TRHIOS: Trust and Reputation in Hierarchical and Quality-Oriented Societies

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Abstract— **In this paper we present TRHIOS: a Trust and Reputation system for HIerarchical and quality-Oriented Societies. We focus our work on hierarchical medical organizations. The model estimates the reputation of an individual, R_{TRHIOS}, taking into account information from three trust dimensions: the hierarchy of the system; the source of information; and the quality of the results. Besides the concrete reputation value, it is important to know how reliable that value is; for each of the three dimensions we calculate the reliability of the assessed reputations; and aggregating them, the reliability of the reputation of an individual. The modular approach followed in the definition of the different types of reputations provides the system with a high flexibility that allows adapting the model to the peculiarities of each society.**

Keywords: Trust; Reputation; Hierarchy; Quality-Oriented.

I. INTRODUCTION

The underlying goal of trust and reputation systems is to predict the trustworthiness and proficiency of peers in future actions based on the information gathered from their past behavior in the environment and how they are seen by their peers [1]. The design of these systems is highly conditioned by the target domain and the related specific requirements [2]. Trust and reputation systems have been prominently applied in open environments such as e-commerce systems [3], the Grid [4] or P2P platforms [5]. In the last few years, the introduction of ubiquitous computing technologies into healthcare has favored the development of new reputation models adapted to the characteristics of pervasive healthcare [6],[7].

Reputation is normally assessed taken into account information coming from direct interactions among individuals and information coming from the direct observation of an agent's behavior by some third-party agent [2]. Some models take also into consideration the structure of the system through the agents' role and predefined relationships between two agents [8] to calculate reputation in the system. However, some important relationships like hierarchical relations are not sufficiently addressed. Hierarchical structure of societies like medical organizations conditions the interactions among the agents through dependence relations and must be considered in the determination of the reputation of each agent.

We focus our model on hierarchical medical organizations, proposing a reputation assessment with information coming from three dimensions: the *hierarchy of the system*; the *source of information* (direct interactions and social information); and the *quality of the results* provided by the agents. By valuating the quality of the results is especially important in medical organizations [9]; we propose some techniques to perform the objective analysis of the results and a method to infer a reputation value from those evaluations.

Throughout the description of TRHIOS, we will consider the agent assessing the reputation as the truster (tr); and the agent whose reputation is being calculated as the trustee (te). The running example is a generic telemedicine multi-agent system integrated in a medical organization composed by several institutions in a hierarchical tree. All the agents within an institution are also hierarchically organized.

II. HIERARCHY OF THE SYSTEM REPUTATION

A. Medical Organizations' double hierarchy

We can consider the structural nature of medical organizations (and telemedicine systems running within the organization) as a double hierarchy system: inter-institutional hierarchy and intra-institutional hierarchy. For both types of hierarchies a classification into hierarchy levels can be done.

Inter-institutional hierarchy reflects the dependence relations among all the institutions that form the medical organization and are represented by the dotted lines labeled with H on Figure 1. Four levels of inter-institutional hierarchy, l_O, are depicted, being level 1 (e.g. regional hospitals) the highest level and level 4 (e.g. small clinics) the lowest level. Note that medical organizations could have more or fewer levels than the four represented in the diagram.

Intra-institutional hierarchy refers to the institutions' internal hierarchy, lines labeled with *h*. Figure 1 shows only the dependence relations between doctors, omitting -for the sake of clarity- the relations among patients, software agents, and doctors, within each institution. In the system, patients are always hierarchically subordinated to all doctors, and software agents to both patients and doctors.

