Structural Determination of Ontology-Driven Trust Networks in Semantic Social Institutions and Ecosystems

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***Abstract*—Social institutions and ecosystems are growing across the web and social trust networks formed within these systems create an extraordinary test-bed to study relation dependant notions such as trust, reputation and belief. In order to capture, model and represent the semantics of trust relationships forming the trust networks, main components of relationships are represented and described using ontologies. This paper investigates how effective design of trust ontologies can improve the structure of trust networks created and implemented within semantic web-driven social institutions and systems. Based on the context of our research, we represent a trust ontology that captures the semantics of the structure of trust networks based on the context of social institutions and ecosystems on semantic web.**

***Index Terms*—Semantic web, trust network, trust, social networks, social systems, ontologies, multi-agent systems, distributed artificial intelligence.**

I. Introduction

Semantic web is described to be a web of knowledge having properties such as heterogeneity, openness and ubiquity. In such environment where everyone has the ability to contribute, trustworthiness of these people and their contributions are of great importance and value. As stressed, trust plays a crucial role in bringing the semantic web to its full potential.

A trust network can be seen as a structure capturing meta-data on a web of individuals with annotations about their trustworthiness. Considering social network as our context, a trust network can be seen as an overlay above the social network that carries trust annotations of the meta-data based on the social network, such as user profiles and information. Social networks are gaining increasing popularity on the web while semantic web and its related technologies, are trying to bring social networks to their next level. Social networks are using the semantic web technologies to merge and integrate the social networking user profiles and information and such efforts are paving the path toward semantic web-driven social ecosystems and institutions. Merging and integrating social networking data and information can be of business value and use to web service consumers as well as to web service providers of social systems and networks.

Ontologies, at the core of semantic-web driven technologies lead the evolution of social systems on the web. Describing trust relations and their sub-components using ontologies, creates a methodology and mechanism in order to efficiently design and engineer trust networks.

"Structure of a given system is the way by which their components interconnect with no changes in their organization" according to [1]. Determining the structure of a society of agents on a trust network structure on a semantic social system, can help us determine the organisational structure of a system. Having this capability we can determine an organization's certain factors such as flexibility, change capacity and etc.

In this paper we investigate how effective design of trust ontologies can improve the structure of trust networks created and implemented within semantic web-based social systems. To address the efficient design of trust networks on semantic web-driven social systems, we will engineer and analyse a trust ontology and we will study the structure of the trust network to describe how a trust ontology can serve as the framework for engineering efficient and scalable trust networks. Our trust ontology is based on the main concept of *Relationship*, that models the main element of trust networks, and two concepts of *Main Properties* and *AuxiliaryProperties*, which model properties of relationships.

The contents of this paper are organized as follows: following the discussion on the related research in section 2, our trust ontology is introduced in the section 3; in section 4 we analyse the structure of sample trust networks made using our ontology. We compare the structure of our network with the structure of networks generated using other trust ontologies. Finally we conclude in section 6 and we discuss future research in section 7.

II. RELATED WORK

Within the context of social semantic systems, there has been an extensive set of efforts based on both academic and practical approaches in order to design and engineer trust networks, but none of the existing works in the field were designed bearing structural and design issues in mind. In this section we briefly introduce the technologies that we have incorporated and considered in our approach.

A. Vision of Semantic web-driven social institutions

As mentioned, merging and integrating social meta-data brings business value to entities living within such institutions and ecosystems. The vision of "Semantic social network (SSN)" according to [2], describes the notion of integrated and merged social networks. This vision is composed of two major components: "First, that there will be, expressed in XML or RDF (resource description framework), descriptions of persons (authors, readers, critics) publicly available on the web, sometimes with explicit ties to other persons; and Second, references to those descriptions employed in RDF or XML files describing resources", according to [3] [2].

There were several attempts to bring this vision into life. One of them is FOAF (friend-of-a-friend) project [4]. According to [5], "FOAF project is an RDF vocabulary that can be used to represent personal data and interpersonal relationships for the Semantic Web" and in this way it can be used as the "glue" between semantic web and social-oriented ecosystems and institutions.

