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Deontic Logic-based Framework for Ontology Aligment in Agent Communities

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Abstract: In this paper we consider a multiagent system with multiple ontologies. The agents maintain the ontologies individually which leads to frequent changes and possible knowledge inconsistencies. We propose a general framework for decision making about ontology alignment and negotiation which takes into account the properties of the actual communication network and utilizes the Deontic Logic formalism for reasoning.

Keywords: deontic logic, social web, semantic web, multiagent systems, ontology aligment
Categories: H.1.0, H.1.2, H.1.3

1 Introduction

Modern networked systems involve cooperation and information exchange between vast number of components which are fundamentally different by their nature – humans, software agents, specialized services, database engines and so on. At the same time World Wide Web established itself as a global, ubiquitous environment for information exchange and processing. By connecting large number of individuals the Web enables creation of virtual communities and, during the last 10 years, established itself as an universal collaboration infrastructure.

Sharing knowledge within such an environment requires a shared conceptual vocabularies - ontologies, which represent the formal common agreement about the meaning of data [Gomez-Perez, 02]. Artificial intelligence defines ontologies as explicit, formal specification of a shared conceptualization [Fensel, 01]. In this case, a conceptualization stands for an abstract model of some concept from the real world; explicit means that the type of concept used is explicitly defined. Formal refers to the fact that an ontology should be machine-readable; and finally shared means that ontology expresses knowledge that is accepted by all the subjects.

From the other hand, it seems inevitable, that ontology, as a knowledge model for given domain, must contain concepts referring to many different objects from real world. Modern socio-technical systems need to be represented by models that capture their components, the relations between them, and attributes of the components and relations [Carley, 07]. In such systems we observe the continuous processes of combining data of different origin to refine state estimates and predictions, which is defined as data fusion [Steinberg, 99]. As we'll see below ontologies may play a key role in modern data fusion scenarios. But we also face the inevitable fact that knowledge creators independently alter domain models causing possible inconsistencies which impact the quality of data fusion processes.

Development of dynamic intelligent services is inevitably connected with so-called *semantic technologies* – functional capabilities that enable *both* humans and machines to create, discover, organize, share and process the meanings and knowledge [Davis, 06]. This is achieved by the use of shared vocabularies (ontologies). On the level of WWW this implies the adoption of the Semantic Web's XML-based standards for annotating and processing information, usually in the form of web ontologies [Berners Lee, 01]. Because ontologies are developed and managed independently the semantic mismatches between two or more ontologies are inevitable. Practical applications show that fully shared vocabularies are rather exceptional - a number of possible different semantic conflicts was identified by Shaw and Gaines [Shaw ,89], other classifications were addressed in [Hameed, 01]. The vision of Semantic Web allowing agents to publish and exchange ontologies requires strong mechanisms supporting ontology alignment [Hendler, 01].

As shown in the next sections there are many results investigating the structure of the contemporary networks and there are also some recent results which evaluate the large-scale structure of semantic nets and ontologies. But there are no works which deal with joining these issues under a common umbrella. The aim of this paper is to propose a framework for modeling *semantic interactions* in large multiagent communities. By semantic interaction we will understand the act of modifying the internal knowledge representation (in the form of ontology) as a result of communication between agents. The rationale for such an environment is to investigate the conditions underlying the emergence of common vocabulary in the agents' community and the dynamics of knowledge changes in the system.

To be compatible with the latest results the framework itself must integrate and formally represent the following components:

- Community structure (the architecture of links between actors).
- Community dynamics (the mechanism of formation of new links).
- Communication model (the rules of choosing the communicating party).
- Semantic interaction model (the rules for establishing communication link and/or modification of internal knowledge representation as a result of the communication)

In order to do this an architecture of modern networks and the properties of large semantic networks will be presented in the following sections. We propose to support the ontology alignment processes with the deontic logic reasoning which will be conducted with respect to the actual roles the agents perform in the conmmunication network. This will allow to overcome the known difficulties met when trying to achieve the semantic consistency between all pairs of the agents (even these which in fact never communicate) – this will be further discussed in sec. 2.3.

2 Agent Networks

2.1 Network Topologies and Dynamics

Complex network structures emerge in many everyday situations among people (social networks), organizations, software agents, linked documents (WWW) and so on. Previous research has identified the most distinctive properties of such networks [Watts, 04], [Carrington, 05]:

- Small diameter and average path length (of the order of Log(N) for N network nodes).
- High clustering (probability that the neighbors of any given node will be also each other's neighbors)
- A famous power-law (or scale-free) network node degree distribution.

These properties may be of use when simulating interaction between system components and building evolution models, and they form a basis of many robust and applicable theoretical results. It was shown that they influence the search strategies, communication and cooperation models, knowledge and innovation spreading etc. [Steyvers, 05], [Watts, 04].

