TSM-Trust: A Time-Cognition Based Computational Model for Trust Dynamics

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Abstract. This paper proposes a hierarchical network model for trust evaluation after introducing time cognition, which mainly considers trust dynamics. In this model, the Temporal Sequential Marker (TSM) is tagged on each item in an implicit or explicit manner and all items are divided into several layers according to their TSMs information. Furthermore, three different kinds of forgetting effects are investigated and quantified for the computing of TSM- Trust. These effects are: distance effect, boundary effect and hierarchical effect. Next, according to the Ebbinghaus curve of forgetting, cosine function is used to model the forgetting process of Experience Information (EI) approximately, the D-S theory is exploited to build up a computational dynamic trust (TSM-Trust) model based on our proposed hierarchical network model. Finally, our future work is pointed out after analysizing the limitations of this paper.

Keywords: TSM, trust evaluation, Dempster-Shafer theory of belief functions, Ebbinghaus curve of forgetting, hierarchical network model.

1 Introduction

It is out of discussion that the importance of trust and reputation in human societies is realized [1]. As a kind of informal social capital, trust has been playing a unique role in maintaining the stability of societies and driving its progress, and especially nowadays its function is even irreplaceable. Trust and reputation has been regarded as one of the most important elements in accelerating transactions and fostering markets in Virtual Organizations (VOs). Furthermore, people have not stopped researching and probing into trust. So far, most researches can be classified into the following: The one that focuses on the concepts of trust, that is "what is trust"; another emphasizes on trust modeling and reputation (i.e. trust management). The last one considers trust decision-making.

Historically, although some contributions on trust dynamics have been contributed, to this date only a few of them have taken into account its reliance

* Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames. This determines the structure of the names in the running heads and the author index.

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to time cognition and focus on trust dynamics. With reference to what we have just highlighted therefore, we will begin this paper with an extensive review and discussions on related literatures. Our main contributions are as follows:

- Interaction experiences includes direct and indirect information, which are regarded as series of items with time information (time information is represented by Temporal Sequential Marker). As far as trust computing is concerned, experiences used to reason the value of trust are imputed to the related information tagged with TSM.
- After the process of tagging information with TSM is achieved, each item is then classified into different groups to form a hierarchical network. Next we discuss the trust reasoning mechanism for each agent, based on which we construct a conceptual model of trust computation on its attribution of dynamics.
- After that we explain its logical method in weaving the hierarchical network and introduce three different kinds of forgetting effects: distance effect, boundary effect and hierarchical effect.
- Considering its fuzzy semantics, trust is fit to be dealt with by such uncertain mathematics theories as Dempster-Shafer theory of belief functions. Here D-S theory is expanded to be used for computing the values of trust in dichotomy (i.e. trust or distrust) situation.

In section 2, we review the related work on trust dynamics and discuss their advantages and disadvantages respectively. We introduce time cognition and Temporary Sequential Marker (TSM) and then consider applications in various multi-agent systems. Section 3 constructs a conceptual Hierarchical Network Model based on TSM. In Section 4, a computational trust model is proposed based on D-S theory. Such a D-S theory model mainly concerns the fuzzy semantics of trust dynamics. Finally, section 5 holds our conclusions and points out our future work.

2 Related Work

Although a few works have attempted to address the dynamics of trust, less of them focus on the attribution of time cognition, that is to say, there are nearly no works which research trust dynamics from a cognitive view. Next we will introduce some outstanding work about trust dynamics.

Liu et al [2] propose a temporal logical belief for specifying the dynamics of trust for multi-agent systems. In their opinion, trusting someone means having beliefs for a given goal in some fixed environment, and the reason for trust dynamics lies in its continuous changing environments. Therefore temporal logical belief is used to specify this dynamics. It is one of the earlier works in considering temporal features and introducing temporal dimensions to model evolving theories of trust for multi-agent systems through proposing TML (Typed Modal Logic, which extends classical first-order logic with typed variables and multiple belief modal operators.). Furthermore, they examine two main aspects of trust dynamics: a) How direct experiences involving trust, with their successes or failures, influences the future trust of an agent about similar facts. The authors believe that a cognitive attribution process is needed in order to update trust on the basis of 'interpretation' of the outcome of interactions between them (failure or success); b) How the fact that A trusts B and relies on it in a situation can actually (objectively) influence B's trustworthiness in the Ω situation.

