**The Influence of Personalities upon the Dynamics of Trust and Reputation**

Mark Hoogendoorn  
Vrije Universiteit Amsterdam  
Department of Artificial Intelligence  
1081 HV Amsterdam, The Netherlands  
mhoogen@few.vu.nl

S. Waqar Jaffry  
Vrije Universiteit Amsterdam  
Department of Artificial Intelligence  
1081 HV Amsterdam, The Netherlands  
swjaffry@few.vu.nl

**Abstract**— When an agent resides in a community, the opinion of other community members concerning whether a particular individual is trustworthy or not influences the trust level of this agent. Hereby, the precise influence depends on the personality of the agent (e.g. whether he lets his opinion be influenced by others a lot). In this paper, a computational trust model which has dedicated parameters for agent personalities is applied to such a social context. A variety of different communities (containing agents with different personalities) have hereby been simulated. The resulting patterns thereof are shown in this paper. Furthermore, the simulation results are formally analyzed to show that certain patterns do occur in all different communities.

**Keywords**—simulation; trust; agent communities; personalities

I. INTRODUCTION

Trust is a widely studied topic in Social Sciences and it is believed that the success of relations, alliances and communities is deeply rooted in the strength of trust among the members of the society [1]. Due to the importance of trust, also in multi-agent systems research, trust is considered to be one of the crucial factors in the modeling of societies, and as a result has been a topic of research for many years (see e.g. [2][3]).

When looking more specific within trust research, trust dynamics within groups of agents is one of the topics addressed (whereby the overall trust of the group in one individual is referred to as the reputation [4]). Hereby, the reputation of an individual changes due to direct interaction of the individual with the members of the group and/or interaction of the members among each other, thereby communicating their experiences with the individual. In some cases, when the individual resides outside the community and the direct interaction with the individual lacks (e.g. historical figures) or is not frequent, the communication between the group members might be the prime factor which determines the reputation of this individual within the group. The dynamics of trust of the group members and the reputation is an interesting process. Hereby, the personalities of the individuals play a crucial role: certain easily influenced agents in the group might for example be severely effected by experiences of other group members.

In this paper, the social dimension of trust and reputation is explored in different agent communities. An existing model for an agent’s trust (cf. [5]) is adapted to a setting where agents can communicate their trust levels to each other. Every agent has personality specific attributes, namely (1) the awareness of history, (2) openness to the opinion of others, and (3) the dependencies between trust levels of individuals. Variation in these attributes makes different agent personalities that generate different agent behavior, and hence diverse communities. These behaviors of the agents at the local level results in emergent patterns at the global level. The precise relationship between these local level setting and the global level is studied in this paper. Hereby, the trust level of the agents in the society on an individual is based on their initial trust value and communication among themselves, and it is assumed that individuals are not giving direct experience to agents. Besides the reasons given before, this has also been done to purely focus the research on the dynamics of trust given different personalities, and avoid any external influences (e.g. experiences with the individual). A variety of different personality settings are studied, and the patterns that emerge are investigated using formal verification techniques, to show how personality attributes influence the global patterns.

This paper is organized as follows. First, in Section 2 the model for trust and reputation in multi-agent systems adopted is explained. Next, in Section 3 the model is used with agent communities based on different personality settings to investigate emergent patterns in trust and reputation. The formal verification of these results is discussed in Section 4. Finally, Section 5 is a discussion.

II. MODELING TRUST AND REPUTATION IN A MULTIAGENT SYSTEM

This section describes the model which is used to represent the trust an agent has on particular individuals. Hereby, a trust model previously developed (cf. [5]) is reused and made suitable for the scenario under investigation.

