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Fuzzy-bayesian Trust Model for Web Service

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Abstract: A Bayesian trust model with fuzzy prior information is proposed for estimating the trust value of Web service. First, the confidence distribution was induced based on test data and it was considered as prior distribution. Then, experts’ fuzzy observation was regarded as test data. Third, posterior distribution was inferred by a general Bayesian method. Finally, the example results demonstrate its feasibility and effectiveness.

Key words: Web service, trust model, fuzzy prior information, bayesian inference

INTRODUCTION

Web service has been the most important means of abstracting and wrapping computing resources on the Internet. Network computing will develop into “center with network and service oriented architecture” gradually (Liu et al., 2008). As the open service oriented information systems are widely used, trust is becoming a central issue in these distributed systems.

However, the network environment is dynamic, distributed, open and etc.,. These features may result in many uncertain factors, such as the uncertainty of Web service behavior. Therefore, it is urgent need a secure and reliable management means. A valid method to security and reliability problems above is to establish trust mechanism for Web service (Shen et al., 2007).

Bayesian trust model has been proposed in previous works (Wang and Zeng, 2010; Denko et al., 2011; Yun, 2013). Their methods using a prior distribution to represent the prior information of experts’ opinion, i.e., to construct prior distribution based on some certain method, such as the conjugate prior distribution. However, it's difficult to have an effective method to construct prior distribution when the experts’ opinion is in the fuzzy form (Wu, 2004). Therefore, Bayesian trust model with fuzzy prior information needs to be extended further.

The general idea of Bayesian method is “prior information+test data = posterior distribution”. The position of the test data and the prior information should be equal (Cooelen, 1996). So, bases on this idea, the test data is treated as the prior information and the experts’ opinion is deemed as the test data respectively and then using the Bayesian formula for statistical inference.

DERIVATION OF PRIOR CONFIDENCE DISTRIBUTION BASED ON TEST DATA

For the binomial events, the success or failure data was tested \((n, s)\), \(n\) is test number and \(s\) is the number of success. The obtained test data can be used to induce a distribution of parameter \(p\) (success probability) which is called confidence distribution. According to the classical theory of confidence intervals, the obtained confidence lower limit of parameter \(p\) is \(p_l\), confidence level is \(\alpha\), if \(P\{p>p_l\} = \alpha\).

\(p_l\) can generate a probability distribution of parameter \(p\) with the change of \(\alpha\), \(p_l\) the confidence lower limit of parameter \(p\) (confidence level is \(\alpha\)) is determined by following equation (Buehler, 1957)

\[
\sum_{i=0}^{\infty} \binom{n}{i} p_i^n (1-p_i)^{n-i} = 1 - \alpha
\]

\(= I_n(s, n-s+1) \tag{1}\)

Let \(F(p) = I_n(s, n-s+1)\), then \(F(p_l) = 1 - \alpha\). So, \(F(p)\) is the distribution function of \(p_l\) its density function is given as follows:

\[
f(p) = \frac{d}{dp} F(p) = \text{beta}(s, n-s+1) \tag{2}\]

Similarly, another confidence distribution of \(p_u\) (the confidence upper limit of parameter \(p\)) is beta\((s+1, n-s)\). Making a compromise, confidence distribution of parameter \(p\) is given as follows:
\[ \pi(p) = \text{beta}(s + 0.5, n - s + 0.5) \]  

(3)

**BAYESIAN INFERENCE WITH FUZZY PRIOR INFORMATION**

If experts have some prior information, such as first order moment, quantile or mode, etc., these information can be represented by the beta distribution mostly in practice. After determining this distribution, it can be equivalent to a group of success or failure data \((n, s)\). Then, according to the confidence distribution and the equivalent test data \((n, s)\), the posterior distribution can be obtained by Bayesian inference:

\[ h(p | n, s) = \frac{c_n p^{n-1} (1-p)^{s-1} \pi(p)}{\int c_n p^{n-1} (1-p)^{s-1} \pi(p) dp} \]  

(4)

