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A hesitant fuzzy model of computational trust considering hesitancy, vagueness and uncertainty

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ABSTRACT

The aim of this work is to introduce a trust model, which is highly consistent with the social nature of trust in computational domains. To this end, we propose a hesitant fuzzy multi-criteria decision making based computational trust model capable of taking into account the fundamental building blocks corresponding to the concept of trust. The proposed model is capable of considering the contextuality property of trust and the subjective priorities of the trustor regarding the chosen goal. This is due to viewing trust not as a single label or an integrated concept, but as a collection of trustworthiness facets that may form the trust decision in various contexts and toward different goals. The main benefit of the proposed model is the consideration of the hesitancy of recommenders and the trustor in the process of trust decision making which can create a more flexible mapping between the social and computational requirements of trust. This type of formulation also allows for taking into account the vagueness of the provided opinions. In addition to the vagueness of the provided opinions, the model is capable of considering the certainty of recommendations and its effect on the aggregation process of gathered opinions. In the proposed model, the taste of the recommenders and the similarity of opinions are also considered. This will allow the model to assign more weight to recommendations that have a similar taste compared to the trustor. Finally, taking into consideration the attitudes of the trustors toward change of personality that may occur for various entities in the environment is another advantage of the proposed model. A step-by-step illustrative example and the results of several experimental evaluations, which demonstrate the benefits of the proposed model, are also presented in this paper.

1. Introduction

Similar to the social domain where trust is considered as the *glue of the society* [1], computational trust is becoming more and more important in various domains of virtual and multi-agent environments. Over the past years, computational trust has found its place in multiple fields such as decision support systems, recommender systems, wireless sensor networks, service oriented environments and social networks.

Without trust, we need lots of control [2,3]. This is the main reason behind the recently developed holistic security approaches with the aim of minimizing the use of classical security control mechanisms and maximizing the use of trust-based relationships and transactions [4,5].

To this end, a wide range of approaches for computational trust modeling have been introduced so far. Fuzzy models, probabilistic-based approaches, logic-driven approaches and statistical models are some of the more commonly used techniques to model the social concept of trust in computational domains. Although all these approaches provide their own unique benefits, some shortcomings can still be identified.

Most of the proposed computational trust models consider the concept of trust as a whole. In other words, trust is considered as a single quantitative or qualitative value. Based on this single value, the trustor tries to decide about the trustworthiness of an entity. The biggest problem with such an assumption is that different people (or any kind of cognitive decision maker) have their own subjective opinion about success. A criterion which is important for the trustor to consider an interaction satisfactory, may not be of much importance to a recommender or another type of trustor. This is a limitation for trust models because they cannot properly take the goal of the trustor and context of application into account.

Another shortcoming is the type of trust metrics that are used in trust models. Trust metric defines the trust values that can be

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used to express trust-related opinions about the existing entities. In computational trust models, this metric can be considered as crisp quantitative numbers, labels or qualitative linguistic variables. Quantitative trust metrics are not compatible with the nature of human relations. People prefer to express their opinions by using linguistic terms such as *good*, *bad* and so on. On the other hand, qualitative trust metrics commonly used by fuzzy trust models in the literature lack the flexibility to allow the entities to express their opinions in a comparative manner. Also, the hesitancy of humans in expressing their opinions is not considered in these models. In addition, most of the trust models are not aware of the uncertainty or vagueness of the entities when they express their trust-related opinions or they incorrectly consider both of these concepts as *confidence*. Certainty denotes how sure an entity is about her/his provided opinion whereas vagueness denotes how vague and unclear the provided opinion is. Therefore, a trust model should be capable of considering both these concepts and their effects on the trust decision making process.

The final identified shortcoming is the consideration of taste or similarity between opinions. A recommender may have a different viewpoint or taste compared to the trustor. This cannot be considered as malicious behavior but should be taken into account when a trustor is aggregating the opinions received from recommenders. A recommender with similar taste to the trustor should have a higher weight compared to a recommender with different taste.

Based on these shortcomings we aim to propose a novel computational trust model capable of taking into account the hesitancy, vagueness, taste and uncertainty of entities in calculating the trustworthiness values.

Recently, the use of hesitant fuzzy linguistic term sets (HFLTS) has gained attention [6–11]. It is shown that by using HFLTS one can flexibly account for the case where decision makers hesitate amongst different values due to thinking of several linguistic terms to express their opinions. Hesitant fuzzy set (HFS) was first introduced by Torra [12].