B. Modelling and representing trust relationships

As mentioned, Trust is a context-sensitive issue. While considering the context of the trust ontology and trust analysis, we realize that this context is a multi-dimensional entity composed of two substantial and fundamental dimensions; semantic web and social ecosystems. Trust in the domain of social semantic institutions and ecosystems, has three relatively close notions such as belief, provenance and justification.

PML [11] ontology is composed of three sub-ontologies; trust, provenance and justification. In PML ontology trust and belief are modelled and described as overlapping notions. Both notions of belief and trust are modelled under inside the same ontology, inside the trust ontology.[11] [12] Golbeck suggests an important distinction between belief in statements and trust in people. [6] [7] In Konfidi [13], trust is modelled and represented as a continuum of both trust and distrust, not a measure of just one or the other. They state that there is always a trade-off between trust and distrust. [4]

C. Trust networks

The work in this field is mostly focused on the mathematical description of networks and the amount of the practical work is limited. Most of the works in this field do not consider design of larger infrastructures and ecosystems.

Trust networks are described as weighted graph structures with directed edges. The edges in the generated graphs represent connections and relationships between individuals. Watts introduces the properties of a small world network [17]. He describes a model called ß-model [17] in order to model, construct and generate the structure of social systems. Many social systems have used this model within their infrastructure [14] [15] [16] [18] [17] [6].

Golbeck has done an extensive effort on trust networks on semantic web. [6] [8] [9] [10] She has constructed a trust ontology, combining RDF and FOAF vocabulary to describe relationships comprising trust networks. She has created applications on resulting trust networks based on her ontology. These applications range from email filtering, TrustMail [5] [6], to web-based recommendation systems, FilmTrust [10].

Brondsema and Schamp have created a system called Konfidi, a system that combines a trust network with the PGP web-of-trust. "The system's main functionality is email filtering and is made of trust network, a trust ontology along with the software that makes it usable" according to [4].

D. Trust ontologies

As our trust ontology shares the structure and context with trust ontologies of Golbeck and Konfidi, It is necessary to address the ontological components of the mentioned ontologies.

Golbeck introduced an ontology, that extends the FOAF vocabulary and ontology and creates an important schema that is used with `foaf:Person` that gives the users this ability to express their trust in people they have knowledge about. The metric used to express trust is a computational value and it's described on a scalar range of 0-9, in which each scale represents a level of trust. Having `foaf:Person` as the domain, this trust ontology sets the trust metric as the properties under this domain. [6] [8]

Our ontology can be seen as an extension to trust ontology used within Konfidi [13] [5]. They represent a trust relationship as the class and concept of ontology, and the trusting person and the entity are associated with that concept or class. Each relationship goes one-way from truster to trusted (sink to source). The most important feature of this work is, like Jennifer Golbeck's ontology, they have incorporated the notion of "*Topical trust*" [8] in their ontology. It is used as an attribute and property, which allows to state different features and properties of a relationship. Trust topics and trust values are stated as the properties of the trust relationship. They have an *about* that connects the Relationship to the *Item* that contains the main properties of a relationship, the trust value and subject of the relationship. Unlike Golbeck's ontology, a relationship using Konfidi's ontology can be about more than one trust item; meaning that a relationship can be about more than one single subject.

Incorporating extra and less-important properties into Golbeck's ontology can be very hard, but in Konfidi's case it seems fair easier. Although both ontologies, cannot describe extra and optional properties of a relationship but we have incorporated an element in our ontology that gives us this ability to do so quite easily, as well leaving space for future properties to be added.

III. TRUST ONTOLOGY

Figure 1 visualizes the structure of our trust ontology using *RDF Gravity*[1].As shown our ontology has 3 main concepts or classes that capture the structure of the trust relationships on the networks. Figure 1 depicts this structure. *Relationship* is the main element and concept of our ontology. *MainProperties* and *AuxiliaryProperties* are the other main components of our ontology. We have two relations that connect both *MainProperties* and *AuxiliaryProperties* to *Relationship*. These relations are *hasMainProperties* and *hasAuxiliaryProperties*.