Moreover, last results show that we may expect similar phenomena on the level of knowledge representation: in [Steyvers, 05] a large-scale structure of the semantic networks of three types was evaluated. It was shown that all the three (free word association network, Roget's thesaurus and WordNet lexical database) appear to be of small-world structure which (as a graph) may be characterized by sparse connectivity, short average paths and high node clustering – just like in the case of abovementioned networks. The Authors state [Steyvers, 05]: *We argue that there are in fact compelling general principles governing the structure of network representations for natural language semantics, and that these structural principles have potentially significant implications for the processes of semantic growth and memory search*. In fact, from now on any computational model should take these results into account. A model of growing semantic network was also proposed but it was based on concept differentiation scheme and didn't assume multiple actors and the nature of interactions between them.

From the other hand the process of acquiring new concepts (concept learning) via communication was investigated in many other works, for example in [Ke, 02] a mathematical model was used to simulate the emergence of coherent dictionary in a population of independent subjects (agents). The Authors proposed a well-known mechanism of language imitation as a self-organization factor. However, in these experiments a random communication and interaction strategy was assumed, which is not straightforward in real multiagent and social environments. As stated in the preceding section neither connection nor communication pattern between the agents are random. They show the properties of the scale-free net.

Now the challenge is to span a bridge between known properties of dynamic self-organizing agent societies and the knowledge representations (ontologies) emerging within them.

So far a little work, both theoretical and practical, has been done within the area of ontology negotiation in multiagent societies [Bailin, 01]. From the other side semantic interoperability between ontologies is crucial in many disciplines – from gathering and processing of scientific information to e-commerce applications.

Consider the society of n agents with multiple ontologies. If we want to effectively resolve semantic mismatches within such a community without intervention of human operator, there are several aspects that must be addressed. They'll be discussed in the next sections.

2.2 The Semantic Interactions in Agent Networks

The architecture of the proposed framework consists of a set of agents (interpreted as software components as the framework is proposed to be applied the Semantic Web environments), each of them is equipped with private vocabulary in the form of ontology. They may mutually overlap but there will also be inevitable differences. These vocabularies are suggested to be large-scale structures, which are then modified in the process of communication between the agents (Figure 1).

The activity of the system components is based on the following assumptions:

1. The architecture of connections (communication links) between agents conforms to the small world model (as shown in [Watts, 04]).
2. The individual semantic nets (ontologies) of the agents show scale-free properties as proved in [Steyvers, 05].
3. The communication model is preferential (agents tend to connect to the hubs first, due to connectivity and information content).
4. Semantic interactions between the agents follow the the *imitation model* [Carrington, 05]. This approach was investigated and documented by many researchers and serves as explanatory mechanism for the emergence of common vocabulary in communities of humans and social animals. It assumes that the agents change their private vocabularies on the basis of interactions with the others. In particular they may accommodate the meaning of the concepts used by their counterparts if they found it reasonable. In most simulations it is assumed that the imitation process is random (see [Steyvers, 05])..

Let's now list the parameters needed in our framework. Let $\boldsymbol{A} = \{A_1, A_2, \ldots A_n\}$ be a set of agents and $\boldsymbol{O} = \{O_1, O_2, \ldots O_n\}$the set of their private ontologies. Each agent A_i uses ontology O_i as an formal conceptualization of particular domain of interest. We denote the set of concepts of ontology O_i as $C_i=\{c_1^i, c_2^i \ \ldots\ c_{m(i)}^i\}$ and the relations between them as R_i. Each agent A_i has also an associated utility function $u_i : \boldsymbol{O} \rightarrow [0,1]$ which is to express the potential attractiveness of the other agents as communication counterparts of A_i. In the simplest case A_i may define a list of important concepts and u_i will return the result based only on the set comparison between set of concepts of given ontology and the list of topics A_i is interested in. This means that A_i is willing to communicate with the agents which have knowledge on the specific topics.

The network structures of the system are represented by communication graph represented by n × n matrix G where an entry g_{ij} indicates the presence of directed link from the node (agent) A_i to A_j, and the graphs reflecting the structure of private agents' ontologies. Each of these ontologies O_i may be viewed as a graph $SemNet_i$ with nodes corresponding to concepts from C_i and edges corresponding to relations from R_i. According to [Steyvers, 05] we assume that these graphs show small world properties.

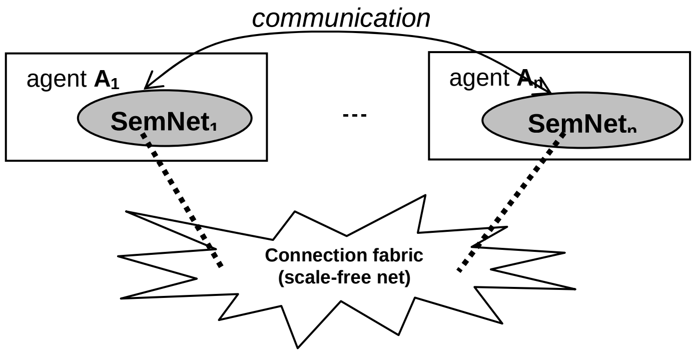

Figure 1: The architecture of the multiagent system

2.3 Building Agent Societies - Complexity vs Semantic Consistency

Existing results show that the task of aligning ontologies is rather complex. Even if there are only two ontologies involved, aligning requires many operations and in general time-consuming. Under assumption that any two of n agents may interact with each other, we may expect up to n^2 operations of ontology alignment. This may lead to unacceptable computational overload and significantly impact the overall consistency of ontologies. Presented framework allows to formally relate concepts from any two ontologies O_i and O_j under condition that there is an "alignment path" between the agents A_i and A_j. The optimal number of alignments depend on many factors (values of thresholds, number of ontologies, topology of agents' society).