The model of trust of an agent in an individual as introduced in [5] is composed from two models: one for positive trust, accumulating positive experiences, and one for negative trust, accumulating negative experiences from individual. Here, experience from the individual of model [5] is replaced by the feedback from other agents about individual. Furthermore, in the model experience from individual is a discrete value from set [-1, 0, 1] which is not capable of representing magnitude of experience, in the current model, the
feedback from agents is from the continues interval [-1, 1] to remove this limitation. Both positive and negative trust of an agent is represented by a number in the interval [0, 1]. Agent i’s total trust on an individual j (say Sj) is \( T_{ij}(t) \). This is a number in the range [-1, 1] which is calculated as the positive trust minus the negative trust of the agent. Hereby, -I and J represent minimum and maximum values of the trust respectively:

\[
T_{ij}(t) = T^+_{ij}(t) - T^-_{ij}(t)
\]

In particular, also the agent i’s initial trust of Sj at time point 0 is \( T_{ij}(0) \) which is the difference of agent’s initial positive trust \( T^+_{ij}(0) \) and negative trust \( T^-_{ij}(0) \) in Sj at time point 0. In the differential equation shown below, the change in positive and negative relative trust of agent i on individual j after receiving agent k’s feedback about individual j is modeled as follows:

\[
\frac{dT^+_{ij}(t)}{dt} = \beta_i \left( \eta \cdot \left[ \left( 1 - T^+_{ij}(t) \right) + \left( 1 - \eta \right) \cdot \left( T^-_{ij}(t) - 1 \right) \right] \cdot M_{ij}(t) + \left[ M_{ij}(t) \cdot \right] \right)
\]

\[
\frac{dT^-_{ij}(t)}{dt} = -\beta_i \left( \eta \cdot \left[ \left( 1 - T^-_{ij}(t) \right) + \left( 1 - \eta \right) \cdot \left( T^+_{ij}(t) - 1 \right) \right] \cdot M_{ij}(t) + \left[ M_{ij}(t) \cdot \right] \right)
\]

In this trust model several personality characteristics of the agents are included, namely openness to opinions of others (\( \beta \)), awareness of history (\( \eta \)) and dependencies between trust levels of individuals (\( \gamma \)). These are the numbers on the continuous interval [0, 1]. The personality attribute called openness (\( \beta \)) represents to what extent the trust level at time point i will be adapted when the agent has a (positive or negative) feedback from another agent about some individual. The personality attribute called awareness of history (\( \eta \)) represents the rate of trust decay of the agent on the individual over time (in particular in time periods when there is no feedback from other agents). The personality attribute depends between trust levels (\( \gamma \)) indicates in how far the trust of an agent on an individual is determined independent of trust in other trustees.

In the above equations, \( M_{ij}(t) \) is the feedback about individual j given by agent k on time t. This is a real number on the continues interval [-1, 1] that represents the level of trust of agent k on individual j. Note that in the model presented in [5] merely a discrete set can be taken into account. \( T^+_0 \) and \( T^-_0 \) represent the relative positive and relative negative trust of agent i on individual j that is the ratio of agent i’s positive trust upon individual j compared to the agent i’s average positive trust on all individuals, and the ratio of negative trust respectively. The calculation of these values for time point t is defined below, here n is the number of individuals,

\[
T^+_i(t) = \frac{T^+_i(t)}{\sum T^+_{ij}(t)/n}
\]

and

\[
T^-_i(t) = \frac{T^-_i(t)}{\sum T^-_{ij}(t)/n}
\]

As, the change in the agent’s total trust is the difference in the change in positive and negative trust of the agent the following holds:

\[
\frac{dT^+_i(t)}{dt} = \frac{dT^-_i(t)}{dt} - \frac{dT^-_i(t)}{dt}
\]

So,

\[
\frac{dT^+_i(t)}{dt} = \beta_i \left( \eta_i \cdot \left[ \left( 1 - T^+_{ij}(t) \right) + \left( 1 - \eta_i \right) \cdot \left( T^-_{ij}(t) - 1 \right) \right] \cdot M_{ij}(t) + \left[ M_{ij}(t) \cdot \right] \right)
\]

\[
\frac{dT^-_i(t)}{dt} = -\beta_i \left( \eta_i \cdot \left[ \left( 1 - T^-_{ij}(t) \right) + \left( 1 - \eta_i \right) \cdot \left( T^+_{ij}(t) - 1 \right) \right] \cdot M_{ij}(t) + \left[ M_{ij}(t) \cdot \right] \right)
\]

This equation is used to calculate the trust value of an agent. In the multi-agent system every agent has the trust model as described in above equations. The trust is updated on every time step based on the feedback communicated by the other agents. The reputation \( r_j(t) \) of individual j at time point t is defined as the average trust value of an individual within the community:

\[
r_j(t) = \frac{\sum T^+_j(t)}{n}
\]

In the definition, n is the number of agents in the community.

