

## Interpersonal Trust Model

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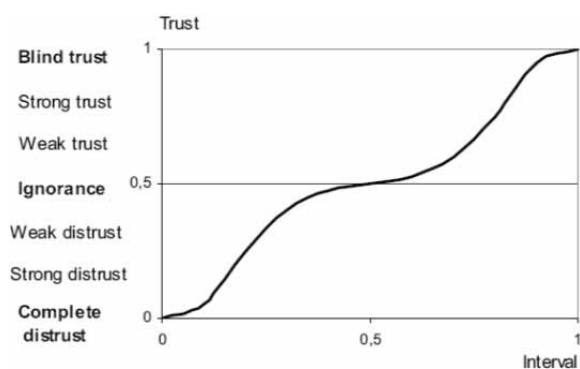
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The paper deals with interpersonal trust modelling. Terms as trust, trust values, trust affecting factors, and representation of interpersonal trust and its implementation are presented. The proposed trust model tries to integrate more factors, which affect trust for trust determination, than usual. The model covers basic factors as reciprocal trust, initial trust, subject reputation, number of subject recommendations, number of mutual contacts, and trusting disposition. The significance of these factors participating in trust forming is discussed. Modifications of parameter values describing mentioned factors and their effects on interpersonal trust evolution are investigated. The interpersonal trust model behaviour is examined by a number of parameter studies. Only some of these studies are presented in this paper and the significant results acquired from them are shown in the graphs.

### Introduction

Trust is a unique phenomenon and plays an important role in the relationships among subjects in the communities. These subjects need not be only humans.

In the internet age, the trust among machines, servers, and network nodes gains more and more importance. Widening of e-service [1], e-commerce [2], e-banking, etc., arises the question of human machine trust. Further, trust plays an important role in peer-to-peer networks [3], ad hoc networks, grid computing, semantic web [4], and multi-agent systems, where humans and/or machines have to collaborate. Trust models and interpersonal trust models particularly, e.g., [1, 2, 3], are used in those uncertain environments [5, 6, 7].



**Figure 1.** Trust value representation – verbal trust levels are on the vertical axis, real interval  $(0,1)$  is on the horizontal axis (example for a trust mapping function).

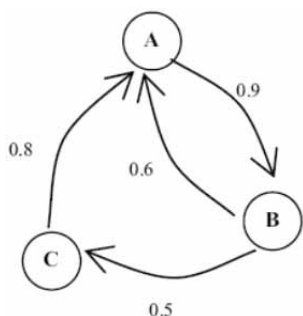
What is trust and how can it be described? The acceptance of trust is wide and various explanations are offered [8]; from honesty, truthfulness, confident expectation or hope, something managed for the benefit of another, confidence in ability or intention to pay for goods or services in the future, till business credit. A universal trust definition does not exist. Bulk of definitions comes out from Gambetta's definition [9]. We will understand trust as a given credit, hope, confidence in ability or intention of some subject to perform to benefit of another subject at some future time.

Trust models, and interpersonal trust models particularly, e.g., [3, 10, 11], are usually focused on merely one of the factors which trust determine. Each of these factors (reputation, recommendations, and initial trust) can be modelled as an individual component. Our model tries to integrate more of trust affecting factors, i.e. initial trust, reputation, recommendations, mutual contacts, and trusting disposition for trust determination.

### 1 Interpersonal trust representation

Generally, trust can be quantified by a values from the interval  $\langle a, b \rangle$ , where  $a, b$  ( $a < b$ ) are integer or real numbers. Value  $a$  represents complete distrust and value  $b$  is blind trust. Other verbal trust levels are possible to represent by values from this interval. Without loss of generality, we will use real values from the interval  $(0,1)$ .

A single trust value can be visualized as a point on the line between point 0 and 1 on the horizontal axis, which is acquired by mapping of the respective circumlocution on the vertical axis in Figure 1.



**Figure 2.** Graph of interpersonal trust in the group – the group consists of three individuals *A, B* and *C*, reciprocal trust is between *A* and *B*, individual *B* trusts *C* and individual *C* trusts *A* (example for trust representation).

Generally, the mapping function is neither linear nor symmetrical. Further we will work with trust values from the interval  $(0,1)$ .

