A Fuzzy Model for Scalable Trust in E-Commerce

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Abstract. With the rapid development of e-commerce and the expansion of e-commerce system scale, scalable trust in e-commerce becomes critical. This article examines scalable trust of multiagent e-commerce system (MECS) and proposes a fuzzy model for scalable trust in e-commerce. It also discusses the realization of scalable trust from the viewpoint of engineering. The proposed approach will facilitate research and development of trust, multiagent systems, e-commerce and e-services.

1. Introduction

Trust is significant for healthy development of e-commerce 1-9. Castelfranchi and Tan assert that e-commerce can be successful only if the general public trusts in the virtual environment, because lack of trust in security is one of the main reasons for e-consumers and companies not to engage in e-commerce 3. Therefore, trust has received an increasing attention in e-commerce and information technology (IT). For example, Finnie and Sun examine trust in e-supply chains 4. Koufaris and Hampton-Sosa examine how the website experience can influence customer trust in the company itself through customer beliefs about the website [8]. Pavlou integrates trust with the technology acceptance model to explore the customer acceptance of e-commerce [14]. Salm et al examine trust in e-commerce and notice that "many customers may still not trust vendors when shopping online" [15]. Slyke, Belanger and Comunale look at the impact of trust on the adoption of Web-based shopping [16].

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Sun et al introduce experience-based trust, knowledge-based trust, reasoning-based trust and hybrid trust in e-commerce and discuss their interrelationships in the context of multiagent e-commerce systems [17]. Verhagen et al examine the relationship between consumer perceptions of trust and the attitude towards purchasing at a consumer-to-consumer e-marketplace [24]. Uslaner discusses trust online and trust offline [23]. Xiu and Liu introduce a formal definition of trust and discuss the properties of trust relation [28]. Xiong and Liu propose a formal reputation-based trust model by combining amount of satisfaction, number of interaction and balance factor of trust in a peer-to-peer e-communities [29]. Yan et al consider that the consumers' trust in e-commerce system includes system-based trust and institution-based trust [30]. Then they discuss the relationship between trust and control, and suggest that trust without control is unstable and dangerous [31]. However, they have not examined how to propagate the trust of agents from individual through group to the whole system.

Trust has been extensively discussed in multiagent e-commerce system (MECS) [4, 23, 24]. Schmidt et al apply a fuzzy trust model to an e-commerce platform [34]. Wong and Sycara address two forms of trust i.e. trust that agents will not misbehave and trust that agents are really delegates of whom they claim to be [25]. Wu et al show that trust can be established if agents learn which other agents exhibit poor behavior and hence which agents do not to be trusted [26]. However, they have not examined scalable trust in MECS, which are of practical significance for multiagent e-commerce and e-services. Zhao and Sun discuss scalable trust in e-commerce from the viewpoint of sociology and engineering [32]. However, they have not provided formal investigation into scalable trust in MECS. This article will fill this gap by examining scalable trust in e-commerce, in particular in MECS, and propose a fuzzy model for scalable trust in MECS. It also discusses the realization of scalable trust from the viewpoint of engineering.

The rest part of this article is organized as follows: Section 2 provides the fundamentals of trust in e-commerce. Section 3 examines scalable trust in e-commerce. Section 4 looks at engineering-based scalable trust for MECS. Section 5 proposes an intelligent model of trust in e-commerce. Section 6 introduces a measure and evaluation of trust. Section 7 proposes a fuzzy logic based model for scalable trust in e-commerce. Section 8 concludes the article with some concluding remarks and future work.

2. Fundamentals of Trust in E-Commerce

This section first reviews the definitions of trust in e-commerce, and then proposes an ontology for trust in e-commerce.

There are many definitions of trust that have been proposed in the literature. Slyke et al define trust in e-sellers (web merchants) as the "truster's expectation about the motives and behaviors of a trustee", where truster is e-customer, and trustee is e-seller [13]. More generally, trust indicates a positive belief or expectation about the perceived reliability of, dependability of and confidence in a person, an intelligent agent, organization, company, object, or process [13]. Therefore, trust is the expectation that arises within a community based on commonly sharing norms from one member to another of that community.