III. COMMUNICATION OF TRUST

In the adopted model the agent’s trust on an individual depends on the agent’s initial trust and the feedback of other agents about the trust of the individuals. The agents hereby incorporate the model presented in Section 2. In the interaction, it is assumed that all agents are centrally synchronized and at each time step an agent will receive feedback about the trust values of individuals from another agent in a predefined agent interaction protocol. More in specific, the communicated feedback about individual j of agent k at time t, \( M_{jk}(t) \) is defined as follows,

\[
M_{jk}(t) = T^+_j(t)
\]

\[
M_{jk}(t) = T^-_j(t) - T^+_j(t)
\]

Fig. 1. m agents communicating reputation of k individuals
The interaction protocol follows the right shift circular row major order of a connectivity matrix (see Table 1) of the completely connected graph of agents (see Figure 1). This guarantees that every agent will send its feedback to others agents in the same pattern at the average of the time steps equal to the number of agents present in the community, this gives a fair chance to every agent to communicate its opinion. On every received feedback from other agents in the group, the agent’s trust level is updated accordingly. Note that this update of the trust is based on the feedback sent by the other agents, and the personality characteristics of the agent.

<table>
<thead>
<tr>
<th>Agents</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>X</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>A2</td>
<td>6</td>
<td>X</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>A3</td>
<td>8</td>
<td>9</td>
<td>X</td>
<td>7</td>
</tr>
<tr>
<td>A4</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 1: Interaction protocol for four agents

### III. DYNAMICS OF TRUST AND REPUTATION IN DIFFERENT AGENT COMMUNITIES

Using the trust and reputation model for multiagent system expressed in previous section, this section studies the patterns that occur in different agent communities. Agent communities are designed based on the personality attributes of agents present in the community. For experimental purposes these attributes are divided into two levels namely low and high (see Table 2). Low and high values of the attributes are selected in such a way that their change should be visible in different cases and should not superimpose the other attributes.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma*</td>
<td>awareness of history</td>
<td>0.25</td>
<td>0.05</td>
</tr>
<tr>
<td>Beta</td>
<td>openness to other’s opinions</td>
<td>0.25</td>
<td>0.75</td>
</tr>
<tr>
<td>Eta*</td>
<td>dependency between individuals</td>
<td>1.00</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Table 2: Parameters used in model (*note that the parameter setting is the inverse of the actual meaning, high means a low parameter setting, and low a high parameter setting)

Using the values of personality attributes described in Table 2, four different personalities of the agents are classified in Table 3.

<table>
<thead>
<tr>
<th>Agent</th>
<th>Awareness of History</th>
<th>Openness to others Opinion</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>P₂</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>P₃</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>P₄</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

Table 3: Agent Personalities with low and high values of the parameters

It should be noted that for experimental purposes and to maintain effectiveness of the presentation of results, the agent’s personality attribute named dependency between individuals is not taken into account in the personalities described in Table 3.

Rather the effect of this personality attributes (η) is studied in separate experiments.

#### A. Experimental Configurations

This section describes the general configuration of the experiments that have been conducted for various scenarios. In Table 4 these settings are shown. It can be seen that the number of agents, individuals, and the initial trust of the agents on the individuals are kept constant throughout the experiments. In this configuration agents A₁ and A₃, and A₂ and A₄ are given the same initial trust values so that the effect of different personality attributes for the same initial trust values can be studied as well. Also, the initial trust of the agents on the individuals is set in such a way that the reputation of the individuals differs, so that dependencies between individuals can be analyzed. The reputation of an individual is hereby defined as the average trust of all agents in the community on the individual. Hence, S₁, S₂, and S₃ have high, medium and low initial reputation in the system respectively. Finally, the time step taken is 0.1, which is used to perform the calculation of the difference equations as presented in Section 2.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of individuals</td>
<td>3</td>
</tr>
<tr>
<td>Number of Agents</td>
<td>4</td>
</tr>
<tr>
<td>Initial Trust of Agents A₁, A₂, A₃ and A₄ on individuals (S₁, S₂, S₃)</td>
<td>A₁=[0.25, 0.25, 0.00], A₂=[0.00, -0.25, -0.25], A₃=[0.25, 0.25, 0.00], A₄=[0.00, -0.25, -0.25]</td>
</tr>
<tr>
<td>Initial Reputation of individuals (S₁, S₂, S₃)</td>
<td>0.125, 0.00, -0.125</td>
</tr>
<tr>
<td>Time Step</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 4: Parameters used in model

