	*EQ*(B, RFQ, C, Call for proposals)
EQ(A, Propose, B, Offer)	*EQ*(A, Propose, C, Propose proposal)	*EQ*(B, Offer, C, Propose proposal)
EQ(A, Modify, B, Counter_offer)	*EQ*(A, Modify, C, Change proposal)	*EQ*(B, Counter_offer, C, Change proposal)
SP(A, Propose, B, Initial_Offer)	*EQ*(A, Withdraw, C, Withdraw proposal)	*EQ*(B, Accept, C, Accept proposal)
SS(A, CFP, B, Initial_Offer)	*EQ*(A, Acknowledge, C, Inform proposal)	*EQ*(B, Reject, C, Reject proposal)
	EQ(A, Accept, C, Accept proposal)	*SP*(B, Initial_Offer, C, Propose proposal)
	EQ(A, Reject, C, Reject proposal)	*SS*(B, Initial_Offer, C, Call for proposals)
	EQ(A, Terminate, C, Terminate communication)	

$$\boldsymbol{REL}(A_i, P_i, A_j, P_j)$$
where
A_i is the agent issuer of primitive P_i
A_j is the agent issuer of primitive P_j

5 EVALUATION

To evaluate our approach we considered important to measure heterogeneity among the set of heterogeneous agents. For this porpouse we defined *heterogeneity* as a numerical measure to compare the results before and after obtaining relations. The level of heterogeneity results from dividing number of different communication primitives (DCPT, without relationship) by the total number of communication primitives (CPT), see Formula 3.

$$\textit{Level of heterogeneity} = DCPT / CPT \qquad (3)$$

Figure 4 shows the level of heterogeneity for each different communication link, this measure was calculated before and after defining relations between primitives.

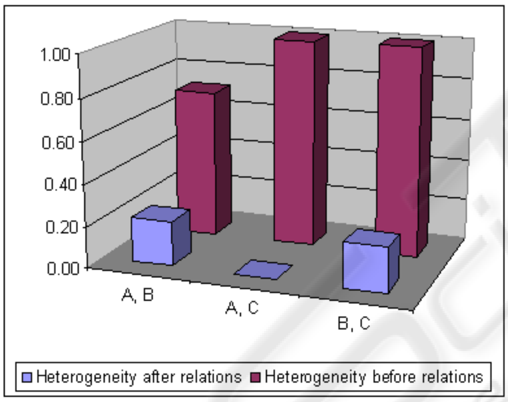

Figure 4: Level of heterogeneity before and after obtaining semantical relations.

6 CONCLUSIONS

In this paper we have presented a pragmatical approach for aligning communication primitives between multiple heterogeneous agents. Our approach is based on classification of human provided descriptions of primitives and the analysis of their usage in the FSM. The result of this analysis helps the developer to identify equality and similarity relationships between primitives by comparing the provided descriptions with the real usage of the primitive in the protocol.

Le level of heterogeneity measure was used to evaluate how the resulting semantical relations reduce the level of heterogeneity in communication scenarios.

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