Next, we specify an interpersonal trust representation, i.e. trust between two subjects. Consider a group of  $n$  subjects represented as the set  $X = \{x_1, x_2, \dots, x_n\}$ . The measure of interpersonal trust between the subject  $x_i$  and  $x_j$  is introduced as follows:

$$t_{ij} = t(x_i, x_j), t_{ij} \in (0,1); i, j = 1, \dots, n; i \neq j \quad (1)$$

Further we suppose that both values  $t_{ij}$  and  $t_{ji}$  exist, thus providing reciprocal trust. The directed weighted graph is applied for interpersonal trust representation in the whole group. Vertices represent the subjects, oriented edges represent trust relations between connected subjects and the weights are trust values. The direction of the edge reflects trust asymmetry, i.e.  $t_{ij} \neq t_{ji}$  (trust of the  $i$ -th subject in the  $j$ -th one may differ, and usually will differ, from trust of the  $j$ -th subject in the  $i$ -th one).

An example of the representation of interpersonal trust in the group is shown by the graph in Figure 2. The group consists of three individuals *A, B* and *C*. The value individual *A* trusts to *B* is 0.9, the trust value of individual *B* to *A* is 0.6, individual *B* to *C* is 0.5, and individual *C* to *A* is 0.8. Individual *A* has no contact to *C* and *C* has no contact to *B*. Note that the graph does not contain self-looped edges.

We use the adjacency matrix, called trust matrix, for graph representations of interpersonal trust in the group. Note that complete distrust is represented by an edge with zero weight, while non-existence of an edge represents the situation when the trust value is not known, e.g., value  $-1$  is used for the matrix element in this case.

The trust matrix for the graph in Figure 1 is following

$$T = \begin{pmatrix} -1 & 0.9 & -1 \\ 0.6 & -1 & 0.5 \\ 0.8 & -1 & -1 \end{pmatrix} \quad (2)$$

The first line (column) of the matrix represents the trust value of individual *A* to *A, B* and *C*, the second one represents trust of individual *B* to *A, B* and *C*, and the third one describes the same for individual *C*.

## 2 Trust affecting factors

Trust forming can be determined by many factors. Based on former related works [3, 10, 11] we consider in our model the following ones: reciprocal trust, initial trust, subject reputation, number of subject's recommendations, number of reciprocal contacts and trusting disposition.

The tendency of reciprocal trust is reflected by the geometric mean. Initial trust to the subject is got on the start. The reputation of the subject comes after individual experience and by some information dissemination about the subject in its neighbourhood and influences trust formation considerably. Trust depends also on the frequency of mutual contacts of subjects.

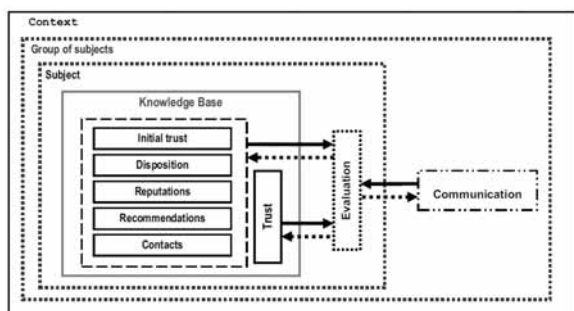
Next, trust is formed by information about another subject that other subjects have passed on. This information is called recommendation. Trusting disposition representing a degree of non-rational behaviour of a subject is modelled by random factor.

Thus, for trust forming of the  $i$ -th subject (trustor) to the  $j$ -th subject (trustee) the formula (3) is proposed:

$$T_{ij} = t_{ij} + \sqrt{t_{ij}t_{ji}} \left( \frac{\Delta c_{ij}}{w_{c_i}} + \frac{\Delta d_{ij}}{w_{d_i}} \right) \frac{r_{ij} G_{\alpha,\beta}}{w_{r_i} w_{g_i}} \quad (3)$$