In the following sections the influence of personalities upon the dynamics of trust of the agents on the individuals are studied in communities where all agents have the same personality attributes (homogenous communities, Section 3B and 3C) and also communities with agents having different personality attributes are studied (heterogeneous communities, Section 3D and 3E). Furthermore, the reputation for the various settings is discussed in Section 3F.

#### B. Dynamics of Trust in Homogeneous Agent Communities with High Trust Autonomy

In this section, the trust dynamics is studied in communities whereby the personalities of the agents are homogeneous. In the simulations, the value of the agent’s personality attribute trust dependency between individuals (η) is kept low, meaning that the calculation of trust on an individual, the agent will not consider the trust it has on other individuals. In the simulations performed, the values of the agents personality attributes are taken from Table 3, and the experimental configuration as presented in Table 4 is followed.

The results of the simulations are shown in Figure 2. In the Figure, time is shown on the x-axis, and the trust level on the y-axes. Hereby, each set of graphs represents a community with agents having personalities from Table 3 (i.e. Figure 2a represents a community with agents having personality P₁)
et cetera. In all graphs, $A_i S_j$ stands for agent $A_i$ trust on individual $S_j$. As in this experiment agents $A_1$, $A_3$ and $A_2$, $A_4$ have the same initial trust values, and the personalities are the same, only the trust levels of $A_1$ and $A_2$ are shown the graphs (which are identical to $A_3$ and $A_4$ respectively).

It can be seen that in Figure 2a and 2b the communities of agents with high history awareness show a slower convergence of the trust value compared to the equivalent cases with low history awareness (Figure 2c and 2d). The figures also show that communities with high openness to other opinions (2b) end up in an equilibrium faster than the low openness personalities (2a). Furthermore, the individual with an initially high reputation in the community ($S_i$) attains a stable reputation before the other individuals. In Figure 2c the community of agents with high history awareness and low openness cannot retain their trust value for a substantial period, and drop their trust on individuals immediately following equilibrium at zero line (neutral trust). In Figure 2d however, the community with high openness besides having low history awareness can attain a trust equilibrium without stabilizing at a neutral trust value. The thick lines in Figure 2d demonstrate the fluctuations in the trust values of agents due to the low history awareness in combination with the high openness, resulting in communication of other agents having a severe effect on the trust level. Here it should also be noted that the individual with an initial high reputation in the community ($S_i$) also attains a stable reputation earlier than others.

C. Dynamics of Trust in Homogeneous Agent Communities with Low Trust Autonomy

In the previous section, the dependency between individuals was set to low, meaning that the trust level upon an individual is not influenced by the trust level the agent has on other individuals. There might however be a dependency between the individuals (e.g. substitutable information sources). In the following section, the behavior of the model is analyzed with a setting of high dependency between individuals, which means that calculating trust on one individual, agent will give significant weightage to the trust on other (competitive) individuals as well. Hence, the increase in trust on one individual will affect others competitively. The values of the personality attributes are again taken from Table 3. The results of the simulations are represented in Figure 2e, f, g, and h.

In Figure 2e and 2f the communities of agents with high history awareness again can retain their trust value much longer. Here, the community with high openness (f) attains higher values of the trust than the low openness (e). In Figure 2g a community of agents with low history awareness and low openness again cannot retain their trust value for a longer
period, and drop their trust on all individuals immediately showing an equilibrium at a neutral trust value. In Figure 2h the community with low history awareness and high openness can attain a slightly higher trust in the beginning compared to case (c) without trust dependency, but the trust soon stabilizes at the neutral trust value as well. When looking at the competitive aspect that has been introduced through the parameters, the community with low openness (e.g.) shows this competitiveness quite clearly through keeping the individual with an initial neutral reputation ($S_i$) low in curves compared to the individual with an initially high reputation ($S_i$) in the community.