The other problem is desired accuracy of the alignment which is strongly connected with the application area the agents act in. Some tasks (like e-commerce applications) require strict accuracy – only identical concepts should be aligned. The other (for example information search) are less restrictive – the approximation of concepts may also be of use here. Accuracy of concepts' mapping is controlled by the threshold values of similarity measures. Of course an agent may freely set the threshold values, they also do not have to be constant. In the case of changing threshold values by one or more agents (regardless their motivation), an information about this fact must be broadcasted and all agents in the society must recalculate their opinions which are dependant on the thresholds. Note that this doesn't lead to repeating operations of ontology alignment.

Society of autonomous agents may be organized in accordance with two basic conceptions. The first one assumes that any two of the agents may independently communicate and align ontologies – this is the case already described in the preceding sections. Figure 2 shows six agents, some of them (joined by lines) have aligned ontologies.

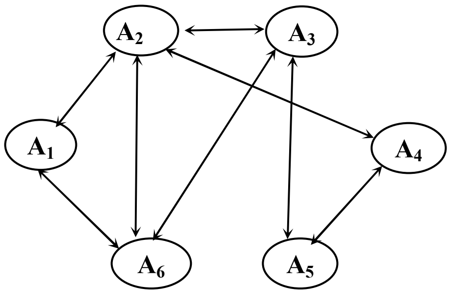

Figure 2: Ontology mapping between independent agents.

The second strategy is to negotiate a global ontology, common for all of the agents. Communication between given pair of the agents is then performed by means of global ontology OG. Private ontologies of the agents are aligned with OG (Figure 3). In this case the number of mappings is reduced to n, and – in theory – high level of semantic integration is assured. Moreover, after creating OG, further processing of ontologies is unnecessary. However, practical realization of this scenario meets serious problems [Silva, 05], creating single ontology OG out of n input ontologies results in unacceptable loss of semantic information and has high computational cost. From the other hand, available global solutions (like WordNet or IEEE Standard Upper Ontology) are too general and, in practical applications, must be replaced by task-specific ontologies.

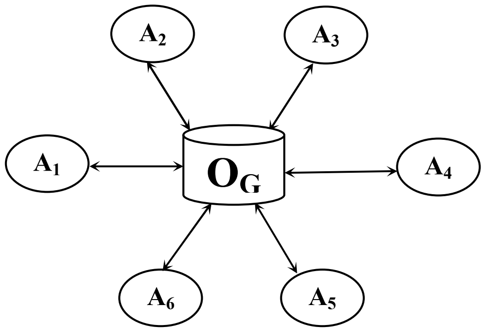

Figure 3: Communication via global ontology.

2.4 Ontologies and Information Fusion Tasks

Typically we distinguish several levels of data fusion [Steinberg 99]. For example we may define a 3-level scheme in which level 1 covers data annotation and attribution. Level 2 of data processing involves associating annotated data into aggregations which means the creation of a network of relations among them. Level 3 means the impact assessment, i.e., estimating the effect of actions being observed (related events are compared with known complex scenarios or patterns which is often referred to as *situation assessment*).

Ontology plays a key role on all levels: data are annotated by using of concepts and attributes contained in the ontology, candidate relations are discovered with respect to domain knowledge model and finally situation assessment is performed on the basis of knowledge about possible domain scenarios. In order to effectively use ontology in multilevel data fusion it should represent possible domain objects and relationships as well as their evolution over time. Also, it is postulated to express any "reasonable" evolution of objects and relationships thus allowing situation assessment and event prediction [Matheus, 03].

From the other hand when we consider a typical multi-user (organizational) scenario, users frequently alter their private ontologies and there's a need of relating concepts that are semantically close or identical (via equivalence or subsumption relations) to achieve mutual understanding of processed data and allow consistent data fusion. The operation of identifying such concepts is called ontology alignment. Ontology alignment is a mapping between concepts defined in a source ontology and concepts defined in a target ontology. To align ontologies one must specify the concept from the target ontology that represents as closely as possible the meaning of the source ontology concept [Klein, 01]. Then the corresponding concepts may be mapped onto each other, thus ensuring knowledge consistency. A further discussion and the survey on ontology-mapping methods was presented in [Kalfoglou, 03].

In this context data fusion processes appear to rely on organizational knowledge sharing activities (in the sense that consistency of domain knowledge - ontologies - has impact on the quality of fusion). Recent results show that sharing and mediation of knowledge is much more effective if performed in accordance with social relations within the organization [Sorenson, 03]. Moreover, it is easier to maintain constant changes in ontologies (a.k.a ontology drift) when we assume following social and communication patterns of the users who create ontologies [Mika, 07]. Hence, an organizational scheme for ontology alignment based on the actual social structure of the organization will be proposed in the next section – it will serve as a basis for making decisions about the ontology alignment processes

If we consider ontology-based data fusion in multi-user environment with an assumption that multiple private ontologies are in use we have to propose an ontology alignment strategy in order to preserve the semantic consistency in the agent society.