where  $T_{ij} \in (0,1)$  is the new trust value of the  $i$ -th subject on the  $j$ -th one,  $t_{ij}$  is the previous trust (trust starting value is  $t_{0,i,j}$ ) of the  $i$ -th subject on the  $j$ -th one,  $t_{ji}$  is the previous trust of the  $j$ -th subject on the  $i$ -th one,  $\Delta c_{ij}$  is the relative gain (loss) of the number of contacts between  $i$ -th and  $j$ -th subject,  $\Delta d_{ij}$  is the relative gain (loss) of the number of recommendations of the  $j$ -th subject to the  $i$ -th subject,  $r_{ij}$  is the reputation of the  $i$ -th subject about the  $j$ -th one,  $G_{(\alpha,\beta)}$ ,  $0 < \alpha < \beta \leq 1$  is the trusting disposition expressed by the probability distribution function,  $w_{c_i}$  is the weight coefficient of the number of contacts of the  $i$ -th subjects,  $w_{d_i}$  is the weight coefficient of the number of recommendations of the  $j$ -th subject  $i$ -th subject,  $w_{r_i}$  is the weight coefficient of the effect of

reputation of the  $i$ -th subject about the  $j$ -th one, and  $w_{g_i}$  is the weight coefficient of trusting disposition. Interpersonal trust design is shown in Figure 3.



**Figure 3.** Interpersonal trust design in a group – components of initial trust, reputations, recommendations, contacts, and trusting disposition and trust in knowledge base; evaluation of trust using information from communication between subjects (example for group trust forming).

### 3 Experiments and results

To pursue trust model behaviour we carried out a series of experiments. The groups of individuals of various sizes have been generated. Reflecting possible non-linearity and/or non-symmetry of the trust distribution, the initial trust matrix and reputation matrix has been chosen with uniform distribution from the interval  $(0,1)$  randomly. The number of contacts among the selected subjects and the number of recommendations of these subjects where stepwise set up and trust forming was pursued. An example is presented below.

Values of initial trust ( $t_{0ij}$ ) and reputation ( $r_{ij}$ ) of six selected couples are in Table 1 and Table 2. The scenarios of the number of mutual contacts ( $c_{ij}$ ) and the number of recommendations ( $d_{ij}$ ) are in Table 3 and Table 4.

First, we have looked how trust is formed in various cases of selected individual relationships. Reputation of individuals is given on the start and as it is rather persistent, it is invariable for all calculated steps. Trusting disposition was generated for each individual of couple. Weight of reputation of individuals was constant, and weight of trusting disposition was not applied ( $w_{g_i} = 1$ ).

$t_{0_{12}}$	$t_{0_{14}}$	$t_{0_{25}}$	$t_{0_{32}}$	$t_{0_{34}}$	$t_{0_{54}}$
0.97	0.35	0.41	0.55	0.03	0.31

**Table 1.** Initial trust of selected couples – numbers of selected couples are in the 1<sup>st</sup> line, values of initial trust are in the 2<sup>nd</sup> line (example for initial trust setting).

$r_{21}$	$r_{41}$	$r_{52}$	$r_{23}$	$r_{43}$	$r_{45}$
0.27	0.14	0.34	0.84	0.74	0.79

**Table 2.** Reputation of selected couples – numbers of selected couples are in the 1<sup>st</sup> line, values of reputations are in the 2<sup>nd</sup> line (example for reputation setting).

Step	$c_{12}$	$c_{14}$	$c_{25}$	$c_{32}$	$c_{34}$	$c_{54}$
0	0	0	0	0	0	0
1	2	1	1	2	0	0
2	4	1	0	0	0	0
3	0	2	0	0	0	0
4	0	2	0	0	0	0
5	0	0	0	0	0	3