**D. Dynamics of Trust in Heterogeneous Agent Communities with High Trust Autonomy**

In this section, the behavior of the model is analyzed in communities where agents have heterogeneous personalities. For the following simulations value of agent’s personality indicating the dependency between trust levels of individuals is set to low. The results of the simulation for these communities are shown in Figure 3. In Figure 3, for the sake of presentational clarity of the results, two graphs are shown per setting, whereby each graph shows the trust levels of two agents.

The community in Figure 3a1 and 3a2 has four agents $A_1$, $A_2$, $A_3$ and $A_4$ with personalities $P_1$, $P_2$, $P_3$ and $P_4$ respectively. Here $A_1$ and $A_2$ have high history awareness and low openness and $A_3$ and $A_4$ have low history awareness and high openness. It can be seen that agents $A_1$ and $A_2$ retain their previous trust value, and gain highest trust on the individual with an initially high reputation ($S_i$), and the individual with an initially neutral reputation ($S_i$). Hereby, $S_i$ gets this high trust level a substantial period before $S$. Furthermore, agents $A_1$ and $A_2$ have the lowest trust level on the individual with an initially low reputation ($S_i$). $A_3$ and $A_4$ with low history awareness and high openness maintain equilibrium which are less extreme (i.e. closer to neutral) than agent $A_1$ and $A_2$. The community in Figure 3b1 and 3b2 has four agents, whereby agent $A_1$ and $A_2$ have high history awareness and high openness and $A_3$ and $A_4$ with low history awareness and low openness. Here, $A_1$, $A_2$, $A_3$ and $A_4$ have almost same pattern of trust for $S_i$, $S_2$ and $S_3$, as in Figure 3a. The only difference is that $A_1$ and $A_2$ in Figure 3a1 have low openness and in Figure 3b1 have high openness. This makes their trust values higher in Figure 3b than in Figure 3a. Similarly, $A_3$ and $A_4$ have a lower trust equilibrium in 3b than 3a. The community in Figure 3c1 and 3c2 has four agents: $A_1$ has high history awareness and low openness, $A_2$ has high history awareness and high openness, $A_3$ and $A_4$ have low history awareness and low openness. Here, $A_2$ attains the highest trust values compared to other agents due to high history awareness and high openness. Agent $A_1$ (with high history awareness and low openness) attains the second highest values. Also, $A_3$ and $A_4$ have the lowest trust values due to low history awareness and low openness. Three equilibria can be distinguished on each side of the x-axis due to three different
Dynamics of Trust in Heterogeneous Agent Communities with low Trust Autonomy

The behavior of the model is studied in communities having heterogeneous personalities but also having dependencies between the trust levels of different individuals. In the experimental results, shown in Figure 4, the results are quite similar compared to the previous section.

Dynamics of Reputation of Individuals in different Agent Communities

Finally, the dynamics of the reputation of individuals as observed in the previous experiments are briefly described in greater detail, and the reputation patterns for different communities are compared. It can be observed that the individual with initially negative reputation (S_i) in the system can at most obtain a neutral reputation (zero). This only holds in communities where there is low history awareness and low openness to others opinion (see e.g. Figure 2c, g and h). Otherwise, the negativity of the reputation of the individual increases over time and stabilize afterwards. The dynamics of the reputation of individuals with an initially high reputation (S_i) in the community is approximately the same, but in the opposite direction of course. Hereby, only in the communities where there is low history awareness and low openness to others opinion (see Figure 2 c, g and h) the reputation decreases and stabilizes at a neutral reputation level. Otherwise, the positivity of reputation of the individual increases over time and stabilizes afterwards. An individual with a neutral reputation (S_i) in the community always ends up with a lower reputation in the community than the individual with an initially high reputation, however this difference becomes smaller over time. In the case of a community where the agents have high history awareness, low openness, and a high dependency between trust levels of individuals, the reputation of an individual with an initially neutral reputation becomes stable at a relatively low point compared to the individuals with an initially high reputation (see Figure 2e, 4a, and 4c). In Figure 4b and 4d where agents have high openness this also appears to occur, but this is due to the length of the simulation. The simulations have however also been conducted for a longer period of time, the results of which show that this phenomena eventually does not occur.
IV. FORMAL VERIFICATION

