

# Ontology-Services to Facilitate Agents' Interoperability

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**Abstract.** Ontology has an important role in Multi-Agent Systems communication once it provides a vocabulary to be used in the communication between agents. It is hard to find out two agents using precisely the same vocabulary. They usually have a heterogeneous private vocabulary defined in their own private ontology. In order to provide help in the conversation among different agents, we are proposing what we call ontology-services to facilitate agents' interoperability. More specifically, in the context of the work we are doing, we intend to include these ontology-services in the framework of an Electronic Institution. Our ontology-based services will be provided through such an Electronic Institution and will be responsible for providing structural and semantic relationships between different vocabularies, useful advices on how to negotiate specific items, leading to appropriate conversations and making agreements possible.

## 1 Introduction

An Electronic Institution (EI) helps the management of electronic transactions based on explicit sets of institutional rules and norms. In the context of our work, the EI will help in the automatic negotiation for the formation and after the monitoring of Virtual Organizations. The electronic institution will be implemented as a framework based in agents, where the agents interact among them according to sets of restrictions mutually established.

In order to make possible the interaction between agents in a Multi-Agent Systems, it is necessary to have a communication platform, a communication language and a common ontology.

One of the big problems to communication-based agents is that each one uses different terms with the same meaning or the same term for different meanings. Once we took this problem as a challenge, representing these differences in a common ontology becomes essential. The ontology includes the entire domain's knowledge, which is made available to all the components active in an information system [6].

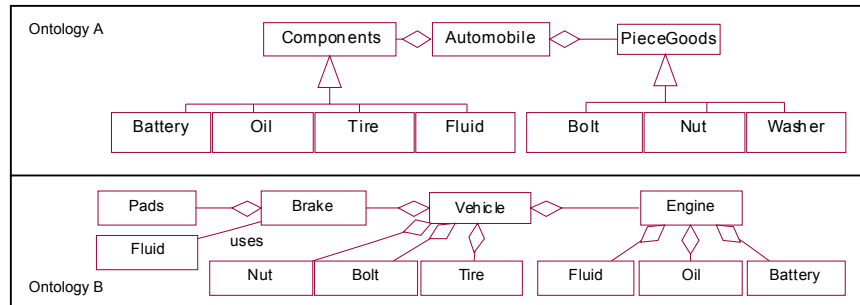
The use of a common ontology guarantees the consistency (an expression has the same meaning for all the agents) and the compatibility (a concept is designed, for the same expression, for any agent) of the information present in the system [10]. How-

ever, it is not sure that all the agents will use a common ontology. Usually, each agent has its heterogeneous private ontology and it cannot fully understand other agent's ontology.

Problems with heterogeneity of the data are already well known within the distributed database systems community [24] and they can be distinguished as follows:

1. Structural heterogeneity: meaning that different information systems store their data in different structures.
2. Semantic heterogeneity: considers the contents of an information item and its intended meaning. There are three main causes for semantic heterogeneity:
  - i. Confounding conflicts: occur when information items seem to have the same meaning, but differ in reality, owing to different temporal contexts.
  - ii. Naming conflicts: occur when naming schemes of information differs significantly.
  - iii. Scaling conflicts: occur when different reference systems are used to measure the same value. An example is the use of different currencies.

Fig. 1 shows two small parts of an ontology representation, with different views, but for the same domain of car assembling. Here, it is possible to see both the structural and the semantic heterogeneity types.



**Fig. 1.** Structural and Semantic Conflicts

If common domain ontology is used, it seems easier to know that people are speaking about the same subject. However, even with a common domain ontology, people may use different terms to represent the same item, the representation can be either more general, or more specific and with more details. Several difficulties are involved in providing a mapping capability between ontologies and several studies are being done to try to find a solution to that problem [24], [1].

It is also clear that agents using different ontologies make it much more difficult to establish a fruitful negotiation. An enterprise agent could provide some product with a better price and better conditions than others agents involved in a specific negotiation. Sometimes this agent does not participate in the negotiation because it does not know precisely the item (product/good/service) under negotiation; this may be caused by the fact that the enterprise agent had a different ontology in a different language or

structure and could not understand the meaning of the needed item or product. Besides these problems with language and terms representation, also other problems may occur like using different currencies to denote different prices, units to represent measures or mutual dependencies of products can make the negotiation process hard.