Ramchurn et al [12] define trust as “a belief an agent has that the other party will do what it says it will (being honest and reliable) or reciprocate (being reciprocative for the common good of both), given an opportunity to defect to get higher payoffs”. They conceptualize trust as (a) individual-level trust (agent believes in honesty or reciprocation of interaction partners) and (b) system-level trust (the agents are forced to be trustworthy by the system). They further characterize individual-level trust models as learning (evolution) based, reputation-based or socio-cognitive based. Learning models are based on interactions with other agents. Reputation-based models work by asking other agents of their opinion of potential partners.

Generally, trust can also be classified into strategic trust and moralistic trust [23]. Strategic trust is the trust that reflects our experience or willingness with particular people doing particular things (e.g. specific exchanges) [13]. This kind of trust can be called business trust or transaction trust [35], and then it is fragile and temporary [13]. Strategic trust can help us decide whether a specific website is safe and our information secure is there, etc. [23]. Strategic trust can be improved by references from past and current customers [13]. One reason for amazon.com’s success with online books selling is that it provides the peer (customers’) reviews for almost every book available at amazon.com. The customer can read the peer reviews (as references) before buying the book.

Moralistic trust is the durable optimistic view that strangers are well-intentioned [13], which is a more general value we learn early in life. This kind of trust will give us sufficient faith to take risks on the Web in the first place [23].

Tan and Thoen [35] propose a generic model of trust for e-commerce consisting of two basic components: Party trust and control trust based on the idea that the trust in a transaction with another party depends on the trust in the other party (party trust) and trust in the control mechanism (control trust) that ensure the successful performance of the e-transaction.

Party trust and control trust constitute transaction trust [35], because transaction trust is a kind of strategic trust. Therefore, party trust and control trust can also be considered as strategic trust, as shown in Figure 1. Further, party trust and control trust are supplementary to each other, because if there is not enough party trust between each other, then a control trust mechanism is prescribed.

It should be noted that trust ontology, proposed in Figure 1, is the first attempt for understanding of trust in e-commerce. The proposed trust ontology will be gradually elaborated in the future.

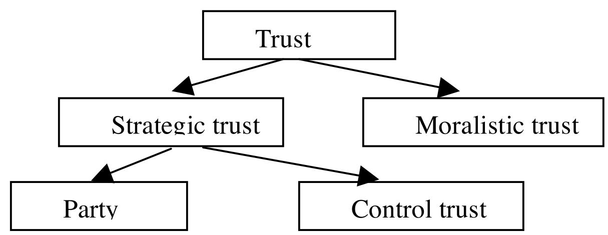

Figure 1. An ontology of trust in e-commerce

3. Scalable Trust in E-Commerce

There are definitions about scalability in many fields [7]. For brevity, we consider the scalable system as the system can deal with the increase of users and resources under the condition of neither remarkably decreasing system performance nor notably increasing management complexity [32].

Based on the definition of scalable system, the scalability of multiagent system (MAS) is when the system parameters change, such as agent number, heterogeneous agent, task scale and task heterogeneity, the system performance does not remarkably decrease, for instance, the declining of task accomplishment ratio, the shortage of resources. Then the scalable trust of MAS can be defined as the trust that can fit for the system parameter changes, that is, these changes cannot lead to the input's remarkable increase and the output's remarkable decrease [32].

Scalable trust can also be considered as trust propagation. That is, the trust between one agent and another is extended to that between one agent and an agent team. The scalable trust between agents within a MAS is the trust that can fit for the remarkable expanding of the MAS system scale and the big increase of agent numbers, provided that the system still keeps appropriate efficiency and modest extra cost.

4. Engineering-Based Scalable Trust for MECS

Scalable trust in the MECS can be treated through trust propagation from the sociology and engineering perspectives respectively [32]. In what follows, we look at the engineering-based scalable trust for MECS.

From the engineering perspective, with the drastic increasing of the agent number in the MECS, the non-scalability of the existed interaction-based trust models will lead to that the trust model has to maintain an enormous agent interaction database. The storage cost of the agent interaction experiences and the cost of selecting trusted agent also increase drastically, and finally these models cannot meet the requirement of the large scale application environment.

How to generalize the individual interaction-based trust to the network-based trust becomes significant for scalability of the system. The existing reputation-based trust models [6, 12, 33] provide the trust recommendation mechanism to make the individual interaction-based trust generalize to interaction network. It is important for these models to have the ability of efficiently processing the dishonest recommendation information in the system in order to guarantee the scalability of trust successful.