3 Social Agent Networks and Ontology Alignment

People who interact with one another or share common interests form a social network. A social network is defined as a finite set of individuals, by sociologists called actors, who are the nodes of that network, and social ties that are the links (connections) between them [Garton, 97]. Of course there exist Internet-based social networks which base on the computer networks services and infrastructure, those can be detected by means of analyzing communication activities. In the simplest (and most popular in literature so far) case only mail logs are analyzed but the other communication channels (chat service, blogs, discussion lists) can also be taken into account [Culotta, 04]. The set of all discovered relations constitutes the organizational social network. We will use this network as a guidance for maintaining ontological consistency within the system.

Communication-based social network is subject to periodic changes – ongoing communication between users may lead to creation of new relations which are reflected in updated network structure. If we consider that the users use their ontologies to perform data fusion we naturally aim to maintain the consistency of their knowledge models (ontologies), which involves ontology alignment. Hence, the lifecycle of our environment consists of 7 steps which are repeated in a cycle:

1. Performing communication activities.
   This means the usual users' activity – exchanging communicates, cooperation, discussion and so on..
2. Updating social network structure.
   Social network's structure is being updated if there appear new communication links. This is being done in the background.
3. Modifying private ontologies.
   The users (as knowledge creators) may modify their domain models (ontologies) by adding or removing concepts, relations or attributes.
4. Checking ontology consistency.
   Ontology consistency is checked along the social links detected in step 2. We assume performing ontology alignment only when needed and only between communicating users.

In our approach we use a Taxonomic Precision (TP), a similarity measure based on the notion of semantic cotopy (see def. 2 below) recently presented and analysed in [Dellschaft, 06]. The reason to chose this measure was its ability to compare ontologies as whole structures and along multiple dimensions. The TP will serve as a general measure of consistency between two ontologies. The legal values of TP are from the range [0,1]. Note that high value of TP means that the two users may consistently use resources annotated with their private ontologies, perform reasoning tasks etc. Now we introduce the basic definitions needed to formulate the notion of Taxonomic Precision.

Definition 1. The ontology O is a structure O := (C, root, ≤X) where C is a set of concept identifiers and root is a designated root concept for the partial order ≤X on C.

Definition 2. Semantic Cotopy sc(c,O) of a concept c from ontology O is a set containing c and all super- and subconcepts of c in O, excluding root concept root(O).

Definition 3. Taxonomic Precision of a concept c and the two ontologies O 1 and O 2 such that c∈ O 1 and c∈ O 2 is defined as:

$$tp(c,O_1,O_2)=\frac{|sc(c,O_1)\cap sc(c,O_2)|}{|sc(c,O_1)|} \tag{1}$$

Definition 4. *Global Taxonomic Precision* TP(O_1,O_2)of the two ontologies O_1 and O_2 is defined as:

$$TP(O_1,O_2)=\frac{1}{|C_1|}\sum_{c\in C_1}\begin{cases} tp(c,O_1,O_2) & if \quad c\in C_2 \\ 0 & if \quad c\notin C_2 \end{cases} \tag{2}$$

where:

C_1, C_2 – the sets of concepts of O_1 and O_2 respectively. Note, that the TP is asymmetric, this feature follows frequent approach according to which semantic similarity is asymmetrical; for example: there is an obvious inherent similarity between a concept and its superconcept (like *truck* and *vehicle*) but their domains are different and the first is contained in the second. Hence, its convenient to reflect this fact when defining semantic similarity measures.

5. Perform ontology alignment along the social links.
   If the global taxonomic precision is below some fixed threshold value (which means that the given pair of users have inconsistent domain models) we perform ontology alignment with help of chosen algorithm (for example: one of the listed in [Kalfoglou 03]).
6. Gather data.
   The users acquire external data which will be further processed and fused.
7. Perform multilevel data fusion.
   Ontology based multilevel data fusion with situation assessment is carried. Consistent ontologies guarantee the common understanding and applicability of fusion results.

In the following section we postulate the assignment of specific roles to the agents. They are to reflect their position within the structure of social network. Then we will define a logic-based framework formalizing and guiding the processes of ontology alignment with respect to the actual communication occuring in the agent network.

4 Roles in the Agent Society

Almost each group of subjects that interacts with each other create its own policy that can be defined either explicitly or implicitly. This policy is intended to influence the behavior of subjects and objects associated with the group. The policy constitutes a set of roles and describes relations between them. The roles are sets of rules that governs the behavior of all subjects that have been activated in it. Each subject active within the group can perform actions in a context of one or several defined in policy roles. In the paper we propose the approach based on the concept of role-based access control [Barkley, 97], [Ferraiolo, 97], [Sandhu, 94]. This approach uses roles to distinguish a few the most essential classes of software agents and to set the boundaries of their activities. The proposed set of roles will be derived from the positions the agents hold in agent network. The analysis of the evolution of relations between communicating software agents resulted in the following types of roles proposition (Table 1).