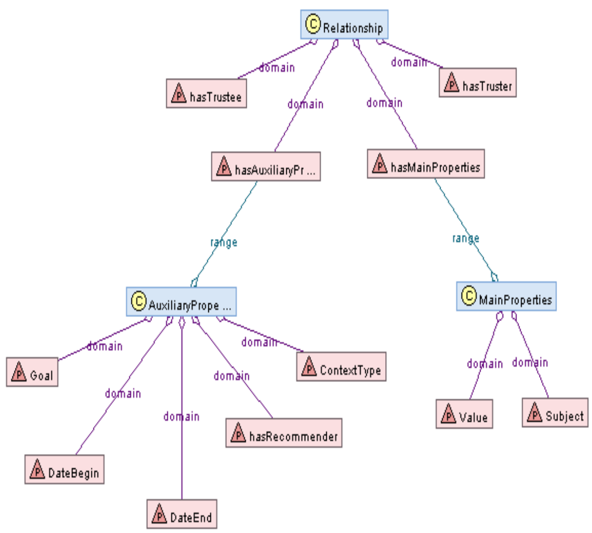

Figure1: Structure of our trust ontology, 3 main Concepts of trust ontology as well as two relationships connecting them together.

Relationship always has a sink and a source, which we have described here as truster and trustee. Both *hasTruster* and *hasTrustee* are defined on the range of `foaf: Agent` which enables us to describe relationships in the context of semantic social ecosystems. This agent can be a person, an organization or just a software agent.

Each Relationship has to have a truster and a trustee and at least one main property. Without these mentioned elements, a relationship is partial and partial relations are undefined using our ontology. In order to ensure having at least these mentioned elements, we have put restrictions on ontology sub-components. Restriction defines a blank node with restrictions. It refers to the property that is constrained and defines the restriction itself. Cardinality constraints define how many times the property can be used on an instance of a class. We have minimum, maximum, exact cardinalities.

We have used two exact cardinalities on *hasTrustee* and *hasTruster*, in order to state having exactly one truster and one truster for a relationship. We have also used minimum cardinality for *hasMainProperties* to make sure having at least a topic and a value for each relationship, and since we can have more than one topic to base the relation upon, we have used minimum cardinality (at least).

MainProperties element has two main properties; *Subject* and *Value*. We have described these two properties using data type properties, in OWL (Web ontology language). Subject takes string value. It is recommended that subject taxonomies or topic ontologies be defined, so we can use a common namespace for describing topics and subjects.

Each relationship can have multiple main properties, which means it can be about different topics and subjects, but each main property has to have one and only one topic and only one value. For instance in the relationship between Alice and Bob, Alice can completely trust bob on Driving (Subject="Driving", Value="0.95"), and also can distrust bob on Cooking completely (Subject="Cooking", Value="0.10"). This constitutes two distinct main properties in relationship between Alice and Bob. But we cannot have multiple subjects and values in the *MainProperties* of Alice and Bob on Cooking, for example. In order to enforce this property we have put restriction on both properties of value and subject. By using exact cardinality restriction we have enforced having exactly one subject and exactly one value for each item of trust within a relationship.

Finally, *AuxiliaryProperties* concept of domain has 5 properties and also leaves space for more properties whenever needed. *AuxiliaryProperties* has an object property and 4 data type properties. It has *hasRecommender*, which is the element describing the strength of relationship and is defined on the range of `foaf:agent` that lets us to state which node on the network is the recommender for the establishment of this link. *ContextType* is defined as a string data type property that states the context of the trust network, the relationship is based on. *Goal* of the relationship is also defined using a string data type property. *DateBegin* and *DateEnd* are described using Date data-type property. Clearly we don't need to have restrictions on any single property of *AuxiliaryProperties* concept.

IV. NETWORK ANALYSIS

We will consider how the structure of the trust network can be determined, by analysing generated ontology-driven networks of trust relations, in order determinate the organization structure. Here we introduce two types of trust network structure.

E. Hybrid trust networks

Here, we will consider 2 groups of people, representing two networks of different context. Each four people are interrelated and interlinked, forming a *simple network*. At the same time a set of these people are connected outside of their own local networks, to other foreign network. These relations work as glue connecting networks of different context, creating *Hybrid networks*.

