
An Evidential Trust Model for Web Services Based on Fuzzy Sets

Vibhor Kant\textsuperscript{a*} and Pragya Dwivedi\textsuperscript{b†}

\textsuperscript{a}The LNM IIT, Jaipur, India
\textsuperscript{b}Motilal Nehru National Institute of Technology, Allahabad, India

Abstract

Trust models assist users in Web services to evaluate each other by assigning trust scores and decide whether to trust or not. Many trust models have proposed several belief functions for measuring the uncertainty associated with trust scores using Dempster-Shafer or Bayesian theory. However, the representation of trust scores in these models does not take into account the uncertainty induced by vagueness. In this work, we propose a fuzzy evidential trust model in which trust scores are considered as fuzzy focal elements consisting of fuzzy trust, distrust, ignorance and conflict. Further, we provide various operators for trust propagation and aggregation based on fuzzy evidential theory. Finally, in order to demonstrate the effectiveness of our proposed model, we present some intuitive results.

© 2015 The Authors. Published by Elsevier B.V.

Keywords: Trust Network; Trust Propagation; Trust Aggregation; Evidence Theory and Fuzzy Sets

1. Introduction

The use of Web services and Internet mediated applications (e.g. Web recommender systems, social networks and auction Websites) has become prevalent in recent years. Users have to interact with a number of different users and they have very less or no knowledge of past interactions to ensure the credibility of their...
responses. However, users need to know whether other users are trustworthy or untrustworthy. Further, trust plays also an important role for enhancing the quality of many Web services. However, trust is quite challenging to define because it manifests itself in many different forms. Generally, trust is defined as a subjective expectation a user has about another’s future behavior based on the history of their encounters. Over the last few years, a lot of research works have been carried out in the area of trust management that includes the trust representation, trust acquisition, trust transitivity, trust aggregation, and decision making of trust scores.

The trust model defines how to represent, compute and reason with the trust scores in a large trust network. Designing an efficient trust model is not an easy task because trust scores are uncertain induced by randomness and vagueness. Further, it can happen that the trust scores can conflict with each other when combining and reasoning with uncertain indications of these scores. Dempster-Shafer and Bayesian theory have been employed in designing efficient trust models for handling conflict and uncertainty. These models either reduce the mass associated with conflicting situations or handle conflicting situations in similar ways for ignorance management. Moreover, these models do not consider the uncertainty associated with these scores induced by vagueness. Therefore, conflicting situations have not yet fully resolved.

The simplest approach to trust representation is a crisp modeling where a user is to be trusted or not. But it is not enough for inferring accurate information especially in conflicting situations. Golbeck and Hendler modeled trust scores in a trust network as a crisp trust graph where simple average is used for trust aggregation. Josang et al. proposed a model for trust derivation with subjective logic based on practical belief calculus where belief, disbelief and uncertainty all take crisp values. More realistic approaches enable us to model partial trust/distrust that reflects natural statements like “to trust someone very much”. Therefore, trust/distrust to a person can be expressed more naturally by using fuzzy sets. In this regard, we propose a fuzzy evidential trust model where trust scores are represented in terms of fuzzy sets for handling the uncertainty induced by vagueness. In our work, we will describe also the trust representation, trust propagation and aggregation in the framework of fuzzy evidence theory.

The rest of the paper is organized as follows: Section 2 describes our proposed fuzzy evidential trust model where trust scores are represented by fuzzy sets and demonstrates the effectiveness of proposed trust model through some intuitive results. Finally, in the last Section, we conclude our work.

2. Proposed trust model

In this section, we propose new representation scheme of trust score that reflects the support degrees of trust, distrust, ignorance as well as conflict and describe trust transitivity including propagation and aggregation strategies based on fuzzy evidence theory.

