Trust Management – From Pervasive Computing Environments to Mathematical Economy and Sociology

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Abstract: Trust management in pervasive computing environments is one of top research areas for quite some years. Although first efforts started in the mid-nineties, the real momentum came some twelve years ago. From that time such methodologies started to appear that were addressing the core of trust phenomenon. Among those naïve Bayesian statistics based methodologies should be mentioned first, then Dempster-Shaffer Theory of evidence based ones, and game theoretic ones. A different perspective, based on linguistic grounds as to operators and operands, has been taken by Qualitative Assessment Dynamics, or QAD, which is presented in this paper. QAD effectively complements other existing methodologies by addressing uncovered issues, like assumptions of rational agents, transitivity of trust, and so on. QAD enables rigorous formal treatment, is implementable in computing environments, and provides multi-disciplinary results that exceed computational environments. Its results can be used as a basis for simulations to address important questions like how to manage societies to increase possibilities that they will become more prospective in terms of pre-assured trusted relationships.

Keywords: pervasive computing, web technologies, trust management, qualitative assessment dynamics, mathematical economics and sociology

1. Introduction
Trust is claimed to be one key ingredient for prosperity of organizations, societies and even nations. As many research endeavors support such claims, the next logical questions can be stated: “How a certain society should be managed to increase trusted relationships between its members?” Or “How can one improve the chances for a disintegrated society to turn around the negative trends in existing relationships?”

Of course, providing definite answers to such questions is likely to be out of reach of our hands. It is more realistic that we aim at means that would increase probabilities of positive outputs by driving societies in certain directions, but definite (so to say, 100% sure) positive outputs cannot be expected. The reason is very fundamental – what we are playing with belongs to the area of complex, non-linear dynamic systems. For such systems it is practically impossible to include all factors, while even almost negligible changes in some small factor may lead to radically changed behavior of the whole system. Consequently, in majority of cases we will not be able to provide exact solutions, and we will have to rely intensively on computer simulations.

These are only the most basic premises when it comes to trust, be it in ordinary or computing environments, like web environments. These issues will be covered in more detail in the second section, while QAD will be covered in the third section. Some experiments with typically settings together with their analysis will be provided in the fourth section, while conclusions are given in the fifth section.

2. Overview of trust management methodologies for computing environments
Although the introduction part has exposed mainly the value of trust in ordinary societies, it should be clear that these issues are applicable also to web environments. The reasons are the following:

- Our lives are increasingly dependent on modern information services, so direct face to face contacts are now frequently replaced by e-media. Therefore when using such “crippled” media that bridge face to face interactions, trust management solutions are definitely needed, even more so due to the reduction of available information in such media.
Modern services are not only depending on new e-media for bridging face to face interactions, but also for new interactions with (intelligent) services as such. Although it may seem that addressing trust in relation to such technological artifacts is not sensible, experiments show that people do perceive such services in a way as if they were humans [1].

Now to support trust management in computing environments, researchers have developed various methodologies. Among those that have origins in computer and information science area the following ones should be mentioned:

- The first group is based on elementary Bayesian statistics. By using Bayesian rules for conditional probabilities, it is possible to construct trees, update corresponding values according to experiences with an entity, and provide probabilities for trust related questions like: “What is the probability that the interaction with this entity is trusted, given that the entity has to provide me with high quality literature and that delivery service is excellent?” This is the core principle behind so called naive trust management methodologies [2].
- The next group of approaches extends elementary Bayesian statistics, which is the case with Dempster-Shafer Theory of Evidence (ToE) that enables treatment of uncertainties. As opposed to standard probability, where, e.g., event $x$ probability $p(x)$ and its complementary event probability $p(\neg x)$ sum up to one, i.e. $p(x) + p(\neg x) = 1$, ToE introduces uncertainty interval $u(x)$. Thus $p(x) + p(\neg x) < 1$, and $p(x) + p(\neg x) + u(x) = 1$. It should be emphasized that this last equation is a bit simplified explanation, and some important distinctions should be clarified. ToE is in fact about perceived, estimated probabilities that are driven by individual’s experiences, and not “hard”, traditional probabilities obtained by, e.g. throwing a dice. Put another way, we talk about distinction between frequentists and Bayesians. In frequentists approach probability lies objectively in the world, and in Bayesians approach probability lies in the observer’s mind. Now a typical trust management representative that is based on ToE is subjective logic [3].

The next group of approaches is based on game theory. This theory models strategic situations where individual’s rational choices depend on the rational choices of other players [4]. It is especially concerned with various equilibria, where a player adopts a strategy by taking into account others' strategy (one very well-known example in game theory is prisoner’s dilemma). Typically such approaches are used in multi-agents systems or MAS [5].

The main problem with all above methodologies is that they, first and most important, assume rational players. Second, they assume knowledge and familiarity with quite sophisticated mathematics. Third, they assume (this explicitly holds true for game theoretic approaches) transitivity of trust relationships, and so on. Therefore they certainly make sense in certain contexts, but there exists many contexts where such assumptions do not hold true, which has already been proved by many experimenters (see e.g. [6]).

And this is where QAD comes in. It complements above methodologies and its basic premise is that trust related behavior has appropriate reflections in our languages as to operators, and operands – the details are following in the next section.

3. Qualitative Assessment Dynamics - QAD

Trust is primarily a manifestation of reasoning and judgment. QAD development was therefore initially tied to Piaget’s research on developmental psychology of reasoning and judgment [7]. This research only provided guidance for the development efforts related to QAD, because computationally supported trust needs tightly formalized system. Despite this, Piaget’s work provided assistance for identification of key ingredients that helped us to address reasoning (i.e. trust related) constituents, which, beside rationality, include irrationality, action binding, feed-back loops, temporal dynamics, and context dependence. Further, we came to conclusions that trust related mental operations and operands have appropriate descriptions in languages. Therefore, to capture trust dynamics, using operands and operators that have well-understood meanings in numerous cultural settings, linguistics based formal system should be considered.