Literature [3] provides a method for modeling the dynamics of trust within a system, which includes a technique for expressing trust changes at a given trust state, and an abstract algorithm for obtaining the new trust state from a given state and a trust change.

Another work is from Chang Jun-Sheng et al [4], their work presents a time-frame based dynamic trust model DyTrust. After incorporating time dimension using time-frame, the authors also introduce four trust parameters in computing trustworthiness of peers. Altogether, these parameters are adjusted in time to reflect the dynamics of trust environment using feedback control mechanism, thus trust evaluation has better adaptability to the dynamics of trust.

Zhang Wei et al [5] point out that the dynamic nature of trust creates the biggest challenge in measuring trust and predicting trustworthiness, therefore they introduce the theory of Fuzzy Cognitive Time Maps (FCTMs) into modeling and evaluating trust relationships and show how relevant is the inter-organizational trust based on trust sources and their credibility. This is a most recent work in considering the time cognition of trust.

Advances in network and microprocessor technology have increased the adoption of computer technology in areas such as consumer shopping, banking, voting, and automotive technology. In the meanwhile, the general public has been aware of the following risk. Trust is playing a crucial role both in the successful introduction of new products and services (including computer technology) and the evolution of intelligent vehicles [6]. However, trust is a dynamic phenomenon in its intrinsic nature, whether in the human society or in the computer-based virtual community. Trust changes with experience, with the modification of the different sources it is based on, with the emotional state of the trustor, with the modification of the environment in which the trustee is supposed to perform, and so on. In other words, since trust is an attitude depending from dynamic phenomena, it is itself a dynamic entity [3]. There are some other studies on the dynamics of trust [7][8].

3 TSM Based Hierarchical Network Model

Information must happen at a given history time, so time is attached to it when coding for each information, either in an implicit or explicit manner. As far as trust computing is concerned, experiences used to reason the value of trust are imputed to the related information tagged with TSM. In this way, we embark on the representation of trust dynamics.

In fact, TSM is a kind of structured social annotation. As a form and tool for network resources or documents, it is widely popular among more and more researchers. In the meanwhile, as a form of knowledge discovery, sharing and co-operating, it also embodies the spirit of web 2.0, and hence has been paid more and more attention to. TSM is tagged to EI so as to model the dynamics of trust.

All TSMs of items form an organization with hierarchical network. As we know, TSM can be any symbolic system with fixed order, e.g. 1, 2, 3 n; a, b, c . . . z. According to Li Boyue et al [9], in order to improve cognitive efficiency, the items (here is EI) should be divided into groups once the number of them reaches a preset threshold. When there are rich semantics in the items, we can depend on the semantic relationship to divide them. Otherwise what we can rely on is TSM. Furthermore, as items become more, more layers division is needed, and as a consequence there emerges distance effect, boundary effect and hierarchical effect. In Li's views [9], there is no direction effect. Next we will give a conclusion about distance effect, boundary effect and hierarchical effect mainly based on Li's experimental results.

Proposition 1. When two items of EI are from different groups, there will exist distance effect, boundary effect and hierarchical effect.

- When several items are combined into groups without a clear boundary, distance effect will exist between two items with an interval of other two items. That is to say, if some EIs for trust are combined, distance effect will exist between any two EIs with an interval of other two EIs.
- When several items are combined into groups with a clear boundary, the boundary effect will exist between two items in different groups. When two items in different groups are combined to compute the value of trust, boundary effect will exist.
- When hierarchical network is formed, the hierarchical effect will exist between two items of EI in different levels.

Of course, how to construct a hierarchical network of EI based TSM is a puzzle, and in most cases in human society it is formed automatically and implicitly. But in e-society or so called computer-centered system, it must be carried out artificially. Therefore different subjective judgment of each individual will impact on three effects derived by distance and boundary dramatically. In this paper, as a TSM tool, calendar time is used to construct a hierarchical network based on TSM, and trust computed and reasoned from such a hierarchical network is called TSM-Trust based on TSM-HN. How distance and boundary and hierarchical effects will impact on the value of trust will be discussed in section 4.

When several items are assembled as a group without an indefinite boundary, distances effect will exist between two items with an interval of other two items. When there is definite boundary between such groups, boundary effect will exist between two items in different groups. And lastly when a hierarchical network is formed, hierarchical effect will exist between two items in different layers. In fact, these effects are same in nature, i.e. all of them belong to time forgetting effects. Each TSM locates at one position of this network, and also owns the corresponding code to represent hierarchical network. The order of two items is compared by searching the positions of their representations (TSMs) in the hierarchical network.