	Name of the role	Short description
1.	*Role_Creator*	This role describes the character of 'active' agents; where the types of the activity can be following: internal ontology modification. The knowledge creator is an agent who changes or creates from scratch his personal ontology. This involves the possibility of obligatory ontology alignment if the change has caused the knowledge inconsistency between agents.
2.	*Role_Hub*	This role brings together all agents that are the hubs in the sense of the communication between agents and the communication graph analysis; they are important in the communication structure and so in information flow. An agent who intensively communicates with the others is taking a hub role. From the point of view of network structure the hub is a node with high degree – there are many edges connecting it with the others.
3.	*Role_Reader*	All agents that play *reader* role are mainly interested in obtaining the knowledge from the other agents, they modify their interior structures (ontology) only as the result of obtaining some 'exterior' signals (the threshold value of the function signalizing the ontology alignment necessity)
4.	*Role_New*	*New* agents are the agents that have joined the network recently and so they do not have long history of interaction with other agents

Table 1: List and short description of possible agents' roles

The question which of the agents may be referred to as *hubs* requires checking the network structure. In general, 5% of network nodes with high degree centrality may be called network hubs. As social and communication networks are mostly scale-free structures, these 5% of nodes group individuals with the number of links exceeding the others by the order of magnitude (or more).

However, degree centrality is not the only one indicator of the importance of a node in communication network. Intuitively, the nodes which serve as *bridges* (connecting nodes which do not form direct links with each other) are also very important, and their semantic consistency within the network should be maintained with special care. These nodes may be detected by computing so-called clustering coefficient, the measure reflecting the local graph connectivity. The standard form of clustering coefficient is defined according to eq. 3:

$$CC = \frac{2\left|E\left(G1(n)\right)\right|}{\deg(n)\left(\deg(n)-1\right)} \tag{3}$$

where:

deg(n) – denotes degree of node *n*,
G1(n) – is the set of nodes which are connected with *n* via single link (its immediate neighbours),
|E(G1(n))| – is the number of edges among nodes in 1–neighbourhood of node *n*,

We also assume that for a node *n* such that $deg(n) \leq 1$ all clustering coefficient are 0. The intuitional meaning of the *CC* is that it represents how many edges exist within 1-edge radius from the node *n* compared to the number of possible edges. *CC* equalling 1 means that the nodes in 1-edge distance from *n* form a full graph.

Summing up, in order to be qualified as a *hub*, a node must belong to the 5% of the nodes with highest degree centrality and show *CC* characteristic for hubs linking different cliques (for social and communication networks it is the value of 0.1-0.5).

Together with roles' definitions various types of constraints can be distinguished in dependence on a profile of environment or additional requirements. In the context of role-based access control the most frequently mentioned are the following types of constraints [Chen, 96], [Ferraiolo, 97], [Sandhu, 96]:

- mutually exclusive roles,
- prerequisite roles,
- limitation of the maximum number of subjects for a role (cardinality constraints).

A basic motivation for application of constraints in role-based access control is to reflect the high level policy of an enterprise at the level of access control [Sandhu, 94]. The second reason why constraints should be considered in role-based access control model is accordance with one of the basic security principles – the principle of the least privilege.In the presented approach we describe some discussion about application of constrains in the context of mobile multi agent environment.

5 Application of Deontic Logic in Roles Description

Deontic logic is the field of logic that is concerned with obligation, permission, and related concepts. It is also a formal system that captures the essential logical features of concepts that define the obligatory, the permitted, and the forbidden operations. Many of the notions listed above are typically employed in attempting to regulate and coordinate social behavior. For these reasons, deontic logics often directly involve topics of considerable practical significance such as morality, law, social and business organizations (their norms, as well as their normative constitution), and security systems.

Each organization can be characterized by the set of roles which are created for various job functions. A role is a set of connected behaviors, rights and obligations as conceptualized by actors in a social situation. So, it defines expected behavior in a given individual social status, social position or position within an organization. The concept of roles has been used in information system access control. In this context the permissions to perform certain operations are assigned to specific roles. System users are assigned particular roles, and through those role assignments acquire the permissions to perform particular system functions.

The developers of role-based access control have distinguished several mechanisms to govern the system's and organisational roles. There are three main categories of these mechanisms which are responsible for:

- definitions of roles,
- definition of role-entity relations, and
- definition of role-role relations.

The first step is the identification of a set of entities that may be active within the system and a set of activities. During the next steps, on the base of the system security policy, the relations between the elements of these two sets should be established.

Let us use the earlier defined set of agents *A* and let us denote *B*= {$action_1$, $action_2$,… , $action_m$} as the set of their activities. There are three possibilities for each $action_k \in B$ in relation to agents from the set *A*:

- $action_k$ is permitted,
- $action_k$ is obliged,
- $action_k$ is forbidden.

In deontic logic it is possible to describe this relation using the modal operators: ***P*** *- it is permitted*, ***O*** *- it is obliged* and ***F*** *- it is forbidden*. According to these operators the sentences above can be formulated in the following way:

- ***P*** $action_k$,
- ***O*** $action_k$,
- ***F*** $action_k$.