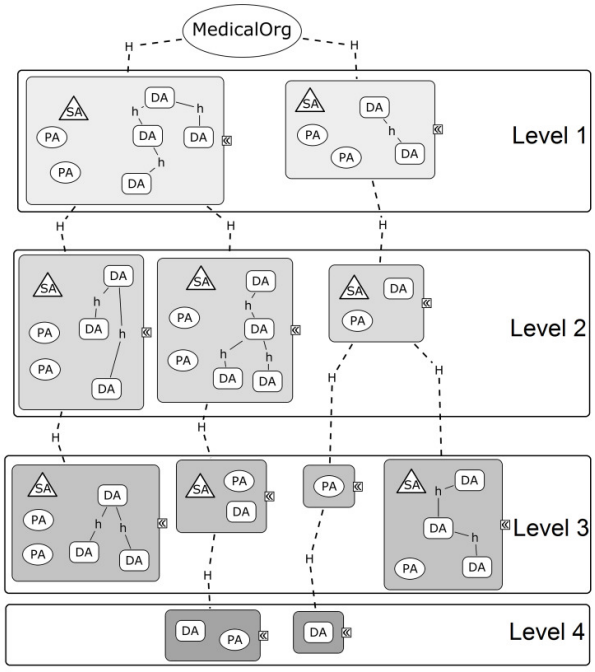

Figure 1. Medical Organizations' Double Hierarchy

Each institution is formed by doctor agents (DA), representing doctors in the telemedicine system; patient agents (PA), representing patients; and finally a set of different software agents (SA) to perform the different functionalities offered by the telemedicine system. In the running example there are five intra-institutional hierarchy levels, l_h: three levels for doctor agents (squares), one for patient agents (circles) and one for software agents (triangles).

We consider patients' level as one level lower than the maximum doctor level, level 4 in the example; and software agents' level as one level lower than patients' level, level 5 in the example.

B. Hierarchy of the System Reputation Assessment

The position of truster and trustee within their own institution, and the position of each agent's institution in the organization's hierarchy tree, conditions not only the interaction but also the perception that one agent has of the other. The ideas behind this affirmation are threefold: 1) usually an individual would trust more in its institution colleagues than the individuals of other institution; 2) there are pre-established hierarchy constraints associated to the structure of institutions, individuals might be 'forced' to trust more in their superiors; 3) there is a direct subordination among institutions in the same branch of the hierarchical tree of the medical organization. The formula we propose to calculate the hierarchy of the system reputation R_{HoS} is:

$$R_{HoS} = \frac{1}{2}\left(1 - \frac{1}{1+HDR}\left(HDR\frac{d_h}{max(l_h)-min(l_h)} + \frac{d_O}{max(l_O)-min(l_O)}\right)\right) \in [0,1]$$

where l_h= Agent's hierarchy level within its institution; l_O= Hierarchy level of agent's institution within organization hierarchy tree; d_h= Difference between the level of hierarchy of the truster and the trustee inside their institution, $d_h=(l^{tr}_h-l^{te}_h)$; d_O= Difference between the level of hierarchy of truster's and trustee's institution, $d_O=(l^{tr}_O-l^{te}_O)$; HDR= Hierarchy dependence ratio.

HDR, calculated heuristically, determines the type of dependence relation between the two agents interacting, according to system's double hierarchy:

- The agents belong to different institutions and there's no hierarchical relation between both institutions (e.g. HDR=0.2).
- The agents belong to different institutions in different branches of the hierarchy tree but they have a common ancestor in the institutions' hierarchy (e.g. HDR=0.5).
- The two agents belong to different institutions but both institutions are in the same branch of institutions' hierarchy tree (e.g. HDR=1).
- The two agents are in the same institutions but they belong to different branches in the hierarchy tree of the institutions. (e.g. HDR=2).
- The agents are in the same institution and there's direct hierarchy dependence between them (e.g. HDR=5).

When the agents is a newcomer to the system, R_{HoS} can be considered as the default reputation of the agents, part of its initial knowledge, and the only reputation perceived by an agent. Thus, we consider its reliability high, RL_{HoS}=1.

III. REPUTATION OF THE SOURCE OF INFORMATION

The reputation of the source of information R_{SoI} is calculated considering the information coming from the direct interaction between the two agents, *individual reputation* R_{ind}; and/or the information coming from other agents that have previously interacted with the target agent, *social reputation* R_{social}. We calculate these reputations using the individual and witness reputation defined in the ReGreT model [3], [10] with some minor changes.

A. Individual Reputation

Individual reputation R_{ind} measures truster's subjective perception of a direct interaction with the trustee. In other words, the truster evaluates the outcomes of every interaction with the trustee giving a rating value, $W \in [0,1]$ (in ReGreT this value $\in [-1,1]$). This evaluation is stored in an internal database (IDB). The reputation of the trustee perceived by the truster is calculated through a weighted mean of all the previous evaluations of the impressions complying with a specific pattern p (IDB^{tr}_p); giving more importance to the latest interactions through the function $\rho(t,t_j)$. The reliability of the reputation is calculated considering the number of interactions used to assess the reputation (an intimacy level is considered to model the state of close relation, from where reliability will not increase) and the variability of the rating values given by the truster, D_t: the greater the variability the more volatile will be the truster and, thus, the assessed reputation will have a low credibility. According to this, the formulae for individual reputation and reliability are [3], [10]:

$$R_{ind} = \sum_{im_j \in (IDB_p^{tr})} \rho(t, t_j) \cdot W_j \in [0,1]$$
$$RL_{ind} = (1-\mu) N_{im}(IDB_p^{tr}) + \mu D_t(IDB_p^{tr}) \in [0,1]$$

We have been considering that a single aspect is used to assure individual reputation, the subjective perception of the outcome of the interaction, understood as a whole concept. But the reputation of an agent might not be a single concept but rather a multi-facet concept; for instance, completeness of the demanded results and results' presentation. The *ontological dimension* of the ReGreT system allows us to combine different aspects to build reputation for complex concepts.