2.1 Representation of trust scores

Consider a body of evidence in the fuzzy evidential theory (FED) over a frame of discernment \( \Theta = \{1, 2, 3, 4, 5\} \) with the following fuzzy focal elements i.e. trust (T), distrust (D), ignorance (I) and conflict (C) such that basic probability assignments (bpa) \( m(T), m(D), m(I), m(C) \geq 0 \) and \( \sum_{x \in \{T, D, I, C\}} m(x) = 1 \):

\[
T = \{\frac{1}{1}, \frac{3}{2}, \frac{5}{3}, \frac{7}{4}, \frac{1}{5}\}; D = \{\frac{1}{1}, \frac{3}{2}, \frac{5}{3}, \frac{7}{4}, \frac{1}{5}\}; I = \{\frac{8}{1}, \frac{4}{2}, \frac{0}{3}, \frac{0}{4}, \frac{0}{5}\}; C = \{\frac{0.1}{1}, \frac{0.9}{2}, \frac{0.25}{3}, \frac{0.49}{4}, \frac{1}{5}\}
\]

In our setting, trust relations between users in large trust networks can be defined by the set of user couples \( \{u_i, u_j\} \) where \( u_i \) provides his trust score in \( u_j \) as a quadruple \( \{m(T), m(D), m(I), m(C)\} \) where \( \forall m \in [0, 1] \) and \( m(T) \rightarrow \) The support of degree of trust; \( m(D) \rightarrow \) The support of degree of distrust; \( m(I) \rightarrow \) The support of...
degree of ignorance & m(C) → The support of degree of conflict caused by paradoxical behaviour.

2.2 Trust transitivity

It is very unlikely that all users know each other directly in a trust network. When a user, say, \( u_i \) does not have a direct trust score with another user \( u_k \), but wants to set up his trust score, he usually searches a connection to \( u_k \) through his trusted neighbours. Trust computation along a path from one to another user is made through trust propagation. Thus, trust propagation operators take part in deriving the trust score about an unknown for a user through his trusted friends. Intuitively, trust has transitive nature because it favours a famous social dictum “Friend of a friend is also a friend”.

As Fig.1 shows, suppose user \( u_i \)'s trust score for user \( u_j \) is expressed as 
\[
T_{u_i}^{u_j} = \{m_{u_i}(T), m_{u_i}(D), m_{u_i}(I), m_{u_i}(C)\}
\]
and user \( u_j \)'s trust score for user \( u_k \) is expressed as 
\[
T_{u_j}^{u_k} = \{m_{u_j}(T), m_{u_j}(D), m_{u_j}(I), m_{u_j}(C)\}.
\]

As Fig.1 shows, suppose user \( u_i \)'s trust score for user \( u_j \) is expressed as 
\[
T_{u_i}^{u_j} = \{m_{u_i}(T), m_{u_i}(D), m_{u_i}(I), m_{u_i}(C)\}
\]
and user \( u_j \)'s trust score for user \( u_k \) is expressed as 
\[
T_{u_j}^{u_k} = \{m_{u_j}(T), m_{u_j}(D), m_{u_j}(I), m_{u_j}(C)\}.
\]
Further, \( u_i \) has no direct interaction with \( u_k \) but wants to establish a trust score in \( u_k \). We describe the indirect trust evaluation through his friend \( u_j \) as follows: 
\[
T_{u_i}^{u_k} = T_{u_i}^{u_j} \otimes T_{u_j}^{u_k}
\]
where
\[
T_{u_i}^{u_j} = \begin{cases}
    m_{u_k}(T) \rightarrow \left( m_{u_i}(T) + \delta \cdot m_{u_i}(C) \right) \cdot m_{u_j}(T), \\
    m_{u_k}(D) \rightarrow \left( m_{u_i}(D) + \delta \cdot m_{u_i}(C) \right) \cdot m_{u_j}(D), \\
    m_{u_k}(I) \rightarrow \left( m_{u_i}(I) + \delta \cdot m_{u_i}(C) \right) \cdot m_{u_j}(I) + m_{u_i}(I) + m_{u_i}(D), \\
    m_{u_k}(C) \rightarrow \left( m_{u_i}(C) + \delta \cdot m_{u_i}(C) \right) \cdot m_{u_j}(C).
\end{cases}
\]  

Example 1 (Trust Propagation)