Deontic logic is useful in this case because its basic notions are fundamental for normative perspective of system description and describes what is permitted, obligatory and forbidden, for a particular agent. The application of deontic logic allows a formal description and a formal analysis of the above-mentioned notions in the context of the agents behaviour.

The first attempt to build a formal theory of normative concepts (permission, obligation, prohibition) was made by E. Mally [Mally, 26], but most of the contemporary interest in deontic logic has been stimulated by von Wright's paper 'Deontic Logic' [von Wright, 51].

We propose to use the formal model based on deontic logic for roles and agents activity description. It is composed of three parts [Kołaczek, 01]:

(a) *Syntax of the model language.*
It is based on the first-order logic syntax where three additional modal operators are added: ***P*, *O*, *F***.

(b) *Semantic of the model language.*
It is based on the Krippke semantic of possible world where the world accessibility relation is serial.

(c) *The language application rules*:

- action's permissions, obligations, prohibitions and action's requests are formulated in the language of the model,
- all the formulas used in description must be in a form of Horn's clauses,
- if Reg is a set of formulas describing permitted, prohibited, and obligatory activities and this set is defined for a particular agent, then this entity may perform all activities described by the formulas that are the logical consequences of the set Reg.

5.1 Automation of Reasoning in Role-based Framework for Ontology Alignment

There are several tools that support the automation of reasoning in the first-order logic. One of them is PROLOG that uses Horn's clauses and the resolution method. This means that the ability to translate formulas of our model into first-order formulas in the form of Horn's clauses would open the application of PROLOG and the resolution method for ontology alignment process.

The following theorem states that it is possible to translate a particular class of role-based access control modal model formulas into form of the first-order Horn's clauses. This theorem makes use of the definition of a semi-functional translation.

The semi-functional translation T_{sf} *()* of a modal logic is a projection that assigns modal formulas and possible world to formulas of the first order logic in the following way [Bolc, 95], [Bolc, 98]:

- $T_{sf}(\phi,x) = P(x)$,
  where ϕ is an atomic proposition and P is the corresponding predicate;
- $T_{sf}(\boldsymbol{O}\phi,x) = \forall\, y[R(x,y) \rightarrow T_{sf}(\phi,y)]$
  where R is a possible world accessibility relation;
- $T_{sf}(\boldsymbol{P}\phi,x) = \exists f\, T_{sf}(\phi,f(x))]$
  where f is a function corresponding to the relation of possible world accessibility.

Theorem 1. $T_{sf}(\phi,w)$ is a conjunction of Horn's clauses iff a formula obtained after deleting all modal operators from the formula ϕ is a conjunction of Horn's clauses, where: ϕ is a formula of role-based access control modal model, $T_{sf}(\phi,w)$ means a semi-functional translation of ϕ, and w stands for a world selected from a set of possible worlds (Krippke model).

Proof. The proof of this theorem is based on the structural induction. The complete proof can be found at [Kołaczek, 01].

5.2 Validation of Agents' Activities in a Context of Policy Requirements

The policy governing behaviour of the autonomous agents can be described by an identified and defined set of roles. Each agent active within the system can be assigned to one or more roles, and it gets the authorisation to the set of actions that is a logical consequence of its set of roles. In this stage of the research we assume that agents play only one of the four previously defined roles (section 4).

Roles are defined by logical formulas. For example, let the role Role_Creator be assigned to the Agent_1. Role_Creator is defined by the following formulas:
Role_Creator:

a) $\forall a\, \forall o\; Play\_role(a,Creator) \wedge Internal\_ontology(a,o) \Rightarrow \boldsymbol{P}Modify\_ontology(a,o)$
b) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Creator)$
   $\Rightarrow \boldsymbol{P}Communicate\ (a1,a2)$
c) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,New)$
   $\Rightarrow \boldsymbol{P}Communicate\ (a1,a2)$
d) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Reader)$
   $\Rightarrow \boldsymbol{P}Communicate\ (a1,a2)$

e) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Hub)$
$\Rightarrow \mathbf{P} Communicate\ (a1,a2)$
f) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Creator)$
$\wedge Difference\_level(a1,a2,threshold1) \Rightarrow \mathbf{O} Align\_ontology(a1,a2)$
g) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,New)$
$\wedge Difference\_level(a1,a2,threshold2) \Rightarrow \mathbf{P}\ Align\_ontology(a1,a2)$
h) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Reader)$
$\wedge Difference\_level(a1,a2,threshold3) \Rightarrow \mathbf{O}\ Align\_ontology(a1,a2)$
i) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Hub)$
$\wedge Difference\_level(a1,a2,threshold4) \Rightarrow \mathbf{P}\ Align\_ontology(a1,a2)$
j) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Creator) \wedge Communicate(a1,a2)$
$\wedge Change\_level(a1,threshold1) \Rightarrow \mathbf{O} Inform(a1,a2)$
k) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Creator \wedge Communicate(a1,a2))$
$\wedge Change\_level(a1,threshold2) \Rightarrow \mathbf{O} Inform(a1,a2)$
l) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Creator \wedge Communicate(a1,a2))$
$\wedge Change\_level(a1,threshold3) \Rightarrow \mathbf{O} Inform(a1,a2)$
m) $\forall a1\, \forall a2 Play\_role(a1,Creator) \wedge Play\_role(a2,Creator \wedge Communicate(a1,a2))$
$\wedge Change\_level(a1,threshold4) \Rightarrow \mathbf{O} Inform(a1,a2)$

Where rule a) says that all autonomous agents playing the role *Role_Creator* are permitted to modify their internal ontology. Rules b)-e) define the permission to communicate between agents playing different roles, rules f)-i) define the obligation or permission to perform ontology alignment when the fixed threshold has been reached. The last rules j)-m) describes the obligation of the agents playing *Role_Creator* to inform other agents about modifications introduced to their internal ontology.