In many cases, to give exact prior information is reluctant. Therefore, experts used to provide their own view in fuzzy form, such as “the success probability \(p\) is very high” or “the success probability \(p\) is about 0.95”. It’s difficult to find a group of test data which is equivalent to this fuzzy information. For the imprecise information, it can be described by using fuzzy set theory. The commonly used membership functions are triangle membership function, trapezoidal membership function, rectangular membership function and normal membership function. These four kinds of fuzzy numbers are defined according to the geometric shape of membership function. In this study, triangle membership function is taken for illustrate. Triangle membership function can be denoted as follows:

\[ \mu_{a}(p) = \begin{cases} 
(p-a)/(b-a), & a \leq p \leq b \\
(c-p)/(c-b), & b \leq p \leq c \\
0, & \text{other} 
\end{cases} \]  

(5)

where, \(A\) is fuzzy observation, \(a < b < c\), \(a\) is lower limit and \(c\) is upper limit which represent fuzzy boundary; \(b\) is the most possible value which represent the center of fuzzy information. The confidence distribution \(\pi(p)\) which derived from test data \((n, s)\) serves as prior distribution and experts’ opinion is described by fuzzy number \(\mu_{a}(p)\). According to Bayesian inference, the posterior distribution can be obtained as follows:

\[ h(p | n, s, A) = \frac{\mu_{a}(p)\pi(p)}{\int \mu_{a}(p)\pi(p) dp} \]  

(6)

According to Bayesian point estimation:

\[ \hat{p} = \int p \cdot h(p | n, s, A) dp \]  

(7)

**TRUST MODEL FOR WEB SERVICE**

Service oriented network presents the following characteristics: Web service has right to choose interacting object, Web service's interaction can leave its behavior information; Web service can be published in the registry; Web service has the obligation to provide recommendation. Therefore, service oriented network is very similar to the social network (Caroni, 2000). In the service oriented network, the interaction success probability of Web service reflects the security and reliability of its behavior. So, the interaction success probability can be served as a measure of trust value.

**Direct trust value:** In order to get trust value directly, Web service \(S\) will analyze its interaction history with \(S_p\) the trust value from \(S\)'s direct experiences is called Direct trust value, denoted \(DT_{S_p}\). The direct trust value \(DT_{S_p}\) is defined as the interaction success probability.

Suppose \(S\) interacts with \(S_n\) times in the past time, where the interaction succeeds \(s\) times and fails \(n-s\) times. Let \(p\) be the interaction success probability, under the condition with “imprecise prior information”, using triangle membership function \(\mu_{a}(p)\) to represent experts’ opinion, according to Eq. 7, then:

\[ DT_{S_p} = \hat{p} = \int p \cdot h(p | n, s, A) dp \]  

(8)

**Indirect trust value:** If \(S\) only has limited direct experience with \(S_p\), a natural way to get trust value for \(S\) is to ask its acquaintances about their opinions. \(S\) asks its one acquaintance, \(S_a\), to get the indirect trust value with \(S_p\). The trust value from acquaintance \(S_a\) is called Indirect trust value, denoted as \(IDT_{S_a}\). As shown in Fig. 1a. The direct trust value between \(S_i\) and \(S_p\) is denoted as \(DT_{S_p}\). \(S_i\) recommends its direct experiences to \(S_i\) and then these experiences become indirect experiences of \(S_i\). But maybe \(S_i\) is not a very familiar friend for \(S_i\) or \(S_i\) has recommend \(S_i\) inaccurate experiences in the past, \(S\) does not think \(S_i\)'s recommendation is completely right. For example, \(S\) may say an 80 percent probability that \(S_i\)'s recommendation is right. 80 percent shows the degree of \(S_i\)'s recommendation for \(S\). Recommendation value, \(R_{S_i}[0, 1]\), is used to represent this degree.

**Suppose that there are three nodes of network:** \(S_a, S_k\) and \(S_p\). The direct trust value between \(S_k\) and \(S_x\) is \(DT_{S_x} \in [0, 1]\).
Fig. 1(a-b): Indirect trust value, (a) One level recommending, (b) Two recommending paths

and the recommendation value is $R_{ik} \in [0, 1]$, then the indirect trust value is defined as, $IDT_{ai} = R_{ai} \times DT_{ki} \in [0, 1]$. S, may wish to ask its friends’ friends. This two levels indirect trust value is defined as, $IDT_{a|0} = R_{ai} \times R_{i} \times DT_{ki} \in [0, 1]$. In this manner, multi levels recommending instance will arise. There is a recommending path. The multi levels indirect trust value can be extended obviously, $IDT_{ai|1} \times \cdots \times IDT_{ai|n} = R_{ai|1} \times R_{ai|2} \times \cdots \times R_{ai|n} \times DT_{ki} \in [0, 1]$.