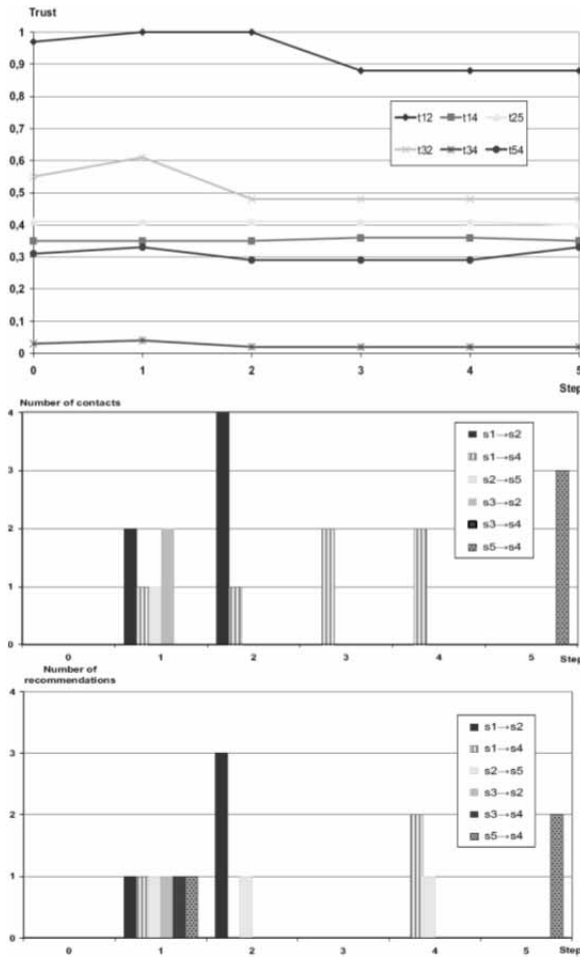
**Table 3.** Numbers of mutual contacts of selected couples – number of selected couples are in the 1<sup>st</sup> line, step number is in the 1<sup>st</sup> column (example for number of contacts).

Step	$d_{12}$	$d_{14}$	$d_{25}$	$d_{32}$	$d_{34}$	$d_{54}$
0	0	0	0	0	0	0
1	1	1	1	1	1	1
2	3	0	1	0	0	0
3	0	0	1	0	0	0
4	0	2	1	0	0	0
5	0	0	0	0	0	2

**Table 4.** Numbers of recommendations of selected couples – number of selected couples are in the 1<sup>st</sup> line, step number is in the 1<sup>st</sup> column (example for number of recommendations).

The behaviour of six selected relationships  $s_1 \rightarrow s_2, s_1 \rightarrow s_4, s_2 \rightarrow s_5, s_3 \rightarrow s_2, s_3 \rightarrow s_4$  and  $s_5 \rightarrow s_4$ , where  $s_i \rightarrow s_j$  represents relationship involving  $i$ -th and  $j$ -th subject, is described in short. Trust evolution of selected couples is depicted in Figure 4.

- $s_1 \rightarrow s_2$ : Subject  $s_1$  trusts  $s_2$  strongly (0.97), but  $s_2$ 's reputation is low (0.27). The number of mutual contacts and the number of recommendations influences trust increasing particularly in the first and second step.
- $s_1 \rightarrow s_4$ : Subject  $s_1$  distrusts  $s_4$  weakly (0.35),  $s_4$ 's reputation is even lower (0.14). Influence on trust evolution is low, with exception of the fourth step. This is an example of changing dynamics.



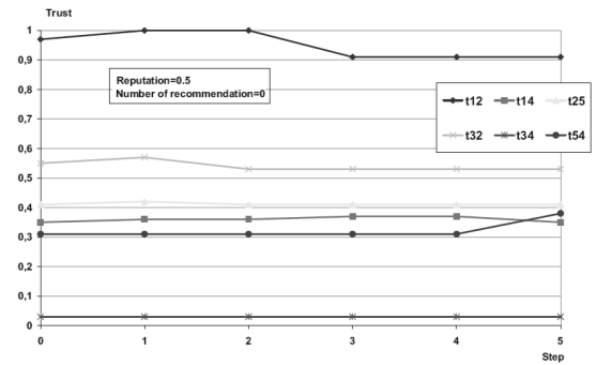
**Figure 4.** Study of trust forming for six relationships of individuals – upstairs is trust forming for six selected relationships between subjects, in the middle is stepwise number of contacts, at the bottom is stepwise number of recommendations (example for trust forming).

- $s_2 \rightarrow s_5$ : Subject  $s_2$  distrusts  $s_5$  weakly (0.41), reputation of  $s_5$  is moderate (0.34). Numbers of contacts and recommendations are low, trust does not change.
- $s_3 \rightarrow s_2$ : Subjects  $s_3$  trusts  $s_2$  close to ignorance (0.55),  $s_2$ 's reputation is high (0.84). Contacts and recommendations noticed in the first step caused trust increase followed by its decrease.
- $s_3 \rightarrow s_4$ : Subject distrusts  $s_4$  strongly (0.04),  $s_4$ 's reputation is high (0.74). High reputation and recommendation produce trust increase in the first step.