To demonstrate the use of proposed recommendation operator for trust transitivity, we show how to compute the indirect trust score through a trusted friend in this example. The computation is based on Fig 1 and...
Case 1: Suppose $T_{u_i}^{uj} = \{1,0,0,0\} \& T_{u_j}^{uk} = \{1,0,0,0\}$ and $\delta = 1$, then

$$T_{u_i}^{uk} = \begin{pmatrix} \((1 + 1 \times 0) \times 1), \\
                \((1 + 1 \times 0) \times 0), \\
                \((1 + 1 \times 0) + 0 + 0), \\
                \((1 + 1 \times 0) + 0) \end{pmatrix}, \text{ using Equation 1.}$$

$$T_{u_i}^{uk} = (1,0,0,0),$$

Case 2: Suppose $T_{u_i}^{uj} = \{1,0,0,0\} \& T_{u_j}^{uk} = \{0,1,0,0\}$ and $\delta = 1$ then

$$T_{u_i}^{uk} = \begin{pmatrix} \((1 + 1 \times 0) \times 0), \\
                \((1 + 1 \times 0) \times 1), \\
                \((1 + 1 \times 0) + 0 + 0), \\
                \((1 + 1 \times 0) + 0) \end{pmatrix}, \text{ using Equation 1}$$

$$T_{u_i}^{uk} = (0,1,0,0),$$

Case 3: Suppose $T_{u_i}^{uj} = \{1,0,0,0\} \& T_{u_j}^{uk} = \{0,0,1,0\}$ and $\delta = 1$ then

$$T_{u_i}^{uk} = \begin{pmatrix} \((1 + 1 \times 0) \times 0), \\
                \((1 + 1 \times 0) \times 0), \\
                \((1 + 1 \times 0) + 1 + 0 + 0), \\
                \((1 + 1 \times 0) + 0) \end{pmatrix}, \text{ using Equation 1}$$

$$T_{u_i}^{uk} = (0,0,1,0),$$

Case 4: Suppose $T_{u_i}^{uj} = \{1,0,0,0\} \& T_{u_j}^{uk} = \{0,0,0,1\}$ and $\delta = 1$ then

$$T_{u_i}^{uk} = \begin{pmatrix} \((1 + 1 \times 0) \times 0), \\
                \((1 + 1 \times 0) \times 0), \\
                \((1 + 1 \times 0) + 0 + 0), \\
                \((1 + 1 \times 0) + 1) \end{pmatrix}, \text{ using Equation 1}$$

$$T_{u_i}^{uk} = (0,0,0,1),$$

Case 5: Suppose $T_{u_i}^{uj} = \{0,1,0,0\} \& T_{u_j}^{uk} = \{1,0,0,0\}$ and $\delta = 1$ then
\[
T_{u_i}^{u_k} = \begin{pmatrix}
(0 + 1 \times 0) \times 1, \\
(0 + 1 \times 0) \times 0, \\
((0 + 1 \times 0) \times 0 + 0 + 1), \\
((0 + 1 \times 0) \times 0)
\end{pmatrix}, \text{ using Equation 1}
\]

\[
T_{u_i}^{u_k} = (0,0,1,0),
\]

**Case 6:** Suppose \(T_{u_i}^{u_j} = \{0,1,0,0\}\) & \(T_{u_j}^{u_k} = \{0,1,0,0\}\) and \(\delta = 1\) then

\[
T_{u_i}^{u_k} = \begin{pmatrix}
(0 + 1 \times 0) \times 1, \\
(0 + 1 \times 0) \times 1, \\
((0 + 1 \times 0) \times 0 + 0 + 1), \\
((0 + 1 \times 0) \times 0)
\end{pmatrix}, \text{ using Equation 1}
\]

\[
T_{u_i}^{u_k} = (0,0,1,0),
\]

From case 1 to case 4 of this example, it is clear that our recommendation operator follows the social dictum “Friend of a friend will be a friend” i.e. users agree with their friends completely about any suggestions provided by their friends. But, from case 5 to case 6 of this example, it is also clear that our recommendation operator follows the fact “generally users ignore those people who are not trustworthy”.

2.3 Trust aggregation

During propagation, when several paths to the trustee exist via various trusted neighbors of trustor, then the evaluated indirect trust from various paths need to be joined and this process is termed as trust aggregation. Generally, users would like to employ various consensus operators for aggregation so that they could get utmost information about the trustee from several paths. As Fig. 2 shows, a user \(u_i\) does not have a direct trust score with another user \(u_j\), but wants to set up his trust score, he usually searches a connection to \(u_j\) through his trusted neighbors say \(u_j\) and \(u_k\).

\[
T_A = T_{u_i}^{u_j} \odot T_{u_j}^{u_k}
\]

\[
T_B = T_{u_i}^{u_k} \odot T_{u_k}^{u_l}
\]