There are other choices such as interval-valued fuzzy sets (IVFS) or intuitionistic fuzzy sets (IFS) and its extensions such as temporal IFS introduced by Atanassov et al., [13,14] but in our opinion using HFS provide a more natural modeling infrastructure for the unique characteristics of trust decision making. The benefits of using HFS for modeling the trust decision making process are as follows:

1. HFSs allow the membership degrees of an element to be a set of several possible values between 0 and 1. Hence, they are highly beneficial in modeling situations where people have hesitancy in providing their preferences over the existing alternatives in the decision making process [15]. In the context of trust decision making, being hesitant about the trustworthiness of a trustee candidate is an inherent characteristic. Trust means nothing if we are certain about a trustee candidate and we have no hesitancy about its trustworthiness.
2. HFSs are able to describe the situations that allow the membership of an element corresponding to a given set having a few different values, which is a useful tool to describe and deal with uncertain information in multi-criteria decision making (MCDM) processes. Consider a situation in which several decision makers exist and they want to estimate the degree that an alternative should satisfy a criterion. Suppose that there are three cases, some decision makers provide 0.3, some provide 0.5 and the others provide 0.6 and these three decision makers groups cannot reach a definite conclusion or persuade each other. Hence, the degree that the alternative should satisfy the criterion can be represented by a hesitant fuzzy element {0.3,0.5,0.6}. It should be noted that the HFE {0.3,0.5,0.6} can describe the above situation more objectively compared to the interval-valued fuzzy set [0.3,0.6]. This is because the degrees that the alternative should satisfy the criterion are not a convex combination of 0.3 and 0.6 or the interval between 0.3 and 0.6 but just three possible values [16,17].
3. If we use any of the extended fuzzy sets such as IFSs or IVFSs to represent the decision given by these three decision makers groups, much useful information may be lost, which may lead to an inconsistent or unreasonable decision. Therefore, it is more suitable and flexible to describe the uncertain evaluation information by using HFS [18,19].
4. The use of hesitant fuzzy linguistic term sets (as an extension of HFSs) improves the previous linguistic approaches. This is due to providing experts a greater flexibility in eliciting linguistic preferences through the use of context-free grammars that fix the rules to build flexible linguistic expressions to express preferences. In particular it allows the use of comparative linguistic expressions [20,21].
5. The process of modeling is very close to the humans' cognitive process when using HFSs. It should be noted that the modeling of fuzzy information by other extended forms such as IFSs or IVFSs is based on the elicitation of single or interval values that should encompass and express the information provided by the decision makers when determining the membership of an element to a given set. Nevertheless, in some cases, the decision makers (or experts) involved in the problem may have a set of possible values, and thus, they cannot provide a single term or an interval value to express their preferences or assessments because they are thinking of several possible values at the same time. In such a case, the HFS, whose membership is represented by a set of possible values, can solve this problem perfectly, while the above mentioned extensions are either invalid or unsuitable [18].
6. The proposition of HFS is motivated for the common difficulty that often appears when the membership degree of an element must be established and the difficulty is not because of an error margin (as in IFS) or due to some possibility distribution (as in T2FS), but rather because there are some possible values that make to hesitate about which one would be the right one [22]. This situation is very common in trust decision making when a trustor might consider different degrees of membership such as {0.67,0.72,0.74}.

The general scheme of our proposed trust decision making model is based on the introduced hesitant decision making approach by Rodriguez et al. [11,20,23], which is a well-established model of decision making based on HFLTS. In the proposed approach, we only use hesitant fuzzy sets where all the memberships are finite sets. Such sets correspond to the so-called typical hesitant fuzzy sets, which were introduced by Bedregal et al. [24,25].

In our formulation, we consider each trustworthiness facets such as *competence*, *motivation*, *availability*, *willingness* and so on as a criterion in a multi-criteria decision making scheme. This will allow our model to take into account the context and goal of the trustor. As an example, in one context, *availability* and *motivation* may be of importance, whereas in another context, *competence* and *willingness* may have the highest priority. Recommenders can express their opinion in a hesitant and comparative manner. Also, by using a separate hesitant linguistic term set, the certainty of recommenders about their opinions can be considered. In addition, smaller weights are assigned to vague opinions whereas larger weights are given to opinions with definite and clear values.

By using the hesitant normalized Hamming distance measure [26,27], we take into account the similarity of evaluations between the recommenders and the trustor. This will allow the model to increase (or decrease) the weights of recommenders with similar (or dissimilar) tastes. In addition, the model is capable of taking into account various attitudes of the trustor toward *change of*