In hybrid network depicted in figure 2, people located on one network, are shaping a social context and their goals are

[1] *RDF Gravity (RDF Graph Visualization Tool),* *http://semweb.salzburgresearch.at/apps/rdf-gravity/index.html*

more or less establishing friendship relations, while people on the other network are members of a business network, and their goals are establishing business partnerships and relationships and they could be colleagues in an office environment. It is also considerable to think of the business network as a business-value adding network, or a service-oriented environment. In that case, then four latter members can be software agents, which can also be described using our ontology.

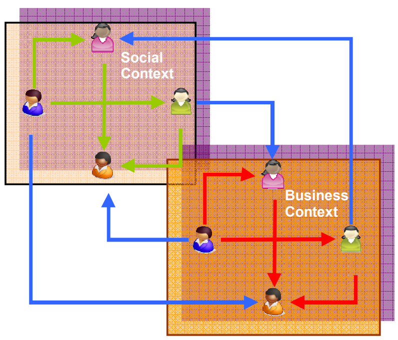

Figure 2: A hybrid network. Two connected networks of different contexts; a social and a business network. Hybrid networks, contains 8 people and 12 relations. 8 links are interconnections (local), and 4 links are acting as glue connecting two networks (foreign).

F. *Meshed trust networks*

The motivation for studying larger networks of trust, was considering real-world scenarios of network formations. Such networks are complex, combined networks of different sizes and different contexts. We call these networks, *Meshed networks*. Meshed networks are considered networks, where every node is connected to all other nodes on the network. As such, assumption is unrealistic, and there is only a subset of nodes available that are fully connected to all other nodes, we consider *partial* and *fully connected meshed networks*. Taking idea from networking topologies, partial meshed networks are trust networks where each node is at least connected to a subset of nodes it has data exchange with. On the other hand, a fully connected meshed network is a trust network where each node is connected to everyone. In the former, inferring trust values between a pair of nodes on the network seems difficult but, finding a path between a set of nodes on the network is guaranteed. Using our ontology, recommendations can find efficient paths on the network.

Figure 3 depicts a partial meshed network of people from different contexts and with different goals perhaps, and can be thought of two hybrid networks integrated and merged together. Figure 4 visualizes the RDF trust network depicted in figure 3.

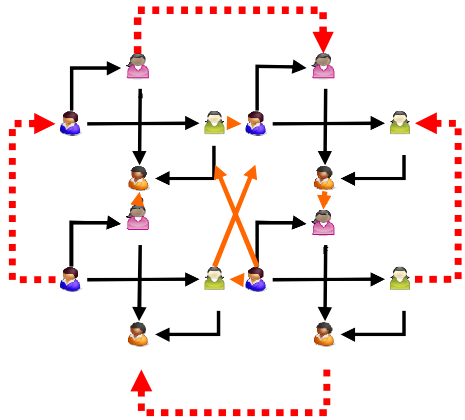

Figure 3: A partial meshed network made-up of two connected hybrid networks. This network contains 16 people and 26 relations.

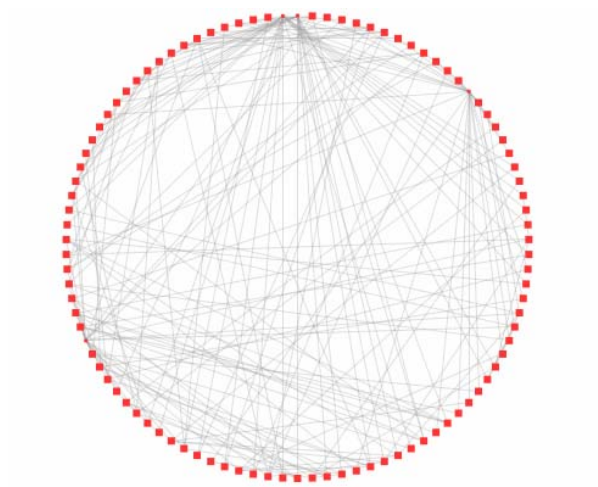

Figure 4: A circular representation of meshed partial network, using Welkin[2]. (Network contains 98 nodes and 198 edges)

V. STRUCTURAL COMPARISON

In order to emphasis the importance structural determination of trust networks, in this section we consider comparing the structure of the trust networks generated based on three different ontologies; our ontology, Golbeck's and Konfidi's. In the last subsection we discuss in details the results of comparison. For the sake of comparison, we have divided the experiment datasets into two sizes; small sized networks and large sized networks.