On this basis, initial version of QAD was developed, which, in abstract algebra terms, was a group. However, experimental results required modifications that have led to semi-ring structure. Finally, additional results have helped us to crystallize operands and
operators, and the formal system as a whole. At this point, QAD was even not a semi-group anymore, but became a formal system on its own.

For the purpose of this paper, only a part of QAD definitions will be given in order to enable understanding experiments that are given in the next section:

- Trust in societies is given by a trust matrix $A$. Elements $a_{i,j}$ of this matrix denote assessment (trust relations) of $i$-th agent towards $j$-th agent. Values of these assessments are taken from the set $\Lambda = \{2, 1, 0, -1, -2, -\}$. These values denote trusted, partially trusted, undecided, partially distrusted and distrusted relationships (symbol $"-"$ denotes an undefined relation to cover cases when an agent is not aware of existence of another agent, or does not want to disclose its trust).

- As to operators, they are taken from the set $\Psi = \{\Uparrow, \Downarrow, \Uparrow, \Downarrow, \sim, \leftrightarrow, \odot, \uparrow\}$, where the symbols denote extreme optimistic assessment, extreme pessimistic assessment, moderate optimistic assessment, moderate pessimistic assessment, centralistic consensus seeker assessment, non-centralistic consensus seeker assessment, self-confident assessment and assessment hoping. These operators are functions $f_j \in \Psi$, such that $f_j(A_{pre} = (a_{11}, a_{12}, a_{21}, a_{22}, \ldots, a_{m1}, a_{m2}) \rightarrow a_{pre}$, $j = 1, 2, \ldots, n$, where $"j"$ denotes the $j$-th agent, superscript $"-"$ denotes pre-operation value, superscript $"+"$ post-operation value.

For the purpose of this paper only the mappings that will be used in the experiments in section 4 are defined in the appendix (the complete set of definitions can be found in [8]). Despite this, the rest of operators could be roughly understood on the basis of their names.

4. QAD Experiments

This section gives some very illustrative cases about applicability of QAD. We will analyze some settings that very often appear in reality. This will be our experiment conditions and settings:

1. Communities will consist of two typical numbers of agents: 10, 100 (only these two numbers are considered because of increasing computational complexity).
2. Agents will be governed by the following operators: extreme optimist, extreme pessimist, self-confident, and assessment hoping operators.
3. All agents in communities will be initially undecided about one another (societies of agents where each agent is initially indifferent about all other agents).

The table below gives more precise settings’ configurations that will be used in our simulations:

<table>
<thead>
<tr>
<th>setting #</th>
<th>distribution of operators</th>
<th># of agents</th>
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<tbody>
<tr>
<td></td>
<td>$\Uparrow$ [%] $\odot$ [%] $\Downarrow$ [%] $\sim$ [%] $\leftrightarrow$ [%] $\uparrow$ [%] $\Downarrow$ [%] $\Uparrow$ [%] $\odot$ [%] $\uparrow$ [%]</td>
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<tr>
<td>7*</td>
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<td>8*</td>
<td>30 60 10</td>
<td>100</td>
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Table 1: Experimental settings details

Before giving the results, one important property of the last two settings compared to the first six settings has to be explained. In settings 7 and 8 agents that randomly change operators get assigned new operators from among all existing operators, while in the first six settings only the other two / three basically deployed operators can be assigned. Now executing 25 runs for each of the the above settings, where each run took 100 steps, the following histograms are obtained:

Figure 1: Results of simulation settings 1-8 (runs 2-6 are similar to runs 1-2 and are not shown)
The results of the first six runs are somehow expected. But the last two results are really surprising. Actually, when allowing that the opinion changing agents randomly choose among all available operators, extremism actually emerges (see runs 7 and 8, Fig.1). Note that initially all agents were undecided of one another, but after some time roughly one third of them becomes extremely trusted, roughly one third extremely untreated, while the rest of assessments are comparably similar, each of them amounting to some 10%.

5. Conclusions
This paper provides only the basic background of QAD related to plenary talk at Tele-Info ‘11. Taking into account that the research in this area has now almost ten years long tradition, a reader is referred to have a look at [8], [9] and [10] for more details.

QAD was initially meant only for computerized environments. A concrete implementation, called trustGuard, has been developed to support users in cyberspace [11]. Despite this basic application area, the paper shows that QAD potentials exceed this area of application. It provides a promising methodology also in multidisciplinary settings related to mathematical economy and sociology.

References:

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Appendix
This appendix gives the definitions of those operators that are used in the experiments described in the fourth section of the paper.

a) $\alpha_{x,t} \triangleq \rightarrow$

$\Delta_j: \max(\alpha_{x_{j-1},t}, \alpha_{x_{j-2},t}, ... , \alpha_{x_0,t}) \to \alpha_{x,t}$

$\Theta_j: \alpha_{x,t} \to \alpha_{x,t}$

$\lambda_j: \max(-1, 0, 1, 2) \to \alpha_{x,t}$

b) $\alpha_{x,t} \triangleq \leftarrow$

$\Delta_j: \min(\alpha_{x_{j+1},t}, \alpha_{x_{j+2},t}, ... , \alpha_{x_n,t}) \to \alpha_{x,t}$

$\Theta_j: \alpha_{x,t} \to \alpha_{x,t}$

$\lambda_j: \min(-1, 0, 1, 2) \to \alpha_{x,t}$