Fig. 2. Example of Trust Aggregation
Thus there are two paths via \( u_j \) & \( u_k \), for finding appropriate trust scores in \( u_i \). If \( m_A \) & \( m_B \) are two bpa of two independent evidential sources for these two paths say, \( A \) & \( B \) over the set \( \theta \), then their combination \( (E) \) will be also a bpa and is computed as follows:

\[
m(E) = m_A(A) \oplus m_B(B) = \Sigma_{A \cap B = E} W(E, A). m_A(A). W(E, B). m_B(B)
\]

where \( W(E, A) = |E|/|A| \) & \( |X| \) is the cardinality of fuzzy set \( X \). Above rule can be expressed more expressively as follows

If \( T_A = (m_A(T), m_A(D), m_A(I), m_A(C)) \) & \( T_B = (m_B(T), m_B(D), m_B(I), m_B(C)) \) are the independent evidences then their combination \( (T_A \oplus T_B) \) can be computed by the following formula

\[
T_A \oplus T_B = \begin{cases} 
1 \cdot 1 + 1 \cdot 0 \cdot \left( \frac{.4}{2.6} \right) + 0 \cdot 1 \cdot \left( \frac{.4}{1.2} \right) + 1 \cdot 0 \cdot \left( \frac{.4}{1.2} \right) + 0 \cdot 0 \cdot \left( \frac{.4}{2.6} \right), \\
0 \cdot 0 + 0 \cdot 0 \cdot \left( \frac{.4}{2.6} \right) + 0 \cdot 0 \cdot \left( \frac{.4}{1.2} \right) + 0 \cdot 0 \cdot \left( \frac{.4}{2.6} \right), \\
0 \cdot 0, \\
1 \cdot 0 \cdot \left( \frac{2.6}{2.6} \right) + 0 \cdot 1 \cdot \left( \frac{2.6}{2.6} \right) + 0 \cdot 0 \cdot \left( \frac{2.6}{2.6} \right) + 0 + 0 - 0 \cdot 0
\end{cases}
\]

\[
\approx T_A \oplus T_B = (1, 0, 0, 0)
\]

This example represents that the combination will be trustworthy because \( T_A \oplus T_B (T) = 1 \) is maximum. Therefore, our combination rule follows the real scenario for trustworthiness (i.e combination of same evidences should be same).

Case 2: \( T_A = (0, 1, 0, 0) \) & \( T_B = (0, 1, 0, 0) \)
This example where $T_A \oplus T_B(D) = 1$ represents that the combination will be untrustworthy. Thus, our combination rule follows the real scenario for distrust (i.e. combination of same evidences should be same).

**Case 3:** $T_A = (1,0,0,0) \& T_B = (0,1,0,0)$

$$T_A \oplus T_B = \begin{pmatrix}
0 \cdot 0 + 0 \cdot 0 \cdot \left(\frac{.4}{2.6} \cdot \frac{.4}{1.2}\right) + 0 \cdot 0 \cdot \left(\frac{.4}{2.6} \cdot \frac{.4}{2.6}\right), \\
1 \cdot 1 + 1 \cdot 0 \cdot \left(\frac{.4}{2.6} \cdot \frac{.4}{1.2}\right) + 0 \cdot 1 \cdot \left(\frac{.4}{2.6} \cdot \frac{.4}{2.6}\right), \\
0 \cdot 0, \\
0 \cdot 1 \cdot \left(\frac{2.6}{2.6} \cdot \frac{2.6}{2.6}\right) + 1 \cdot 0 \cdot \left(\frac{2.6}{2.6} \cdot \frac{2.6}{2.6}\right) + 0 + 0 - 0 \cdot 0 \\
\end{pmatrix}$$

$$\approx T_A \oplus T_B = (0,1,0,0)$$

This example where $T_A \oplus T_B(C) = 1$ shows an evaluation of conflict. Therefore, our combination rule conforms the real scenario “When two evaluations are very different, intuitonally, the degree of conflict in the result should increase”.

3. Conclusions

In this work, we propose a new trust model for Web services based on fuzzy evidence theory to handle the uncertainty associated with trust scores involving fuzzy trust, distrust, ignorance and conflict. We consider these concepts as fuzzy focal elements for analysing the human perception about the notion of trust. Furthermore, we propose appropriate propagation and aggregation operators to handle the issue of trust transitivity. Finally, we have provided some intuitive results to demonstrate the effectiveness of our proposed trust model.
References