Comparing with the semantic hierarchical network model initiated by Collins and Quillian [10], TSM based Hierarchical Network (TSM-HN) has the following characteristics, which are also reasons why we choose TSM-HN as our reasoning foundation.

- TSM-HN´ s representation has automatic embedded and implicit features. Firstly, any item happens at a given time, therefore time information is tagged upon this item automatically and implicitly. That is to say, there is no need to worry about losing time information of each item, because the time information is stored in system logs automatically. Secondly, when dealing with item with TSM, it is implicit that items are divided into chunks, groups and levels. Of course, as far as trust evaluation is concerned, EI (including direct information and indirect information) is tagged with time information intentionally and artificially, and then just because of its automatics of TSM-HN, each EI is existent together with its TSM all the time.
- The fuzzy characteristic of the representation of TSM-HN. Individual can deal with TSM-HN in a fuzzy way, which results into fuzzy boundary problem of TSM-HN. For a system with continuous sequential markers, there is not a line of definite boundary. "1" and "3" can belong to one group, "3" and "5" can belong to another group, "5" and "7" can belong to another group, but "1" and "5" can not belong to the same group, "1" and "7" can not either. Conversely, "5" and "3" can belong to one group, and "5" and "7" can belong to another group. In a word, human must divide all items into more layers, but no boundary line can be found, such a moving line in fact is a fuzzy line, it is dependent on individual subjective judgment. That is one of the most important reasons for our exercising D-S theory to compute the value of trust.
- The capacity of the representation of TSM-HN is also fuzzy. In order to improve the efficiency of our searching for TSM, we also need make the capacity of each group consistent with the capacity of time memory of human, although computer system has much more capacity of memory and storage. For human, what is the biggest capacity of a group? To answer this question, one point should be mentioned: because of the limitation of the capacity of human's work memory, one group can contain at most seven items. Broadbent et al [11] point out each group can contain no more than three items. However Li Boyue et al [10] believe that one group can contain at most four to five items after repeated experiments, which is in conflict with results from Broadbent et al. Simply put, such a capacity of one group is also fuzzy, it relies on individual age and other individual differences. In this paper, we assume this capacity is seven, which is the limitation of the capacity of work memory and can improve the efficiency of searching TSM information.
- The subjectivity of the representation of TSM-HN. Objective time is linear, TSM-HN is formed artificially, hence is subjective. The above automatics,