From the scalability viewpoint, the lowest level of trust is the individual interaction-based trust (or individual-level trust) [32]. This trust is just between individuals or agents themselves, one's trust in others cannot influence the trust building or computing of another individual's trust in others. Network-based trust is at a higher level, and group-based trust is at a higher level than the network-based trust. The critical issue of the propagation from individual-level trust to network-based trust is that an individual's trust in others can efficiently contribute to the trust construction of another individual's trust in others in the network. The transformation from network-based trust to group-based trust requires at least one group head that represents the group to interact with others. How to propagate the network-based trust to the group-based trust, and how to successfully build the group-based trust models are still open problems.

The still higher level trust is organization-based trust [32]. The differences of group and organization mainly are: (1) in organization, the relationship between members and the task representation are based on economic exchange, such as wage and salary, and they are regulated by contracts. The loyalty to the controller is strengthened through the punishment to the contract violation. (2) Trust of the non-organization member to the organization members is free from organization individuals. (3) Organization members must act according to organization rules. It is still lack of sound contributions on how to propagate group-based trust to organization-based trust.

The top level scalable trust is institution-based trust. By using trustworthy ways generalizing signals and symbols, such as personal skill, ability, etc., makes them not rely on group or organization that they belong to. For example, in our real life, the education diploma and driving license subjecting to one organization are these signals or symbols. The key of the realization of institution-based trust is to make the generalized signals and symbols trustful.

From the viewpoint of engineering, to make the trust scalable, it is necessary study: (1) the distributed storage and transmission of the interaction data and the recommendation information. (2) The distributed generation of one agent's trust value to others [10, 27].

5. An Intelligent Model of Trust in E-Commerce

In this section we will provide an intelligent model of trust in e-commerce from a viewpoint of knowledge based systems [17].

We assume that P is an agent and Q is another agent. P has a knowledge set K_P, which can be considered as the knowledge base in a knowledge-based agent [19], a set of reasoning methods R_P, which can be considered the problem-solving methods or strategies. Q has also a knowledge base K_Q and a reasoning set R_Q. Therefore, from a viewpoint of knowledge based systems [11], the behavior of P and Q *will be decided by (K_P, R_P) and (K_Q,R_Q) under the same environment*.

In the most general case, one of the necessary conditions for "agent *P* trusts agent *Q*" is that agent *Q* has more knowledge and reasoning methods or problem solving methods than agent *P*, because this is the important premise of agent *P* placing confidence in agent *Q* [2]. In other words, a necessary condition for "agent *P* trusts agent *Q*" is that at the time *t*, agent *P* and agent *Q* satisfy [17]:

$$K_P \subseteq K_Q \quad \text{and} \quad R_P \subseteq R_Q \qquad \text{(1)}$$

Based on (1), we can see that trust as a binary relation satisfies [17]:

1. Reflectivity. Agent *P* trusts agent *P* itself.
2. Anti-symmetry. If agent *P* trusts agent *Q,* and agent *Q* trusts agent *P,* then *P=Q*. This is usually inconsistent in reality, because in e-commerce, agent *P* and agent *Q* can trust each other for an e-transaction. However, there are really many cases in e-commerce, in which agent *P* trusts agent *Q* whereas agent *Q* might not trust agent *P* [2]. This model (1) is more suitable for the latter case. This is the limitation of this model. However, if one agrees that trust is temporary, whereas distrust or mistrust is ubiquitous, then this model is still of practical significance.
3. Transitivity. If agent *P* trust agent *Q*, and agent *Q* trust agent *R,* then agent *P* trust agent *R*. For example, it is very common in e-commerce if customer *A* trusts his friend *B*, and *B* trusts eBay.com, then *A* trusts eBay.com. This is a kind of transitive trust or trust propagation in customer-to-business e-commerce. However, trust is not transitive in some cases. For instance, customer *A* trusts his friend *B*, and *B* trusts an e-commerce website, however, *A* does not trust this website.

Therefore, a trust relation is conditionally symmetric and transitive [28].

It should be noted that Xiu and Liu [28] also discuss the common properties of trust as a binary relation, and they argue that a trust relation is reflexive and only symmetric, and transitive conditionally, which is consistent with the above discussion. However, their formal definition of trust is based on the action of agent and its effect (action-effect), whereas our formal definition is based on the viewpoint of knowledge base systems.

In reality, the condition (1) can be weakened to three different possibilities that lead to "agent P trusts agent Q" [17].