Our ontology-based services will be responsible for providing useful advices on how to negotiate specific items, leading to appropriate conversations and making agreements possible.

Next section presents all the steps needed for the operation of the electronic institution. Section 3 discusses about ontologies and the barriers to the effective agent communication process. Section 4 presents the architecture of the proposed system. The ontology-services are explained in the section 5. An integration of services-ontology and ForEV is proposed in section 6, and finally we conclude the paper in section 7.

## 2 Electronic Institutions

An Electronic Institution (EI) is a framework for enabling, through a communication network, automatic transactions between parties according to sets of explicit institutional norms and rules [16]. Due to characteristics of autonomous agents, a multi-agent system can encompass an EI to facilitate agent's interoperability in the Virtual Organization formation process. Below, the generic steps where the EI has a role are presented:

- i. The enterprise agents register in the EI.
- ii. When some enterprise agent needs some kind of service, it informs the EI about the basic requirements.
- iii. The EI send announce for the registered enterprises, which provide the service required.
- iv. Each one of the enterprise agents that provides the services required send announce for the EI.
- v. Those enterprises, which offer best proposes, are selected through a flexible negotiation process including learning and multi-attribute capabilities as well as distributed dependencies resolution.
- vi. According to sets of rules and norms, a contract is established between partners, forming a new Virtual Enterprise.
- vii. The EI monitors the partners' activities, keeping information about these activities for possible future intervention.
- viii. The EI breaks up the virtual enterprise distributing the obtained profits and storage of the relevant information for future use of the EI.

In order to obtain the efficient operation of the EI, it is necessary to use a communication standard, including communication protocols, communication languages and ontologies.

In the last years, standards for agent's communication language such as KQML (Knowledge Query and Manipulation Language) and ACL (Agent Communication Language) were developed. Platforms for distributed agents communication are also

available, such as JATLite (Java Agent Template Lite) and Jini. Content description language, such as KIF (Knowledge Interchange Format) and FIPA-SL (Content Language Specification) are also available.

In which ontologies are concerned, many studies are being done [2], [23], [8] but, currently, there is neither a standard ontology language nor a standard ontology knowledge representation. This lack of standardization, which hampers communication and collaboration between agents, is known as the interoperability problem [27].

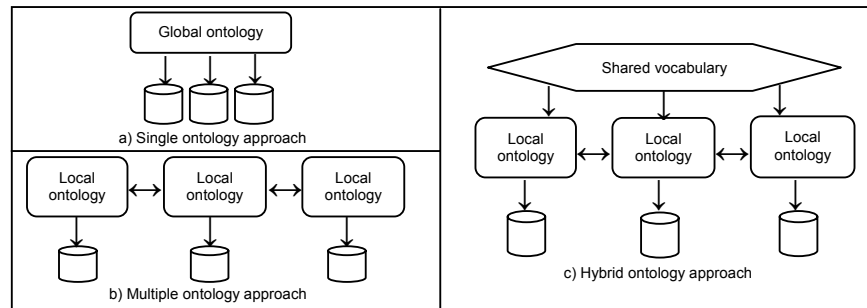
### 3 Ontologies and Tools

Ontologies are a popular research topic in various communities such as knowledge engineering, natural language processing, cooperative information systems, intelligent information integration, and knowledge management. The reason for ontologies being so popular is in large part due to what they promise: a shared and common understanding of some domain that can be communicated across people and computers [4].

There is not a unique definition for ontology. Several definitions [6], [25], [13] have been used and some of them are contradictory. A definition accepted in the multi-agent systems area, says that an ontology is a formal representation of concepts, characteristics and relations in each specific domain, allowing the common agreement of the people and software agents, and enabling a machine to use the knowledge of some application, multiple machines to share knowledge and still enabling the knowledge reuse [13].

Agents may use different ontologies to represent their view of a domain. Each domain can be specified in many different ways and this ontology mismatch is a question under intensive research.