The appropriate sets of rules for *Role_New, Role_Reader, Role_Hub* can be defined in similar way.

Apart from the definition of roles, logical values of several system variables must be set to reflect the current system state. For example:

- *Play_role(Agent_1, Role_Creator) ≡ TRUE.*
- *Play_role(Agent_2, Role_Hub) ≡ TRUE.*
- *Internal_ontology(Agent_1, Onto_car) ≡ TRUE.*
- *Change_level(Agent_1, Max_3) ≡ TRUE.*
- …

Where Play_role, Internal_ontology, Change_level, Difference_level are the predicates symbols.

While a system policy is defined and the values of the system variables are known it is possible to verify the agent's requests. For example, an answer to the question about permission to set up communication between Agent_1 and Agent_2 can be looked for. To give an answer to this question an appropriate logical program should be generated. The logical program is a result of semi-functional translation of the formulas defining roles and system variable values. Finally, the logical program is as follows:

- *Plays(x,Agent_1, Role_Creator)⇐*
- *Plays(x,Agent_2, Role_Hub)⇐*

- *Internal_ontology(Agent_1, Onto_car)* $\Leftarrow$
- *Change_level(Agent_1, Max_3)*$\Leftarrow$
- …
- *R(x,f(x))* $\Leftarrow$
- *Modify_ontology(f(x),a,o)*$\Leftarrow$ *Play_role(x,a,Creator),Internal_ontology(x,a,o)*
- *Communicate (f(x),a1,a2)* $\Leftarrow$ *Play_role(x,a1,Creator)*$\wedge$*Play_role(x,a2,Hub)*
- …

The formula describing communication request is also translated and it is a question for the logical program. The access request after semi-functional translation:

- *Communicate(y,Agent_1,Agent_2)*

The final answer of the logical program in this example will be "YES". This means that the action requested by Agent_1 in Role_Creator to communicate with Agent_2 is admissible in the context of present policy definition.

In [Kołaczek 01] a precise way of role's application, definitions, role-entity relations and definition of role-role relations has been defined.

5.3 Application of Constrains in Deontic Logic-based Framework

There are several possible situations that could happen in multiagent environment when some more complex relations between agents and roles should be investigated. For example, an agent may be a part of an organisation which defines and uses to govern their members' behaviour some sort of internal structure. It is usually a type of hierarchical structure (chief executive → manager → assistant manager → staff) but also more egalitarian variants are possible. So, all agents must respect the set of norms associated to their organisational role. Simultaneously agents may create the other structure based on the bilateral communication. This structure may be also used to define a new set of norms describing the position and so a scope of permitted/forbidden actions of the agent. This two structures must coexist and so we may need to define some additional conditions – constraints that could allow us to model the agent behaviour better.

The proposed language can be used to check if activation of a agents in a role does not violates the defined constraints. Roles are defined as sets of formulas describing what is allowed, forbidden and obligatory for agents playing the particular role. To govern constraints an additional set of formulas called *set of constraints* is associated with each role. The formulas within these sets establish additional requirements related with roles as separation of duties, cardinality constraints, etc. These sets are analysed each time when a new relation between agents and role is going to be established.

Using the same notation that has been introduced at the beginning of this section the examples programme illustrating the automation of reasoning process concerning the mutually exclusive roles and prerequisite roles will be described in the following subsection.

5.3.1 Prerequisite Roles

The problem of implementation constraints of prerequisite roles is similar to a case of mutually exclusive roles. As in mutually exclusive roles the condition is formulated: *an agent is forbidden to play A if the agent plays B*, what equals to the formula:

- $TRUE \Rightarrow \mathbf{F}Play\_role(A)$

In prerequisite roles the condition formulated in a natural language is: *an agent is obliged to play A if the agent want to play B,* what can be represented by formula:

- $TRUE \Rightarrow \mathbf{O}Play\_role(A)$

The defined language can be used to verify if activation of an agent in a new role violates the defined constraints. The process of verification performed while an agent is being activated in a new role is almost the same as in a case of mutually exclusive roles. Example:

Set of constraints associated with a role *A*:

- $TRUE \Rightarrow \mathbf{O}Play\_role(B)$

Logical programme:

- $Play\_roles(x,B) \Leftarrow R(x,y)$
- $R(x,y) \Leftarrow$

Let consider two cases:

a) agent *X* plays roles *B* and *C*

b) agent *Y* plays roles *C* and *D*

ad. a)