1. $K_P \subseteq K_Q$
2. $R_P \subseteq R_Q$
3. $K_P \subseteq K_Q$ and $R_P \subseteq R_Q$

The first possibility is that "agent P trusts agent Q" because agent Q has more knowledge, data, information, and experience than agent P. For example, in a primary school, a student trusts his teacher, because the latter has more knowledge and experience than himself. Therefore, the trust resulting from this possibility is called *knowledge-based trust*, or agent P trusts agent Q *with respect to knowledge*. *In other words,* knowledge-based trust is based on one's knowledge and experience about competencies, motives, and goals of the agent [2, 17].

The second possibility is that "agent P trusts agent Q" because agent Q has more reasoning methods or problem solving methods than agent P. For example, in a system development team, a young team member trusts his team leader, because the latter has more problem solving methods than the former in systems analysis. Therefore, the trust resulting from the second possibility is called *reasoning-based trust*, or agent P trusts agent Q *with respect to reasoning*. *This implies that* this trust is based on one's reasoning and problem solving abilities [2, 28].

The third possibility is that "agent P trusts agent Q" because agent Q has more knowledge, experience and reasoning methods or problem solving methods than agent P. For example, a patient trusts an experienced doctor working in a clinic, because the doctor has more knowledge, experience and methods in diagnosis and treatment. Therefore, the trust resulting from the third possibility is called *hybrid trust,* or agent P trusts agent Q *hybridly. In other words,* hybrid trust is a combination of knowledge-based trust and reasoning-based trust [17].

6. Measure and Evaluation of Trust

Tweedale and Cutler examine trust in multiagent systems and notice the measure of trust [22]. However, they have not gone into it. In what follows, we will introduce a unified measure of trust based on the discussion of the previous section.

Generally, let the cardinality (size) of knowledge set *K* and reasoning methods set *R* be $|K|$ and $|R|$ respectively, which can be considered as a membership of $|K|$ and $|R|$ and ranged in [0, 1] respectively [33]. Then the trust degree of agent *P* in agent *Q* can be denoted as:

$$T(P,Q) = \alpha(1-\frac{|K_P|}{|K_Q|}) + (1-\alpha)(1-\frac{|R_P|}{|R_Q|}) \quad \text{..........................} (2)$$

Where, when $\alpha = 1$, $T(P, Q)$ is the knowledge-based trust degree of agent *P* in agent *Q*. When $\alpha = 0$, $T(P, Q)$ is the reasoning-based trust degree of agent *P* in agent *Q*. When $0 < \alpha < 1$, $T(P, Q)$ is the hybrid trust degree of agent *P* in agent *Q*. For example, if knowledge-based trust degree of agent *P* in agent *Q* is 0.8, the reasoning-based trust degree of agent *P* in agent *Q* is 0.4, and $\alpha = 0.7$, then hybrid trust degree of agent *P* in agent *Q* is $T(P,Q) = 0.7\times 0.8 + 0.3\times 0.4 = 0.68$.

Further, $1-\frac{|K_P|}{|K_Q|}$ implies that agent *P*'s trust degree is greater whenever the size of knowledge set of the agent *Q* is greater than that of agent *P* taking into account (1). Similarly, $1-\frac{|R_P|}{|R_Q|}$ implies that agent *P*'s trust degree is greater whenever the size of reasoning methods of the agent *Q* is greater than that of agent *P*. The key idea behind it is that agent *P* easily trust agent *Q* if the latter has more knowledge and experience or problem solving ability than agent *P* taking into account (1). This case usually happens when a student trusts his teacher. With the age increasing the trust between any two persons will be decreasing based on (2), because they have similar knowledge and experience or problem solving ability. In other words, it is more difficult for one to trust others in the adult world. Therefore, $1-\frac{|K_P|}{|K_Q|}$ or $1-\frac{|R_P|}{|R_Q|}$ will be decreasing when the size of knowledge set of the agent *P* approaches to that of agent *Q* or the size of reasoning methods of the agent *P* approaches to that of agent *Q*. Therefore, the trust value proposed in (2) is of practical significance. For brevity, we use *T*(*P*, *Q*) to denote either knowledge-based trust degree or reasoning-based trust degree or hybrid trust degree and do not differ one from another without specification.

It should be noted that Xiu and Liu assert that "trust evaluation result should be a Boolean value" [28], which has been extended and revised by the above discussion based on fuzzy logic [33].