[24] Presents three different directions on how to employ the ontologies: (i) single ontology approach, (ii) multiple ontology approach, (iii) hybrid ontology approach. Fig. 2 illustrates the three architectures derived from these approaches:



**Fig. 2.** The three possible ways for using ontologies

- i. Single ontology approach: uses a global ontology providing a shared vocabulary for the specification of the domain semantics. All informa-

- tion sources are related to a global ontology. The global ontology can also be a combination of several specialized ontologies.
- ii. Multiple ontology approach: each information source is described by its own ontology. In principle, the “source ontology” can be a combination of several other ontologies but it cannot be assumed that the different “source ontologies” share the same vocabulary.
  - iii. Hybrid ontology vocabulary: similar to multiple ontology approaches the semantics of each source is described by its own ontology. But in order to make the source ontologies comparable to each other they are built upon one global shared vocabulary. The shared vocabulary contains basic terms of the domain.

In this work, we are using the multiple ontology approach where each agent explores its own ontology. It is a decentralized and distributed approach according our multi-agent system architecture.

One would expect that by using ontology, heterogeneous agents developed by different participants and located at different places could be able to share a common ontology to provide a basis to a meaningful conversation, to ease advanced knowledge sharing between computers and human beings and to assure the accuracy as well as the quality with which agents communicate their abilities and properties to other agents.

One of the problems of using different ontologies is that there exist different representations and terminologies and there is not a formal mapping between high-level ontologies. [20] Enumerates some barriers to effective agent communication:

- i. There are many different ontology languages.
- ii. Different ontology languages are sometimes based on different underlying paradigms.
- iii. Some ontology languages are very expressive, some are not.
- iv. Some ontology languages have a formally defined semantics, some do not.
- v. Some ontology languages have inference support, some do not.

Even if the exact same language is used, these ontologies can be incompatible in various ways:

- vi. People or agents may use different terms for the same thing.
- vii. People or agents may use the same term for the different things.
- viii. A given notion or concept may be modeled using different primitives in the language.
- ix. A given notion or concept may be modeled with very different fundamental underlying primitives.

A lot of different tools for developing ontologies [4] and tools for mapping, aligning [14] and reusing [15] of ontologies are available but there is no automatic way to do that, it is still a difficult task.

There already are tools for ontology translation [5] through some representation language. The uses of such tools imply offline processing and, therefore, are inappropriate for an agent-based system.

A real challenge is the automation of items translation from one ontology used by agent A to another one used by agent B.

Some research has been done trying to solve the problem of interoperability, using semantic relations, lexical taxonomy, semantic similarities, linguistic similarities of terms, taxonomic relationships, using text information.

Taxonomies are a central part of most conceptual models. Properly structured taxonomies helping bringing substantial order to elements of a model, and are particularly useful in presenting limited views of a model for human interpretation, and play a critical role in reuse and integration tasks [26].

[9] Proposes a system to compare versions of concepts. The system maintains the transformation between ontologies, some meta-data about versions, as well as the conceptual relation between concepts in different ways.

For measuring semantic similarity between words and concepts a new approach is presented by [7]. It combines the lexical taxonomy structure with corpus statistical information so that the semantic distance between nodes in the semantic space constructed by the taxonomy can be better quantified with the computational evidence derived from distributional analysis of corpus data. This is an important application for word sense disambiguation.

An approach about computing semantic similarity that relaxes the requirement of a single ontology and accounts for differences in the level of explicitness and formalization of the different ontology specifications is present by [17]. A similarity function determines similar entity classes by using a matching process over synonym sets, semantic neighbourhoods, and distinguishing features that are classified into parts, functions, and attributes.

[12] Presents two implemented methods based in linguistic similarities of terms used in the ontologies. The first looks up a dictionary or semantic network like WordNet and the second determines similarities of words based on word similarity composed from a domain-specific corpus of documents.

Other researchers are developing ontology learning trying to do a semi-automatic ontology creation using a balanced cooperative modeling paradigm [11]. Ontologies are built in different ways and with different formalisms; because of that, using text is an interesting way of eliminating the problem of different representations.

In the specific multi-agent system area some proposals have been made and implemented:

[21] Presents an upper ontology based on content reference model that provides the semantic for message content expressions. A tool is also presented which can assist agent programmers in designing message content ontologies with the Protégé.

A communication mechanism in which translators between the vocabularies of agents are generated was developed by [22]. These translators are dynamically constructed during execution stage system, and are both based on the information the agents exchange and on their underpinning ontologies. Moreover, these translators

are not necessary defined for the total vocabulary of the agents, but instead, only for the parts that have been involved in communication steps.