Question to a programme:	$\Leftarrow Play\_role(B)$
Answer:	$\Leftarrow \square$
Question to a programme:	$\Leftarrow Play\_role(C)$
Answer:	*STOP*

Because one question returned positive answer the final answer for the question: if an agent X playing roles B and C is allowed to be activated in role A? is yes, the agent X can be activated in a role A.

ad. b)

Question to a programme:	$\Leftarrow Play\_role(C)$
Answer:	*STOP*
Question to a programme:	$\Leftarrow Play\_role(D)$
Answer:	*STOP*

Because all questions generated for active roles of an agent *X* returned negative answers, so also final answer is negative: *no, the agent Y cannot be activated in a role A.*

5.3.2 Cardinality constraints

The application of cardinality constraints requires the existence of a global counter in a system and additionally an operation of checking a current number of active agents in a role must not be divisible. To represent cardinality constraints the following predicate and variables should be defined:

- $Card(Rx)$

Rx is the name of the role and Card(Rx) is a predicate which value is TRUE only when the maximum permitted number of agents are active in the role Rx and FALSE in other cases.

- *r11,r12,…,r1n, r21,r22,…,r2m,…, rx1,rx2,…,rxz*

Sets of variables associated with the first and following roles, where x - is the number of the roles in the system and n,m,…,z are the numbers of maximum active agents in a particular role.

The variables *r11*,… are used to indicate the current number of agents active in this role. If there is only one active agent in a role *R1* then *r11≡TRUE* and *r12≡r13≡…≡r1n≡FALSE*. If two agents are active, then *r11≡r12≡TRUE and r13≡…≡r1n≡FALSE*, etc.

According to the defined variables, formulas included in constraints sets are in the following form:

- *r11∧…∧r1n⇒Card(R1)*
- …
- *rx1∧…∧r1z⇒Card(Rx)*

Each time before a new agent is activated in one of the roles from the set {R1,…Rx}, the cardinality constraints must be verified. This verification can be performed by sending to the system the following question:

- *⇐Card(Ra)*

where *Ra* is the name of the role which is to be tested for a cardinality constraint.

An answer to this question is TRUE only when maximum number of permitted agent has already been activated in a role Ra. In other cases (when the number of active agents in the tested role is less then maximum) the answer is FALSE.

Example.

a) Cardinality constraints for *R1* equals 3 and there are three agent activated in *R1*.

Set of cardinality constraints:

- *r11∧r12∧r13⇒Card(R1)*
- *r11≡r12≡r13≡ TRUE*

Logical programme:

- *Card(R1) ⇐ r11,r12,r13*
- *r11⇐*
- *r12⇐*
- *r13⇐*

Question:

- *Card(R1)*

Answer:

- *⇐□*

The programme returned empty clause, so no more agents can be activated in a role *R1*.

b) Cardinality constraints for *R1* equals 3 and there are two agents activated in *R1*.

Set of cardinality constraints:

- *r11∧r12∧r13⇒Card(R1)*
- *r11≡r12≡ TRUE,*
- *r13≡FALSE.*

Logical programme:

- *Card(R1) ⇐ r11,r12,r13*
- *r11⇐*
- *r12⇐*

- *r13*

Question:

- *Card(R1)*

Answer:

- STOP

The programme stopped, so some new agents can be activated in a role *R1*. The activation of a next agent requires values of the variables r11,r12,r13 to be updated. One variable which value before the agent activation was FALSE must change its value to TRUE. Analogously, when an agent is deactivated from a role, one variable associated with this role must change its value from TRUE to FALSE.

The benefit of this representation of cardinality constraints is the correspondence with the general requirements of the proposed model. However in this case it seems to be more effective to analyze and implement this type of constraints in more simple way, for example on a base of some global counters.

6 Conclusions and Future Research

We have proposed an integrated solution which supports decision making in ontology alignment domain on the basis of the actual structure of the communication links in the system. The measures used in social network analysis for deriving user roles and positions in the network were used along with the deontic logic formalism in order to automate decision making and maintain global ontology consistency. Further research will address experiments which allow to estimate what are the limits of the proposed scheme – multilevel fusion involves intense reasoning and ontology processing tasks and it is not obvious that known methods of ontology alignment and negotiation may indeed sustain knowledge consistency in dynamic multi-user environment. It will be also checked if semi-automatic methods are feasible here – knowing the structure of social links in the system we may propose a heuristic which will warn the users of possible inconsistencies thus helping to solve the problem manually.

The entire scheme is intended for the use in corporate multiuser environments, where we experience continuous processes of annotating different types of data (like complex reports stored in corporate memories by expert and engineers who add interpretation to detailed event descriptions).Mechanisms that govern evolution of emergent semantic structures in modern web-based multiagent environments are relatively new and not widely addressed research task. Its successful completion has potential to influence novel interconnection architectures (like Semantic Web and Semantic Grids) in many ways. The most interesting are:

- Creating knowledge and innovation spreading models.
- Developing intelligent search algorithms.
- Formulating the conditions for semantic integrity of distributed systems.
- Support for knowledge-based virtual organizations.

The further development of the proposed framework includes also experiments on the rules that govern evolution and behavior of the emerging Semantic Web environment and its underlying semantic network structures.

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