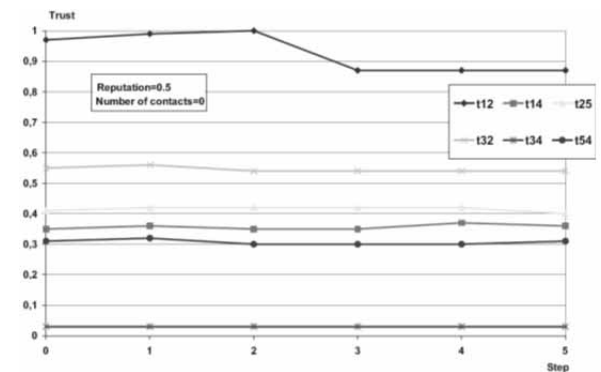
- $s_5 \rightarrow s_4$ : Subjects  $s_5$  distrusts  $s_4$  weakly (0.31),  $s_4$ 's reputation is high (0.79). Recommendation in the first step, contacts and recommendations in the fifth step influence trust increase in these steps and decrease in the second step.

Experiments studying the influence of reputation were performed next. The number of contacts and the number of recommendations were stepwise increased to illustrate trust forming.

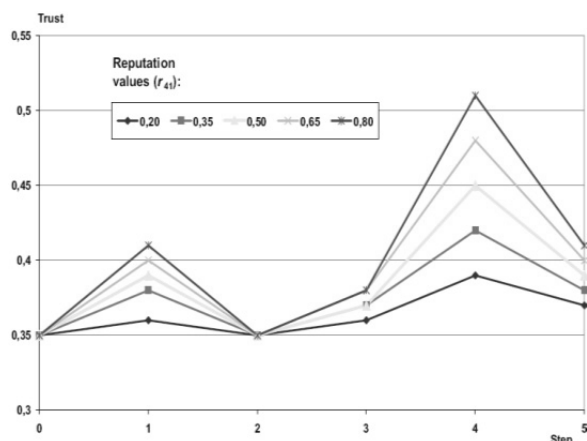
Trusting disposition was generated randomly for every subject and every step. Five values of reputation were chosen (0.2, 0.35, 0.5, 0.65, and 0.8). This study was performed with the same parameters, trust matrix and number of contacts, recommendations and steps.



**Figure 6.** Study of number of contacts influence – reputation size is 0.5; number of recommendations is zero, the results for six couples of individuals (example for study of contacts influence).



**Figure 7.** Study of number of recommendations influence – reputation size is 0.5; number of contacts is zero, the results for six couples of individuals (example for study of contacts influence).



**Figure 5.** Study of size reputation – reputation values 0.20, 0.35, 0.50, 0.65, and 0.80, on horizontal axis are the steps (0 – 5), and on the vertical axis are trust values (example for reputation size study).

The reputation study results of relationship  $s_1 \rightarrow s_4$  are shown in Figure 5. Trust increase and decrease followed the number of contacts and recommendations accordingly. The increasing value of reputation causes trust increase, which can be scaled using the weight coefficient  $w_{g_i}$ .

The study of contact influence and recommendation was performed for a mean value of reputation. While influence of contacts was examined, then number of recommendations was neglected and vice versa.

The results for six selected couples are presented in Figure 6 and Figure 7.

Results of recommendation influence indicated greatest change in relationship  $s_1 \rightarrow s_2$  due to loss of recommendations, changes in relationship  $s_3 \rightarrow s_2, s_1 \rightarrow s_4, s_2 \rightarrow s_5$ , and  $s_5 \rightarrow s_4$  were smaller, no trust change was in relationship  $s_3 \rightarrow s_4$ .

#### 4 Conclusion and future work

We developed an interpersonal trust model integrating factors influencing trust evolution. The experiments proved that its behaviour to be in accordance with models considering a particular factor or a subset of factors in our model.

The model provides trust formation reasonably sensitive to parameters in the proposed formula. Hence, they can be tuned to reflect trust formation under various conditions.

Next, we intend to pursue the collaboration with sociologists to apply the model to real cases. The model itself will be deployed in an agent-based trust management model under development

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