B. Social Reputation

When the reliability of the individual reputation of an agent is low or when the interactions with another agents are scarce and it is not possible to assign to it a reputation based on direct experiences we use the information coming from other agents, social reputation R_{Social}. The assessment of this reputation is based in the witness reputation defined for ReGreT system [3],[10].

The information coming from other agents, the witnesses, would be affected by the hierarchical relationship existing between each witness and the target agent, the trustee; so the reputation of the witnesses must be weighted considering the trust of each witness. The trust is calculated by means of the outcome trust reputation (individual dimension) and the social trust. Fuzzy rules are used to relate the social relation between each witness and the target; and the social trust.

In ReGreT two different types of relation are used: cooperation and competition. In medical organizations we only consider cooperation, and we define two new types of hierarchical relations on top of cooperation: ancestry and subordination. Some possible rules would be:

IF subord(w_i,te) is high THEN socialTrust is very_low

IF ancest(w_i,te) is low THEN socialTrust is slightly_high

IF ancest(w_i,te) is moderate THEN socialTrust is high

That is, if the witnesses w_i are strongly subordinated to the trustee, then the truster will give a very low importance to the information coming from the witness, because it is conditioned by having the witness a lower hierarchical level than the trustee. In the second case, if the hierarchy level of the witness is a bit higher than the trustee's then we can trust the witness a little bit but not as much as in the third example.

The calculation of witness reputation and reliability is made with the formulae defined for ReGreT system [3],[10] witness reputation.

C. Reputation of the Source of Information Assessment

The reputation and reliability of the source of information is calculated aggregating the individual and social reputations and reliabilities:

$$R_{SoI} = \alpha_{ind} \cdot R_{ind} + \alpha_{Social} \cdot R_{Social} \in [0,1]$$
$$RL_{SoI} = \alpha_{ind} \cdot RL_{ind} + \alpha_{Social} \cdot RL_{Social} \in [0,1]$$

where, $\alpha_{ind} + \alpha_{Social} = 1$

Through α_j coefficients we can 'modulate' the use of the information coming from others to calculate the final source of information reputation and reliability by weighting their values.

IV. Quality of Results Reputation

The third dimension of trust in TRHIOS system is the quality of results reputation R_{QoR}. We decompose this dimension in two related reputations: the *trustee's quality of results reputation* R^{te}_{QoR}; and the *trustee's institution quality of results reputation* R^{I}_{QoR}.

A. Trustee's Quality of Results Reputation

Objective estimation of the quality of the results offered by a certain individual is especially important in medical organizations. The outcome of this assessment is an objective evaluation value E ϵ [0,1], stored in an internal evaluations database (EDB). In the calculation of trustee's individual quality of results reputation R^{te}_{QoR} we give more importance to the latest evaluations, which we suppose will be closer to the evaluation value of future results than the old ones:

$$R^{te}_{QoR} = \sum_{j \in |EDB_{te}|} \rho(t, t_j) \cdot E_j \in [0,1]$$
$$RL^{te}_{QoR} = 2\left(\frac{1}{1 + e^{-k\left(\mu(E^{te}) / \sigma(E^{te})\right)}} - \frac{1}{2}\right) \in [0,1]$$

where,

$$\rho(t, t_j) = \frac{f(t_j, t)}{\sum_{j \in |EDB_{te}|} f(t_j, t)} \qquad e.g.\ f(t_j, t) = {}^{t_j}/_{t}$$

For the assessment of the reliability we use the signal to noise ratio SNR, $\mu(E^{te})/\sigma(E^{te})$, of all the evaluations of the results provided by the trustee, E^{te}. This ratio gives information about how good are the results offered by an agent and also the variability in the quality of those results.

