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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 (Coolen, 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 α, if $P\{p \geq p_L\} = \alpha$.

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

$$\begin{aligned}&\sum_{i=0}^{n-s}\binom{n}{i}p_L^{n-i}(1-p_L)^i\\&=I_{p_L}(s, n-s+1)\\&=1-\alpha\end{aligned} \quad (1)$$

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

$$\begin{aligned}f(p)&=\frac{d}{dp}F(p)\\&=\mathrm{beta}(s, n-s+1)\end{aligned} \quad (2)$$

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:

$$\pi(p) = beta(s + 0.5, n - s + 0.5) \tag{3}$$

BAYESIAN INFERENCE WITH FUZZY PRIOR INFOMATION

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:

$$h(p \mid n, s) = \frac{C_n^s p^s (1-p)^{n-s} \pi(p)}{\int_0^1 C_n^s p^s (1-p)^{n-s} \pi(p) dp} \tag{4}$$

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:

$$\mu_A(p) = \begin{cases} (p-a)/(b-a), a \le p \le b \\ (c-p)/(c-b), b \le p \le c \\ 0, \text{other} \end{cases} \tag{5}$$

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:

$$h(p \mid n, s, A) = \frac{\mu_A(p)\pi(p)}{\int_0^1 \mu_A(p)\pi(p) dp} \tag{6}$$

According to Bayesian point estimation:

$$\hat{p} = \int_0^1 p \times h(p \mid n, s, A) dp \tag{7}$$

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 (Caronni, 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_i will analyze its interaction history with S_j, the trust value from S_i's direct experiences is called Direct trust value, denoted DT_{ij}. The direct trust value DT_{ij} is defined as the interaction success probability.

Suppose S_i interacts with S_j n times in the past time, where the interaction successes 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:

$$DT_{ij} = \hat{p} = \int_0^1 p \times h(p \mid n, s, A) dp \tag{8}$$

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

Suppose that there are three nodes of network: S_i, S_k and S_j. The direct trust value between S_j and S_k is $DT_{kj} \in [0, 1]$

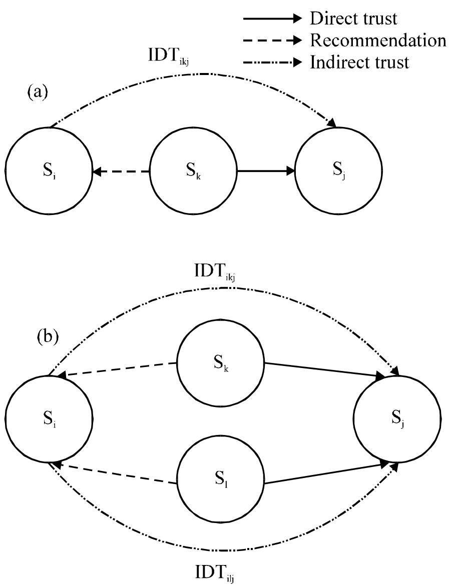

Fig. 1(a-b): Indirect trust value, (a) One level recommending, (b) Two recommending paths

and the recommendation value is $R_{ik} \in [0, 1]$, then the indirect trust value is defined as, $IDT_{ikj} = R_{ik} \times DT_{kj} \in [0, 1]$. S_i may wish to ask its friends' friends. This two levels indirect trust value is defined as, $IDT_{iklj} = R_{ik} \times R_{kl} \times DT_{lj} \in [0, 1]$. In this manner, multi levels recommending instance will arise. There is a recommending path. The multi levels indirect trust value can be extended obviously, $IDT_{i\,k1 \cdots knj} = R_{ik1} \times R_{k1k2} \times \ldots \times R_{kn-1kn} \times DT_{knj} \in [0, 1]$.

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_{ij}. 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_{ikj} and IDT_{ilj} respectively. Then the reputation value Rep_{ij} is defined as, $Rep_{ij} = \max\{IDT_{ikj}, IDT_{ilj}\}$.

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, $TT_{ij} = \lambda \cdot DT_{ij} + (1-\lambda) \cdot Rep_{ij}$, $\lambda \in [0, 1]$.

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

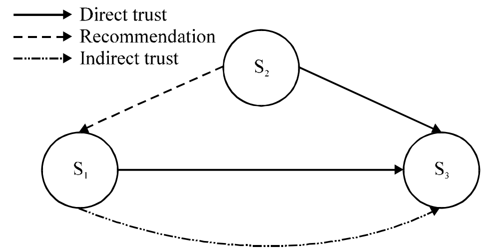

Fig. 2: Trust value computing model

between S_1 and S_3, S_2 has direct trust relation with S_3 and can recommend its direct trust value to S_1. Here we suppose $R_{12} = 0.95$. Suppose S_1 interacts with S_3 50 times in the past time, where the interaction successes 49 times. At same time, S_2 interacts with S_3 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_3 is about 0.95, then their opinion, according to Eq. 5, can be represented by triangle membership function as follows:

$$\pi(p) = \text{beta}(s+0.5, n-s+0.5) = \frac{\Gamma(51)}{\Gamma(49.5)\Gamma(1.5)} p^{48.5}(1-p)^{0.5}$$

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

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

According to Bayesian point estimation:

$$h(p) = \frac{\mu_A(p)\pi(p)}{\int_0^1 \mu_A(p)\pi(p)dp} = \frac{\mu_A(p)\text{beta}(49.5, 1.5)}{\int_0^1 \mu_A(p)\text{beta}(49.5, 1.5)dp} = \begin{cases} 17397(p^{48.5} - p^{49.5})(1-p)^{0.5}, 0.95 \le p \le 1 \\ 17397(p^{49.5} - 0.9p^{48.5})(1-p)^{0.5}, 0.9 \le p \le 0.95 \\ 0, \text{other} \end{cases}$$

Namely, $DT_{12} = DT_{23} = \hat{p} = 0.96$. If the parameter λ is taken 0.8, then the total trust value is:

$$
\begin{aligned}
TT_{13} &= \lambda \bullet DT_{13} + (1-\lambda) \bullet Rep_{23} \\
&= 0.8 \times DT_{13} + 0.2 \times 0.95 \times DT_{23} \\
&= 0.8 \times 0.96 + 0.2 \times 0.95 \times 0.96 \\
&\approx 0.95
\end{aligned}
$$

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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