Besides merely presenting the graphs of the simulations, also properties have been specified which express certain expected patterns of the trust and reputation over time. These properties are specified in a logical format, enabling an automated verification. First, the logical language and tools used are explained. Thereafter, the properties and the result of the verification are shown.

A. Temporal Trace Language (TTL)

The verification of properties has been performed using a language called TTL (for Temporal Trace Language), cf. [6] that features a dedicated editor and an automated checker. This predicate logical temporal language supports formal specification and analysis of dynamic properties, covering both qualitative and quantitative aspects. TTL is built on atoms referring to states of the world, time points and traces, i.e. trajectories of states over time. In addition, dynamic properties are temporal statements that can be formulated with respect to traces based on the state ontology ont in the following manner. Given a trace γ over state ontology ont, the state in γ at time point t is denoted by state(γ, t). These states can be related to state properties via the infix predicate |=, where state(γ, t) |= p denotes that state property p holds in trace γ at time t. Based on these statements, dynamic properties can be formulated in a sorted first-order predicate logic, using quantifiers over time and traces and the usual first-order logical connectives such as ¬, ∧, ∨, ⇒, ∀, ∃. For more details, see [6].

B. Properties

Below, the properties that have been verified are shown. First, the ontology used in these properties is expressed in Table 5.

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>highest_trust_level: AGENT x INDIVIDUAL</td>
<td>The agent has the highest trust value on the specified individual of all agents.</td>
</tr>
<tr>
<td>lowest_trust_level: AGENT x INDIVIDUAL</td>
<td>The agent has the lowest trust value on the specified individual of all agents.</td>
</tr>
<tr>
<td>has_trust_level_on: AGENT x INDIVIDUAL x REAL</td>
<td>The agent has the specified trust level on the individual.</td>
</tr>
<tr>
<td>has_reputation_level: INDIVIDUAL x REAL</td>
<td>The individual has a particular overall reputation.</td>
</tr>
<tr>
<td>stable_trust_level: AGENT x INDIVIDUAL x REAL</td>
<td>The specified agent has a stable value on the individual which is centered around the real value specified, and has a deviation of the specified value.</td>
</tr>
<tr>
<td>stable_reputation_level: INDIVIDUAL x REAL x REAL</td>
<td>The reputation of the individual has a stable value which is centered around the real value specified, and has a deviation of the specified value.</td>
</tr>
</tbody>
</table>

The first property which has been specified concerns the occurrence of a stable trust point within the traces.

RTP1(P): Stable point trust

For all agents and individuals there exists a time point such that after this time point a stable trust point occurs which does not fluctuate more than P.

∀γ:TRACE, A:AGENT, I:INDIVIDUAL
[∃γ:TIME [∀γ:TIME > t, r:REAL, p2:REAL
[ state(γ, t2) |= has_trust_level_on(A, I, r) & state(γ, t2) |= has_trust_level_on(A, I, r2) ⇒ r2 < P ]]]

This property is satisfied for all traces with a setting of P=0.04.

Besides the stable trust point, also the influence of other group members is an interesting element in this setting. Hereby, first a property is specified about group members that decrease the trust level of the agent which currently has the highest trust level. Thereafter, a property expresses the opposite.

RTP2(D): Negative influence of group

When an agent has the highest trust level t for an individual i in the group, then within duration D this trust level will go down.

∀γ:TRACE, A:AGENT, I:INDIVIDUAL, r:REAL, t:TIME
[ state(γ, t) |= highest_trust_level(A, I) & state(γ, t) |= has_trust_level_on(A, I, r) ]
⇒ ∃γ:TIME > t & t2 ≤ t + D, r2:REAL
[ state(γ, t2) |= has_trust_level_on(A, I, r2) & r2 < r ]

This property is satisfied for all traces with a setting of D = 20 time steps.