[3] Presents the project OntoMap, whose objective is to facilitate an easy access, understanding, and reuse of general-purpose ontologies and upper-level models. They propose a language OntoMapO that provides some expressive power via single kind of expressions-binary relations between concepts. The idea is that domain specific and upper-level ontologies are loaded in the ontology of OntoMap and hosted there. This way the ontology will become accessible in all the formats supported, and the mapping will be also available in all of the supported formats.

An ontology model is presented by [19], which supports knowledge sharing in multi-agent systems where the agents are heterogeneous. The proposed model extends the usual ontology frame-based model such OKBC by explicitly representing additional information on the slot properties. This knowledge model results from a conceptual model which encompass semantic information aiming to characterize the behavior of properties in the concept description

[27] Deals with the heterogeneity by identifying an agent's internal knowledge representation with an abstract ontology representation (AOR). This AOR can be used to capture abstract models of communication related knowledge and make it possible for the agent to manipulate all elements of message in a uniform way.

An implementation of FIPA 98 Spec 12: Ontology Service is presented in [18]. There a sample application of ontology shopping service that integrates multiple database schemata using the ontology service to verify and demonstrate the specification and the implementation is presented.

## 4 Architecture

In an open environment where the agents can register themselves and negotiate, an ontology agent is useful to monitor all the communications and negotiations.

In our multi-agent system for VE formation there are at least 4 agents: market agent, builder agent, provider agent and ontology agent. However, it is possible and interesting for the negotiation process to have more than one provider agent.

The market agent is the entity that facilitates the meeting of agents and supports the negotiation process.

The builder, provider and ontology agents have to register themselves in the market to be able to communicate. Each agent has its own private ontology built in a private and unknown way.

Builder agent represents the enterprise interested in buying some components to build a final product. Several providers in the world may have these components with different prices and conditions. The builder agent sends a message to market to inform about the nature of components of the product (which product) that it wants to buy in order to build the corresponding product.

Provider agent represents the enterprise interested in providing some kind of product. Whenever a product is necessary, the market agent will send announce to provider agent.

Ontology agent is monitoring the whole conversation trying to help when it is necessary, providing some kind of services (discussed in section 5).

Whenever agents register, they also indicate their capabilities. This information becomes crucial for the negotiation stage. For the sake of tests, the initial scenery is the assembling car domain. We have an agent builder, which wishes to buy components to build cars of a specific model, and several provider agents, which may have, or not components to sell them.

The platform we are using to implement the multi-agent system is JATLite and the communication language is KQML. The ontology agent includes a basic domain ontology represented in XML.

The Fig. 3 shows an example of the multi-agent architecture where links represent agent's communication and the ontology agent monitoring.

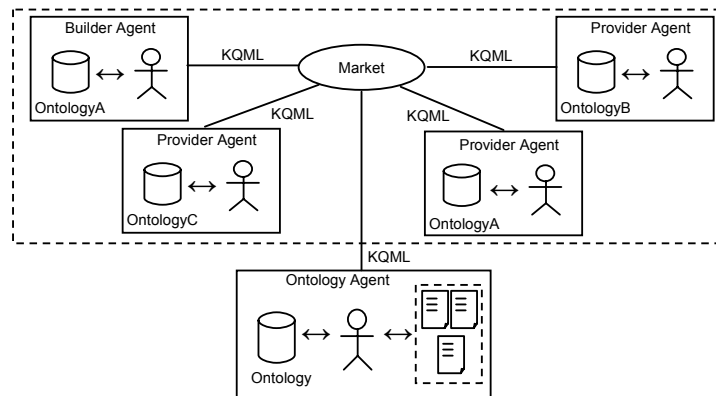


Fig. 3. Architecture of the system

## 5 Ontology-Services

In order to help in the communication and negotiation between agents, some ontology-services are provided:

- i. Definitions or relationships between expressions.
- ii. Definition of product attribute's dependencies.
- iii. Capabilities for defining, modifying and deleting expressions and ontology definitions.
- iv. Abilities to translating expressions between two different ontologies.
- v. Possibility to learn with the ontology services already provided so that it could be possible to use this information in a future negotiation.
- vi. Converting values when agents work with different metrics (like currencies).



We will also try to integrate an ontology editor to allow the definition of new ontologies.

Our proposal is that the ontology agent will monitor and help the communication process at the moment when it is happening, without having to do a mapping of all the ontologies involved.