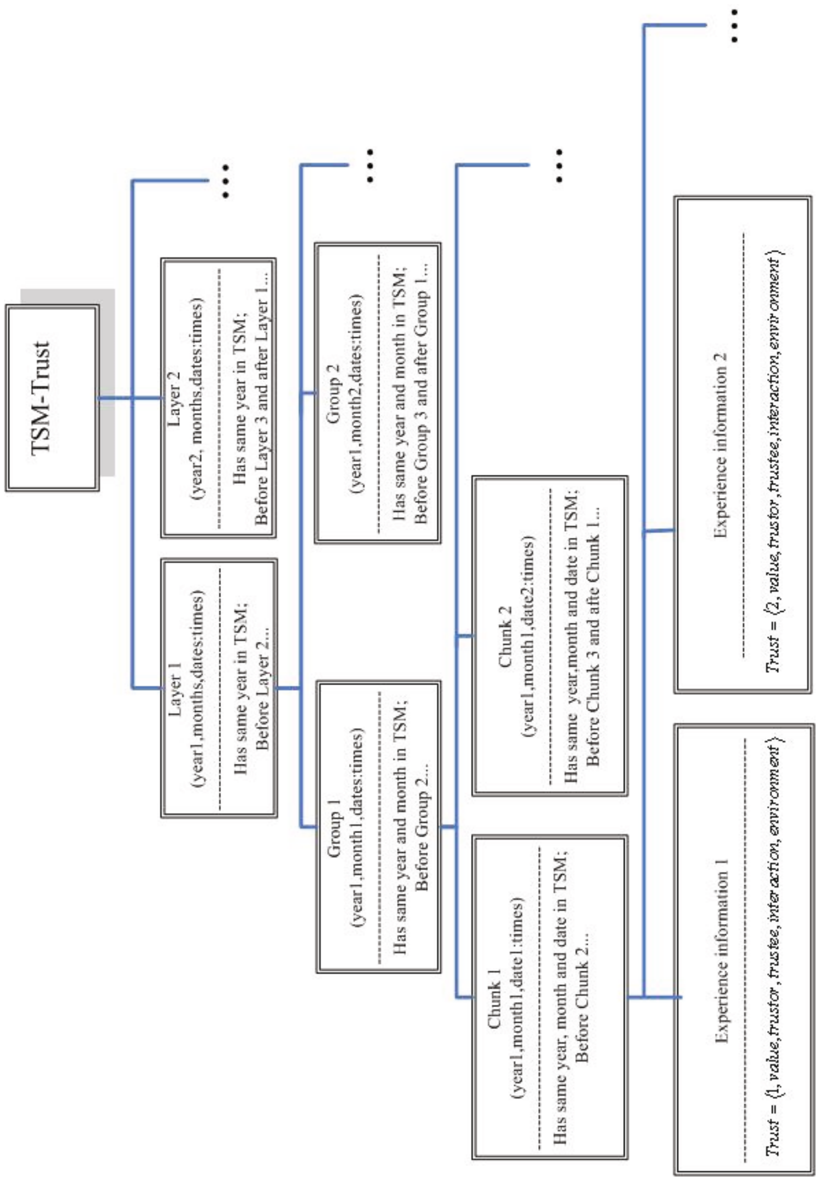

Fig. 1. The trust reasoning model based on TSM-HN

implicit, fuzzy and capacity and so on, are all resulted from the subjectivity. More importantly, in Li's [10] views, even "objective" TSM-HN organization coded by calendar time is limited by this subjectivity.
– The forgetting effects mentioned above exist in TSM-HN. Bigger the interval between items is, more obvious the forgetting effect becomes.

In this paper, trust dynamics involving the time information of interaction is paid more attention to. As for space dimension, much work has pointed out trust can be classified into direct trust and indirect trust, which are derived from direct experience and indirect experience information respectively. Like some work considering time dimension, here short time trust and long time trust are also regarded as the most two kinds of trust.

Our model is two-dimensional metrics of time-space, so although there are many unique aspects including considering both time and space characteristics concurrently, some work is based upon previous achievements from either time dimension or space dimension respectively. As other models mentioned above, trust is computed by EI (including direct information and indirect information, the latter is also called recommending information). This kind of trust is reasoned from space dimension, and it can only represent the attribution of space; as for the time attribution, the following trust reasoning model is built up based on TSM-HN[Fig.1].

4 Computational Model Based on TSM-HN and Its Algorithm

Ebbinghaus is famous for the Ebbinghaus curve of forgetting effect [12]. There is still much evidence which have proved that memory is changing with time in a curve of attenuation trend. Since TSM is used to represent time information of EI, when assessing the trust of given agent, our reasoning model shown in Figure 1 becomes our main foundation. What's more, actually time characteristics is reduced to a problem of space through introducing TSM-HN, then first trust is considered from space dimension aspect. As some research work has pointed out that trust is classified into direct trust and indirect trust, and they are also combined to compute the value of trust. Here the rating of trust is defined as follows:

Definition 1. Space Trust (Space-Trust) is made up of direct trust (DT_{ij}) and indirect trust (IT_{ij}), that is

$$(Space - Trust)_{ij} = f\left(DT_{ij}, IT_{ij}\right) = \lambda \times DT_{ij} + (1 - \lambda)\, IT_{ij} \tag{1}$$

Where λ is the preference factor, whose value depends on much more complicated factors than expected. As in human society, each agent focuses on direct experience while pays less attention to indirect experience. Therefore although the value of λ can not be confirmed concisely, its value always lies above 0.5. According to trust transfer mechanism and trust clustering mechanism [13], direct trust (DT_{ij}) and indirect trust (IT_{ij}) are defined as follows.

Definition 2. Direct Trust $DT_{ij} = [Bel_{ij}(\{T\}), Pl_{ij}(\{T\})]$ can be computed in that all EIs are looked as parallel information, and then they can be combined by Shafer's rule of combination.