RTP3(D): Positive influence of group

When an agent has the lowest trust level t for information source s in the group, then within duration D this trust level will go up.

∀γ:TRACE, A:AGENT, I:INDIVIDUAL, t:TIME
[ state(γ, t) |= lowest_trust_level(A, I) & state(γ, t) |= has_trust_level_on(A, I, r) ]
⇒ ∃γ:TIME > t & t2 ≤ t + d, r2:REAL
[ state(γ, t2) |= has_trust_level_on(A, I, r2) & r2 > r ]

This property is again satisfied for all trace for D = 20.

Besides the patterns on the individual trust level, properties have also been expressed on the combination of all trust levels of a trustee, the reputation. The first property addresses the occurrence of a stable reputation point.

RRP1(P): Stable point reputation

For all individuals there exists a time point such that after this time point a stable reputation point occurs which does not fluctuate more than P.

∀γ:TRACE, I:INDIVIDUAL
[∃γ:TIME [∀γ:TIME > t, r:REAL, p2:REAL
[ state(γ, t2) |= stable_reputation_level(I, r, P2) ⇒ p2 < P ]]]

This property is satisfied for the setting P=0.02.

Finally, the last property expresses that once an individual has the highest reputation, the individual will remain the highest.
RRP2: High reputations remain
If an individual i initially has the highest reputation, then this reputation will never become lower than the reputation of other individuals.

∀γ:TRACE, I:INDIVIDUAL
[ highest_reputation(γ, I, t) ]
⇒ ∀t:TIME [ highest_reputation(γ, I, t) ]

Where

highest_reputation(γ:TRACE, I:INDIVIDUAL, t:TIME) = ∀r:REAL
[ state(γ, t) = reputation(I, r) ⇒ ∀I₂:INDIVIDUAL, r₂:REAL
[ [ state(γ, t) = has_reputation_level(I₂, r₂) & r₂ ≥ r ] ⇒ T2 = T ] ]

This property is also satisfied for all traces.

V. DISCUSSION

In this paper, an existing computational trust model (cf. [5]) has been taken as a basis, and has been modified to apply the model in a social context. Hereby, the setting included a group of agents that exchange their trust level about certain individuals, and update their trust model based upon these communications. The agents are not influenced by actual experiences to avoid the distortion of the group process, and the resulting trust level. This study is applicable particularly when the individual resides outside the community, and the direct interaction with the individual lacks (e.g. historical figures) or is not frequent. The characteristics of the agents in the group have been varied by changing parameter settings in the computational model. The parameters include the awareness of history of the agent, the openness to others opinion, and the dependency between trust level of different individuals. Simulation runs have been performed, showing interesting patterns in communities. Hereby, communities of homogeneous agents have been investigated, as well as heterogeneous communities, showing quite diverse results. As expected, individuals with high awareness of history, and low openness tend to stick to their initial opinion longer, whereas individuals that are more open to others, or have a lower awareness of history, tend to move towards newer trust values faster. Furthermore, in case trust levels of individuals are dependent upon each other, the trust levels tend to diverge more, which is in accordance with the results shown in [5]. Finally, the results have been formally analyzed, thereby showing that stable trust levels eventually occur, and showing how the most positive individuals are negatively influenced by the group, and vice versa. Furthermore, the persistence of high reputation was also shown to hold.

In the research of trust and reputation in agent communities (see e.g. [7]-[12]) personality attributes of the agents involved have not been investigated in depth. In [11] the notion of a personalized rating is used to calculate the trust and reputation in an agents community, which is based on an agent bias towards the context rather than the agent’s personality attributes. In [12] a model is proposed which includes the influence of social structure on trust and reputation.

For future work, larger communities will be investigated, and also the trust level of the agents upon each other will be investigated (you might trust the opinion of one agent more than another). Finally, instead of the current sequential communication, parallel communication will be investigated as well thereby allowing the mathematical model to be analyzed, and hence, define equilibria up front.

REFERENCES