**Reputation value:** There may be not only one recommending path between $S_i$ and $S_j$. The trust value from asking its all acquaintances Reputation value, denoted as $Rep_i$. The two recommending paths instance is shown in Fig. 1b.

Suppose there are two recommending paths between $S_i$ and $S_j$, the indirect trust value is $IDT_i$ and $IDT_j$ respectively. Then the reputation value $Rep_i$ is defined as, $Rep_i = \max \{IDT_{i|0}, IDT_{i|j}\}$.

**Total trust value:** In order to get more accurate trust value, the direct trust value and reputation value between $S_i$ and $S_j$ are combined. This combination is called Total trust value, denoted as $TT_{ij}$. The combining way is defined as, $TT_{ij} = \lambda \times DT_{ij} + (1-\lambda) \times Rep_i, \lambda \in [0, 1]$.

**EXAMPLE**

To estimate the feasibility and effectiveness of Bayesian trust model with fuzzy prior information, Fig. 2 is taken for illustration. Measuring the trust value between $S_i$ and $S_j$, $S_i$ has direct trust relation with $S_j$ and can recommend its direct trust value to $S_j$. Here we suppose $R_{ij} = 0.95$. Suppose $S_i$ interacts with $S_j$ 50 times in the past time, where the interaction successes 49 times. At same time, $S_i$ interacts with $S_j$ 50 times and successes 49 times, i.e., test data $(n, s) = (50, 49)$. According to Eq. 3 the confidence distribution is $\beta(s+0.5, n-s+0.5)$ which will be considered as “prior distribution”.

If the prior information experts provide is that the trust value of $S_j$ is about 0.95, then their opinion, according to Eq. 5, can be represented by triangle membership function as follows:

$$\pi(p) = \frac{\beta(s+0.5, n-s+0.5)}{\Gamma(51) \Gamma(1.5)} \rho^s \left(1-p\right)^{n-s}$$

According to Bayesian inference, the posterior distribution can be obtained as follows:

$$\mu_a(p) = \begin{cases} 1-p, & 0.95 \leq p \leq 1 \\ 1-0.95, & 0.9 \leq p \leq 0.95 \\ 0, & \text{other} \end{cases}$$

According to Bayesian point estimation:

$$h(p) = \frac{\mu_a(p) \pi(p)}{\int_{0}^{1} \mu_a(p) \pi(p) dp} = \frac{\mu_a(p) \beta(49.5, 1.5)}{\int_{0}^{1} \mu_a(p) \beta(49.5, 1.5) dp} = 1739 \rho^s \left(1-p\right)^{n-s} \frac{1}{\Gamma(1.5)} \left| \begin{array}{cc} 0.95 \leq p \leq 1 \\ 0, & \text{other} \end{array} \right.$$  

Namely, $DT_{ij} = DT_{ij} = \hat{p} = 0.96$. If the parameter $\lambda$ is taken 0.8, then the total trust value is:
\[ TT_{12} = \lambda \cdot DT_{12} + (1 - \lambda) \cdot R_{np} \]
\[ = 0.8 \times DT_{12} + 0.2 \times 0.95 \times DT_{12} \]
\[ = 0.8 \times 0.96 + 0.2 \times 0.95 \times 0.96 \]
\[ = 0.95 \]

CONCLUSIONS

It is difficult to use the Bayesian method to infer in the situation of fuzzy priori information, because it is hard to determine prior distribution with fuzzy information. A new method based on comprehensive utilization of fuzzy priori information and test data is proposed to solve the problem. This method avoids the difficulty of construction of the prior distribution from fuzzy information and provides a new way for evaluation of trust with fuzzy priori information. From the perspective of information theory, the method is the comprehensive use of a variety of information, subjective and objective, so the evaluation is more credible. The example results demonstrate its feasibility and effectiveness.

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