7. Scalable Trust in E-Commerce: A Fuzzy Logic Perspective

Scalable trust has drawn some attention in e-commerce [2, 29, 32]. However, how to measure scalable trust in order to realize trust propagation from individual trust to system trust is still a big issue. This section will fill this gap based on the fuzzy operation (max-min) [33].

We consider the scalable trust in the following scenario: agent *P* trust in agent Q_1, Q_2,…, Q_n, which are all the agents within a MAS or MECS, that is, $Q = \{Q_1, Q_2, \ldots, Q_n\}$. The question is what trust degree of agent *P* is in *Q*.

For any $i \in \{1, 2, \ldots, n\}$, the trust degree of agent *P* in agent Q_i is $T(P, Q_i)$, and then the maximal trust degree of agent *P* in the agent team *Q* can be denoted as

$$T(P,Q)_{\max} = Max\{T(P,Q_i), i \in \{1,2,...,n\}\} \quad \ldots\ldots\ldots\ldots\ (3)$$

and the minimal trust degree of agent *P* in agent team *Q* can be denoted as

$$T(P,Q)_{\min} = Min\{T(P,Q_i), i \in \{1,2,...,n\}\} \quad \ldots\ldots\ldots\ldots\ (4)$$

The maximal trust degree of agent *P* in agent team *Q* implies that the agent *P* trust the agent team *Q* with a trust degree $T(P, Q_K)$ and $\exists K \in \{1,2,...,n\}$ that satisfies

$$\text{For any } i \in \{1, 2, \ldots, n\},\ T(P,Q_K) \geq T(P,Q_i) \quad \ldots\ldots\ (5)$$

Therefore, this trust can be considered as "blind trust", because if the agent *P* trusts one agent of the agent team *Q* with the maximal trust degree, then he trusts the whole agent team in the MAS with the maximal trust degree. An e-commerce owner or vendor hopes that his customers trust his company employers with the maximal trust degree based on (3).

The minimal trust degree of agent *P* in the agent team *Q* implies that the agent *P* trusts the agent team *Q* with a trust value $T(P, Q_K)$ and $\exists K \in \{1,2,...,n\}$ that satisfies

$$\text{For any } i \in \{1, 2, \ldots, n\},\ T(P,Q_K) \leq T(P,Q_i) \quad \ldots\ldots\ (6)$$

This trust can be considered as "hostile trust", because he trusts the whole agent team *Q* in the MAS with the minimal trust degree that an agent within the MAS possesses. Currently, e-commerce owners or vendors try their best to avoid this trust degree that customers use to their companies based on customer relationship management and customer experience management [19].

The above two different trust propagations or scalable trusts represents two extreme cases. In reality, the trust degree of agent *P* in the agent team *Q* in the MAS or MECS will be in the interval of $[T(P,Q)_{\min}, T(P,Q)_{\max}]$. This fuzzy-based model can be used to propagate trust from individual-level through network-level and group-level as well as organization-level to institution or system level in a hierarchical way.

In the rest of this section we illustrate the maximal trust and minimal trust with the following example.

Let agent P be an e-customer who is visiting a MECS to buy an MP5 online. The MECS consists of a web client agent (a website) Q_1, a data provider agent (Q_2), and e-transaction agent (Q_3), the trust degree of agent P in these three agents are $T(P, Q_1) = 0.7$, $T(P, Q_2) = 0.9$, $T(P, Q_3) = 0.4$ respectively. Then

$$T(P,Q)_{\max} = Max\{0.7, 0.9, 0.4\} = 0.9 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

and

$$T(P,Q)_{\min} = Min\{0.7, 0.9, 0.4\} = 0.4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

If this customer uses $T(P,Q)_{\max} = 0.9$ as his trust degree to the MECS, then he will buy the MP5 because he has tried for some time to buy an MP5. However, if he uses $T(P,Q)_{\min} = 0.4$ as his trust degree to the MECS, then he is heavily concerned about the security of the e-transaction, and believes that the information from the data provider agent is incomplete or distorted, then he will not buy this product.

8. Concluding Remarks

This paper examined scalable trust in e-commerce, discussed the realization of scalable trust from the viewpoint of engineering, and proposed a fuzzy logic-based model for scalable trust in e-commerce. The proposed approach will facilitate research and development of trust, multiagent systems, e-commerce and e-services. In future work, we will further examine scalable trust in e-commerce and e-services in more detail and develop a spiral model for scalable trust in e-commerce and e-services. We will also look into scalable trust management and scalable trust protocol for e-commerce.

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