A. *Trust networks of small size*

Based on our structural point of view, Table 1 lists the number of nodes and edges on the compared networks. As it is clear, in general the nodes and edges on the networks generated using Golbeck's ontology is quite smaller than networks generated using our ontology and Konfidi's. At the same time in both cases our network has a smaller number of

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[2] Welkin, http://simile.mit.edu/welkin/

nodes and edges than Konfidi's networks, although the difference is not that much.

TABLE 1: COMPARISON BETWEEN THE SIZES OF SMALL NETWORKS

Trust Networks	Golbeck	Ours	Konfidi
Nodes	15	20	22
Edges	28	34	37

a) Networks of 4 people and 4 relationships. (Increase in size)

Trust Network	Golbeck	Ours	Konfidi
Nodes	19	28	29
Edges	46	54	58

b) Networks of 4 people and 6 relationships. (Increase in depth)

B. *Trust networks of large size*

We described and defined hybrid and meshed networks. At the same time, we modelled these networks using datasets that to some extent reflect the structure of such networks. The same datasets were also injected into the structure of two other tested ontologies to consider the structure of the resulting trust networks.

Based on our structural point of view, Table 2 lists the number of nodes and edges on the networks. Table 2a shows the number of nodes and edges on the networks representing the hybrid network. Network generated using Golbeck's ontology has less nodes and edges than both of ours and Konfidi's. Although, network generated using our ontology has less number of edges and nodes in comparison to Konfidi's. Table 2b shows the number of nodes and edges on the networks representing meshed networks. Again, Golbeck's network has less number of nodes and edges than our network and Konfidi's network. Our network has greater number of nodes than both, Golbeck's and Konfidi's networks, but lesser number of edges than Konfidi's.

TABLE 2: COMPARISON BETWEEN THE SIZES OF LARGE NETWORKS

Trust Network	Golbeck	Ours	Konfidi
Nodes	27	48	50
Edges	73	92	105

a) Hybrid Network (network of 8 people and 12 relationships).

Trust Network	Golbeck	Nima	Konfidi
Nodes	49	98	86
Edges	132	198	211

b) Meshed network (Networks of 16 people and 26 relationships).

C. *Detailed analysis of structural comparisons*

In this section we further analyse and study the results of our experiment and comparisons.

As shown in tables 1 and 2, trust networks modelled, described and presented using our ontology and others are compared based on the number of nodes and edges (structural perspective). Comparison shows that in networks of small size, our ontology shows average performance in comparison to other ontologies, meaning that trust networks generated have average sizes, in comparison. But as the size of the networks increase, certain aspect of trust network size increases more than other compared network, showing less efficient performance. There are a set of reasons, which can be stated here.

Clearly, the main reason, for size increase in networks, is *the number of elements incorporated* within the structure of ontology. Golbeck's ontology uses only one main element, Konfidi uses two main elements, while our ontology uses three main concepts. The second reason would be *efficient design of the ontology*. Golbeck's ontology is indeed, a mile stone in the work on trust in semantic web. Her trust schema has a very efficient design. Such design has certain aspects that reduce the size of the networks described using that ontology; first, defining levels of trust (*trust0...trust10*) and *trustRegarding* on the range of `foaf: Agent` lets you to describe the trust directly as the properties of agents and on the trust network. Such efficiency in design lets you to describe relations very easy with lesser elements, as seen in results. Konfidi's trust ontology has more or less the same structure like our ontology. Our ontology has one more element than Konfidi's, but we have seen networks of smaller size generated using our ontology rather than ones generated using Konfidi's ontology.

Figures 5 visualizes the structure of the networks generated using our ontology. The emphasis on the visualizing was put on the gravity of the instances on the network toward their originated main elements. An efficient structure will depict the overall organization of the ecosystem and its sub-ecosystems. Our network shows better clustering of elements among two other samples.