B. Trustee's Institution Quality of Results Reputation

The idea behind this reputation refers to the perception of quality of an institution X associated to the prestige or fame that the institution has within the organization. If an agent belongs to a renowned institution for the high quality of results offered by its members the perception of the quality of its results would be conditioned by the assumption that s/he would also give good results. Trustee's institution quality of results reputation R^{I}_{QoR} and reliability RL^{I}_{QoR} take into account the trustee's individual quality of results reputation and reliability of all the institution's members -weighted by their hierarchical position in the institution- and the hierarchical level of the institution itself within the medical organization:

$$R^{I}_{QoR} = \frac{l^X_O}{max(l_O)} \sum_{j \in |X|} \frac{l_h(i)}{\max(l_h)} R^{te}_{QoR}(j) \in [0,1]$$
$$RL^{I}_{QoR} = \frac{l^X_O}{max(l_O)} \sum_{j \in |X|} \frac{l_h(i)}{\max(l_h)} RL^{te}_{QoR}(j) \in [0,1]$$

where $l_h(i)$= Agents' hierarchy level within institution X; l^X_O= Hierarchy level of institution X; $R^{te}_{QoR}(j)$ and $RL^{te}_{QoR}(j)$ are the trustee's individual quality of results reputation and reliability of each agent of the institution X.

C. Objective evaluation

The process of objective assessment can be modeled as a three-sided problem [11]: 1) the clinical side; 2) the technological side; and 3) the analytical side. The *clinical side* deals with the definition of the optimal tasks, metrics and conditions to consider for the assessment of the quality of diagnosis, treatment/therapy prescription, etc. This dimension of objective assessment is domain-dependent and different metrics would be used for each domain and/or even for the different roles of individuals of a system. For instance clinical metrics might not be applied to an email agent.

The *technological side* is related to the analysis of parameters that could be associated to quality of service (QoS) assessment like probability of response, delay, accuracy, etc. Finally, the *analytical side* studies the use of statistical analysis, in order to ascertain whether automatic classification systems to aide objective assessment are viable or not. High level statistical analysis and machine learning techniques can be employed to infer knowledge and correlate metrics to specific evaluation values (for our system in the range [0,1]).

D. Quality of Results Reputation Assessment

The final quality of results reputation R_{QoR} and reliability RL_{QoR} can be easily calculated:

$$R_{QoR} = \theta_{te} \cdot R^{te}_{QoR} + \theta_I \cdot R^I_{QoR} \in [0,1]$$
$$RL_{QoR} = \theta_{te} \cdot RL^{te}_{QoR} + \theta_I \cdot RL^I_{QoR} \in [0,1]$$

where, $\theta_{te} + \theta_I = 1$

V. Final Reputation

Considering all the reputations and reliabilities of the different dimensions explained above, we calculate the global reputation and reliability of TRHIOS system as:

$$R_{TRHIOS} = \beta_{HoS} \cdot R_{HoS} + \beta_{SoI} \cdot R_{SoI} + \beta_{QoR} \cdot R_{QoR}$$
$$RL_{TRHIOS} = \beta_{HoS} \cdot RL_{HoS} + \beta_{SoI} \cdot RL_{SoI} + \beta_{QoR} \cdot RL_{QoR}$$

where: $\beta_{HoS} + \beta_{SoI} + \beta_{QoR} = 1$

Adjusting these parameters we can give more or less importance to each type of reputation.

VI. Conclusions and Future Work

We have presented TRHIOS system, a novel trust and reputation model aimed at filling the void in reputation systems, usually oriented to open environments without relationship constraints. In our model we assess reputation by gathering information from three trust dimensions: 1) hierarchical structure of the system, 2) interactions among agents, and 3) quality of the results offered by the agents.

We have described how to calculate hierarchy-based reputation values in complex societies like medical organizations were a double hierarchy structure can be defined. Our model contemplates different hierarchical dependence scenarios and adapts to different hierarchies. We consider another dimension of trust, especially important in medical organizations, the quality of the results offered by the agents. We propose performing an objective analysis of the results offered as an outcome using different metrics, allowing an evaluation of the results 'virtually' independent and free of different agents' interpretations and/or moods.

The model presented in this paper has been applied to a generic multi-agent telemedicine system but it can be applied to any hierarchical and quality-oriented society like academic or enterprise societies. Furthermore, the modular approach followed in the definition of the different types of reputations allows adapting the model to the peculiarities of each system. Finally, the flexibility of the model grants creating systems more or less constrained by the hierarchy and/or systems where the quality of the results is considered as the foremost parameter for assessing the reputation, at the expense of the source of information reputation.

Although preliminary results of the use of TRHIOS model seem promising, we have not yet performed a complete evaluation. Our main goal for the near future is to do this analysis and to apply THRIOS in a real environment.

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