Based on the Shafer's rule of combination [14],
$m_{ij} = m_1(i,j) \oplus m_2(i,j) \oplus \cdots \oplus m_n(i,j)$

If evidence information (namely Experience Information, EI) $e_1(i,j),\ e_2(i,j),\ \cdots,\ e_n(i,j)$ have basic probability assignments $m_1(i,j), m_2(i,j), \cdots, m_n(i,j)$, and the corresponding belief intervals are noted as $DT_{ij}^k = [Bel_k(\{T\}), Pl_k(\{T\})]$, $1 \le k \le n$. Then according to trust clustering mechanism [13], direct trust between agent i and agent j is:

$$DT_{ij} = \mathop{\oplus}_{k=1}^{n} DT_{ij}^k = \mathop{\oplus}_{k=1}^{n} [Bel_k(\{T\}), Pl_k(\{T\})], 1 \le k \le n \tag{2}$$

Definition 3. Indirect Trust can be gotten approximately by regarding each recommendation router as series case, then regarding all routers as a parallel case, that is to say, indirect trust (IT_{ij}) can be computed as follows:

Assuming that there are μ routers between i and j, and there is no less than one node. For any given router ν, if there are p nodes between i and j, i.e.

$$\nu = \{i \to r \to r+1 \to \cdots r+p-2 \to r+p-1 \to j\}$$

Then

$$Bel_{ij}^v(\{T\}) = Bel_{i,r}(\{T\}) Bel_{r,r+1}(\{T\}) \cdots Bel_{r+p-2,r+p-1}(\{T\}) Bel_{r+p-1,j}(\{T\}) \tag{3}$$

$$Pl_{ij}^v(\{T\}) = Pl_{i,r}(\{T\}) Pl_{r,r+1}(\{T\}) \cdots Pl_{r+p-2,r+p-1}(\{T\}) Pl_{r+p-1,j}(\{T\}) \tag{4}$$

So we can get indirect trust between i and j transferred by router ν:

$$IT_{ij}^\nu = \left[Bel_{ij}^\nu(\{T\}), Pl_{ij}^\nu(\{T\})\right] \tag{5}$$

Since all routers between i and j are regarded as parallel relationships, their combination can use trust clustering mechanism [13].

$$\begin{aligned} IT_{ij} &= [Bel_{ij}(\{T\}), Pl_{ij}(\{T\})] \\ &= \mathop{\oplus}_{\nu=1}^{\mu} IT_{ij}^\nu = IT_{ij}^1 \oplus IT_{ij}^2 \cdots \oplus IT_{ij}^v \oplus \cdots \oplus IT_{ij}^\mu \\ &= \mathop{\oplus}_{\nu=1}^{\mu} \left[Bel_{ij}^\nu(\{T\}), Pl_{ij}^\nu(\{T\})\right] \\ &= \left[Bel_{ij}^1(\{T\}), Pl_{ij}^1(\{T\})\right] \oplus \left[Bel_{ij}^2(\{T\}), Pl_{ij}^2(\{T\})\right] \cdots \\ &\quad \oplus \left[Bel_{ij}^\nu(\{T\}), Pl_{ij}^\nu(\{T\})\right] \oplus \cdots \oplus \left[Bel_{ij}^\mu(\{T\}), Pl_{ij}^\mu(\{T\})\right] \end{aligned} \tag{6}$$

Definition 4. TSM based Dynamic Trust (TSM-Trust) is classified into two kinds of trust: non-forgetting trust(trust without forgetting effect), trust with forgetting effect (including trust with distance effect, trust with boundary effect and trust with hierarchical effect). For any two nodes (i,j), if there is two pieces of EI (e_1, e_2) to support the same proposition, then according to the Ebbinghaus curve of forgetting, cosine function is exploited to model trust dynamics in time dimension.

$$(TSM-Trust)_{ij} = f\left((Space-Trust)_{ij}, dt\right) = \begin{cases} (Space-Trust)_{ij}, & no\ forgetting\ trust \\ g(dt) \times (Space-Trust)_{ij}, & otherwise \end{cases} \tag{7}$$

And

$$g(dt) = \cos\left(\frac{\pi(dt)}{2T_{\max}} \times \gamma\right) \tag{8}$$

Where $g(dt)$ is called function of forgetting, $dt = |t_\varphi - t_\phi|$ is the time interval between two pieces of current EI(e_1, e_2); $T_{\max}$ is the maximal time interval which the trustor can tolerate or memorize trustee (here means EI between nodes i, j); $g(dt)$ is called "the attenuation function of trust", it is modelled by cosine function about the dispersion of time [15]; what's more, in order to normalization, then

$$\begin{array}{ll} for & \frac{x}{dt} = \frac{\pi/2}{T_{\max}} \\ then & x = \frac{\pi(dt)}{2T_{\max}} \end{array} \tag{9}$$