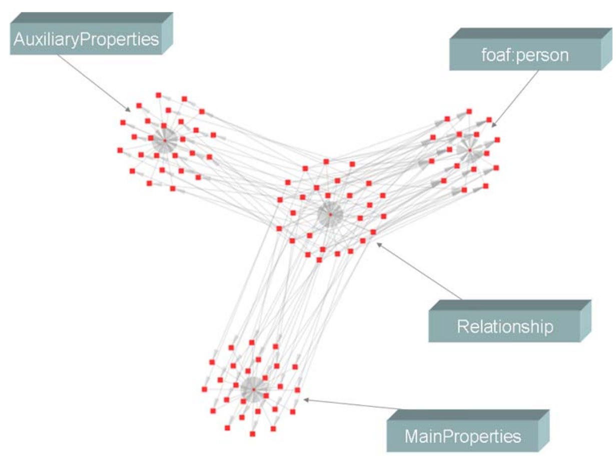

Figure 5: A clustered visualization of the structure of a meshed trust network based on our trust ontology.

The third reason is the *AuxiliaryProperties* element of our ontology. As we incorporated an extensibility element for describing secondary and optional properties, we will incorporate extra nodes and more importantly extra edges into the network. In most of the test data for the comparison section, we have auxiliary property elements with at least one sub-element filled. For instance, when describing hybrid networks, all relationships have *AuxiliaryProperties* with *ContextType* property of either simple social network, or simple business network, or hybrid network. It should be mentioned here that none of the other compared ontologies, have any element for describing extra properties; extending Golbeck's trust ontology seems to be very hard and needs drastic changes because of its architecture, and Konfidi doesn't have any elements for describing extra properties. Taking into account this information, if we eliminate the *AuxiliaryProperties* element, then the size of our network becomes even more efficient than both other ontologies, in certain situations.

D. Conclusions

We analysed the modelling and representation of trust relationships across the networks within semantic web-driven institutions and ecosystems. In order to capture, model and represent the semantics of trust relationships within semantic web, main components of relationships are represented and described using ontologies. In order to analyse the methodologies and mechanisms used to described trust relations, we studied and analysed a set of trust ontologies, specially Jennifer Golbeck's and Konfidi's trust ontologies, which share the same context with our research context. At the end, we engineered and analysed a trust ontology based on the context of our research, social networks and semantic web.

We constructed a trust ontology in which relationship is the focus of ontology, as ontology captures the semantic of trust relationships, and two other elements state the properties of trust relationships. In comparison to previous works, there are certain new features that our work introduces to trust ontologies in this context; using our *AuxiliaryProperties,* we give relationships more weight and meaning. We have introduced the *hasRecommender* property that can determine the strength of the links on social network and can be used for finding the suitable inference path on the network.

We claimed that determining the structure of trust networks could be possible by efficiently designing and engineering trust ontologies that such networks are based upon. We also showed this fact by using the same datasets on our ontology and two other ontologies. Results of our experiment fairly prove our claim. Having more elements than other ontologies, networks generated based on our ontology show average size and structure. Also our trust networks shows far more manageable structure and architecture as the size increases, in comparison with two other compared ontologies.

As a conclusion, we can state that ontologies are very promising technologies. Utilizing ontologies in modelling and representing trust in semantic web-enabled social systems seems to be a highly efficient methodology and mechanism.

E. Future works

Studying the social phenomena within computer science and especially semantic web, demands more attention. I believe by having a liaison between social sciences and computer sciences, more fruitful results can be achieved and be obtained, that can help bringing social ecosystems into life on the web.

Number of vocabularies, used to describe the elements of ontologies should increase. There is a vocabulary to express relationships, but there is no standard vocabulary to express for instance, common subjects and topics of a relationship, while we can describe vocabularies using Metavocab[3], we can easily describe a vocabulary for this matter.

The application domain is very limited and one of the most important future works on this field is spotting certain fields that demand further attention. Current applications are just limited to Spam filtering and user rating systems across web sites on internet. One of the most important future works is spotting further applications for social trust, where trust relationships can be modelled and expressed using ontologies.

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