One of the most complex services is to help in the communication when the agents use different terms for the same meaning. When a provider agent receives announce of some product/component, the provider agent has to answer if it has the component to provide or not. If the answer is “I don’t know”, the ontology agent understands that this agent may have the component but it may not know the meaning of the used term.

Therefore, in order to help the resolution of this incompatibility, the ontology agent:

- i. Searches for synonymous in its own ontology to find equivalent terms known by the receiving agent.
- ii. Searches for relations like “is”, “is-a”, “part-of”, and “compose-by”, in order to find out a different way of expressing the unknown term.
- iii. Searches for characteristics of the component, which can help the provider ontology to find another component with the same characteristics.
- iv. If all the previous steps are not enough, the ontology agent may not know the terms in appreciation, and then it looks in texts for new meanings and characteristics. A database of domain texts is used for the ontology agent to find terms. The text processing stage can help to find terms of a domain and can help to find relations between concepts. Using texts is not an easy work but it looks natural to use texts based on natural language to understand the communication, which is going on.

If in the end of all the process it was possible to find some matching terms, it becomes necessary to establish a protocol for confirmation when the provider agent sends the term that is the probable matching term and the ontology agent makes the validation.

Another service provided by ontology-services agent is to help during the negotiation when agents are using different currencies. The ontology agent accesses a free web service that gives the currencies in real time. This way the agent can choose the currency, which will be used during the negotiation.

The dependencies are also a problem about which the ontology services can help. Some products already have dependencies, which are better to be known during the negotiation. For example, when the agent is buying a light for the car, there are several kinds of lights, brake light, cross light, fog light, and others. In order to be able to insert the light in the car, it is necessary to buy a light-holder. There is already a standard, which says which light-holder is necessary for each kind of light. So, the ontology agent can help during the negotiation giving this kind of information.

## 6 Integration of Ontology-services in ForEV

ForEv (acronym for Virtual Enterprises Formation equivalent in Portuguese) is an appropriate computing platform, which includes and combines negotiation's methods in the context of Multi-Agent Systems, which is suitable for Virtual Enterprise formation scenario [10].

The negotiation's methods try to satisfy the electronic market dynamics and competitiveness requirements. The negotiation process is between independent enterprises leading to the Virtual Enterprise formation, and relies on an iterative, multi-attribute negotiation protocol appropriated for the context of a business activity. In order to solve the simultaneous partial inter-dependent negotiations dependency problem, arising during the Virtual Enterprise formation phase, a specific algorithm was developed. This algorithm is a decentralized distributed dependency satisfaction problem solver, which is based on the progressive utility decrement concept. Through the application of this algorithm, the Multi-Agent System is able to, in a non-centralized way, select that solution which minimizes the total agent's utility decrement value for those agents involved in that specific dependency.

Agents represent the enterprises and customers in the system. There is a Market Agent (MA) and several Enterprise Agents (EA). The MA and EAs all together through a website cooperating with the objective of providing or getting goods, keep their own preferences and objectives.

The goods are described in an ontology, which is known and understood for all the participants. The system has also a register agent responsible for building and maintenance of the domain ontology. This agent is responsible for distribute the necessary information about this ontology when asked for some agent. The ontology-services can be integrated in ForEv allowing the use of heterogeneity ontology.

Integrating the ontology-services with ForEV makes ForEV more opened, enabling establishment of the negotiation process between agents with different ontologies although representing the same domain of knowledge.

## 7 Conclusions

A big challenge for communicating agents is to resolve the problem of interoperability. Through the use of a common ontology it is possible to have a consistent and compatible communication.

Several problems involved in the resolution of interoperability are difficult to be solved, at least nowadays, but it is important to look for possible ways to resolve parts of the problem.

This paper was focused on the use of multiple ontology approach, where each agent explores its own ontology. It is a decentralized and distributed approach according to our multi-agent system architecture.

Ontology-based services were proposed to help the communication and negotiation between agents. In an open environment where agents can register themselves and negotiate, ontology agent is used to monitor and lead the communication process

at the moment when it is happening, without having to do a mapping of all the ontologies involved.

The integration of ontology-based services with ForEV is also proposed to make this computing platform more opened and to allow ForEV to use the heterogeneity ontology by the agents during negotiation process.

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