γ is the forgetting factor, its value is assumed as:

$$\gamma = \begin{cases} 1.5, & there\ is\ distance\ effect \\ 2, & there\ is\ boundary\ effect \\ 3, & there\ is\ hierarchical\ effect \\ 0, & there\ is\ no\ forgetting\ effect \end{cases} \tag{10}$$

That is to say, when two EIs with an interval of two other chunks in different chunks are combined, distance effect will exist, i.e. $\gamma = 1.5$; when two EIs in different groups are combined, boundary effect will exist, i.e.$\gamma = 2$; when two EIs in different layers are combined, and hierarchical effect will exist, i.e.$\gamma = 3$. Of course, the value of γ is dependent upon trustors' subjective judgment according to their experience knowledge or other factors like trust preference, here we choose a simple assignment for simplicity.

Since the domain of cosine function is limited within $\left[0, \frac{\pi}{2}\right]$, that is

$$\begin{array}{ll} for & 0 \le \frac{\pi(dt)}{2T_{\max}} \times \gamma \le \frac{\pi}{2} \\ then & 0 \le dt \le \frac{T_{\max}}{\gamma} \end{array} \tag{11}$$

and $\cos\left(\frac{\pi}{2}\right) = 0$, When $dt \ge \frac{\pi}{2}$, the attenuation function of trust equals zero. Then (Eq. 7) becomes:

$$(TSM-Trust)_{ij} = f\left((Space-Trust)_{ij}, dt\right) = \begin{cases} (Space-Trust)_{ij}, & no\ forgetting\ trust \\ g(dt) \times (Space-Trust)_{ij}, & 0 \le dt < \frac{T_{\max}}{\gamma} \\ 0, & dt \ge \frac{T_{\max}}{\gamma} \end{cases} \tag{12}$$

The above work is devoted to the computation of TSM-T, and however it can only be used in situation with two pieces of EI and does not consider the situation with more than two pieces of EI, so modification about should be given out: $dt = |t_{\max} - t_{\min}|$, here $t_{\max}$ is the maximum time (more close to $T_{\max}$) among all TSMs; $t_{\min}$ (more far from $T_{\max}$) is the minimum time among all TSMs.

Then TSM-Trust can be computed by the following:

$$(TSM - Trust)_{ij} = f\left((Space - Trust)_{ij}, dt\right) = \begin{cases} (Space - Trust)_{ij}, no\ forgetting\ trust \\ \cos\left(\frac{\pi(t_{\max}-t_{\min})}{2T_{\max}}\gamma\right)(Space\_Trust)_{ij}, otherwise \\ 0, \quad dt \geq \frac{T_{\max}}{\gamma} \end{cases} \tag{13}$$

It should be noted that all the time information is gotten from TSM of EI based on the TSM-HN. Lastly a method for TSM-Trust computing is gotten till now.

5 Concluding Remarks

To investigate the dynamic evolvement of trust, this study bases on the research of time cognition, which formally constructs a hierarchical network model with time lags as TSM. Next, three different kinds of forgetting effects (distance effect, boundary effect and hierarchical effect) are investigated and quantified for the computing of TSM-Trust. Furthermore, Ebbinghaus curve of forgetting is introduced, and then cosine function is exercised to model the attribution of trust dynamics approximately. And then D-S theory is exploited to build up a computational dynamic trust (TSM-Trust) model based on our proposed hierarchical network model.

Some limitations should nevertheless be underlined. First, our hierarchical network is structured according to the TSM system of calendar time, which becomes the only base of classifying different groups, such as chunks, groups and hierarchical levels. Of course, as an attempt of TSM network, it is of importance in investigating the attribution of time cognition for trust dynamics, however more common paradigm should be found out. Second, when dealing with the quantifying the forgetting effect, cosine function is used, whose rationality should be studied more. Finally, the largest memory time $T_{\max}$ is assumed as seven years, and the value of forgetting factor γ is assigned by 0, 1.5,2 and 3, both of which may be an arbitrary decision and more related study should be committed. In conclusion, trust dynamics is more complex than expected and much more related work should be carried out till people completely mater its natural properties so as to foster and manage trust effectively within whether human society or agent society.

It must be pointed out that our example and experiments are discarded here for the limitation of pages, which will be published in a journal paper soon.

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