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INCREASING COLLECTIVE INTELLIGENCE WITHIN ORGANIZATIONS BASED ON TRUST AND REPUTATION MODELS

Abstract. *Trust and reputation are fundamental concepts in multi-agent systems, but at the same time are significant to human life. The purpose of this paper is to find a way to enhance collective intelligence within organizations. First, we present some perspectives concerning the concepts of collective intelligence, trust and reputation. Then we suggest four computational models of trust and reputation, describing the main characteristics of each model and based on a cognitive model of trust, it is shown up how trust can increase collective intelligence in an organization. We try to simulate agents' behavior using the preferential attachment hypothesis.*
Key Words*: Collective Intelligence, Trust, Reputation, Preferential Attachment*

JEL Classification: C 63; C 92

1. Introduction

Artificial intelligence is quickly moving from the paradigm of an isolated and non-situated intelligence to the paradigm of situated, social and collective intelligence. The paradigm of the intelligent or adaptive agents and multi-agent systems, together with the emergence of the information society technologies (through the emphasis on electronic commerce) are responsible for the increasing interest on trust and reputation mechanisms applied to knowledge societies.

Collective intelligence is a shared intelligence that emerges from the collaboration of individuals. The study of collective intelligence is considered a subfield of sociology, communication or behavior, computer science or cybernetics. Collective intelligence explores collective behavior from the level of quarks to the level of bacterial, plant, animal and human societies. The concept of collective intelligence can be extended to relationship intelligence. The use of new informational and communication technologies should be oriented to collective intelligence field for helping people think, develop and implement ideas collective.

The presence of collective intelligence has been felt for a long time: families, companies and states are groups of individuals that at least sometimes act intelligent. Bee and ant colonies are examples of groups of insects that are finding food sources acting intelligent. Even the human brain could be seen as a collection of individual neurons that collectively act intelligent. In the last few years there have been shown up new examples of collective intelligence: Google and Wikipedia. Google takes the collective knowledge created by millions of people for making websites, using sophisticated algorithms and technologies to answer the questions typed in. Wikipedia uses less sophisticated technologies, but very clever organizational principles and motivational techniques, to get people from all over the world to create a huge collection of knowledge.

A measure applied in this field is the "collective intelligence quotient", which can be calculate like the individual intelligence quotient. Szuba (2001) proposed a formal model to describe the collective intelligence concept. The process, random and distributed, is tested in mathematical logics by social structure. Beings and information are modeled as abstract informational molecules which have expressions of mathematical logic. They are displaced quasi-randomly due to interactions with their environments. Their interactions in abstract computational space create an inference process perceived as "collective intelligence".

Haylighen (1999) has characterized collective intelligence as a group ability to solve more problems than its individuals. In order to overcome the individual cognitive limits and the difficulties of coordination a collective mental map can be used. A collective mental map can be defined as an external memory with shared access. A formalization of this map can be realized by drawing a directed graph.

Collective intelligence is trying to offer a new perspective to different economic and social phenomena. The concept is trying to suggest another way of thinking about effectiveness, profitability or teamwork in the knowledge societies.

2. Trust and Reputation

The domain of trust and reputation is quite recent, but in the last years there have been proposed interesting models with direct implementation in different areas. In the following we will present a selection of computational trust and reputation models and will describe their main characteristics, but first we need to clarify the notions of trust and reputation.

2.1 Trust

Trust is important to human society due to its social component. The concept of trust has different meanings, but Gambetta's point of view is the most significant:

"*... trust (or, symmetrically, distrust) is a particular level of the subjective probability with which an agent assesses that another agent or group of agents will* *perform a particular action, both before he can monitor such action (or independently of his capacity ever to be able to monitor it) and in a context in which it affects his own action*". [3]

There are some significant characteristics of trust mentioned in the above definition:

- Trust is subjective;
- Trust is affected by the actions that cannot be monitor;
- The level of trust is dependent on how our actions are affected by the other agent's actions.

Typologies of trust

In a social perspective, there have been identified three types of trust:

- interpersonal trust (the direct trust that an agent has in another agent);
- impersonal trust (the trust within a system that is perceived through different properties);
- dispositional trust (the general trusting attitude).

2.2 Reputation

An agent behavior can be induced by other agents that cooperate, determining a reputation mechanism. The simplest definition of reputation can be the opinion others have of us. Otherwise, reputation represents a perception that an agent has of another agent's intentions or an expectation about an agent's behavior.

Abdul-Rahman and Hailes (2000) have defined reputation as *"an expectation about an agent's behavior based on information about or observations of its past behavior."* This definition considers reputational information based on agent's personal experiences.

2.3 Computational Trust and Reputation Models

This field is quite recent, but in the last years new approaches have been proposed, with direct implementation in different domains, in order to determine the level of trust. For example, Marsh (1994) has introduced a computational trust model in the distributed artificial intelligence. An artificial agent can absorb the trust and than he can make trust-based decisions. This model proposes a representation of trust as a continuous variable over the range [-1, +1). There are differentiated three types of trust: basic trust (calculated from all agent's experiences), general trust (the trust on another agent without taking into account a specific situation) and situational trust (the trust on another agent taking into account a specific situation). There are proposed three statistical methods to estimate general trust, each determining a different type of agent: the maximum method leads to an optimistic agent (takes the maximum trust value from the experiences he has), the minimum method leads to a pessimistic agent (takes the minimum trust value from the experiences he has) and the mean method that lead to a realistic agent (takes the mean trust value from the experiences he has). Trust values are used in agents' decision whether to cooperate or not with another agent.

Zacharia (1999) has proposed two reputation mechanisms (Sporas and Histos) in online communities based on collaborative ratings that an agent receives from others. Sporas takes into consideration only the recent ratings between agents, and Histos comes as a reply taking into consideration both direct information and witness information. Reputation mechanisms could generate social changes in users' behavior. A successful mechanism ensures high prediction rates, robustness against manipulability and cooperation incentives of the online community.

Abdul-Rahman and Hailes (2000) have suggested a model that allows agents to decide which other agents' opinion they trust more. In their view, trust can be observed from two perspectives: as direct trust or as recommender trust. Direct trust can be represented as one of the values: "very trustworthy", "trustworthy", "untrustworthy" or "very untrustworthy". For each partner, the agent has a panel with the number of past experiences in each category, and trust on a partner is given by the degree corresponding to the maximum value in the panel. The model takes into account only the trust coming from a witness, the recommender trust, which is considered "reputation".

Sabater and Sierra (2001, 2002) have proposed a modular trust and reputation model (ReGreT) to e-commerce environment. This model takes into consideration three different types of information sources: direct experiences, information from third party agents and social structures. Trust can be determined combining direct experiences with the reputation model. The reputation model is composed of specialized types of reputation: witness reputation (calculated from the reputation coming from witness), neighborhood reputation (calculated from the information regarding social relations between agents) and system reputation (calculated from roles and general properties). Those components merge and determine a trust model based on direct knowledge and reputation.

3. A Cognitive Model of Trust

Cognitive aspects are the basis for the collective intelligence concept and this is the reason of according more and more importance to the cognitive models of trust.

In a socio-cognitive perspective, trust can be seen as a mental attitude. To argue this perspective, have been suggested three statements:

- Only a cognitive agent can trust another agent; it means that only an agent endowed with goals and beliefs (an agent trust another agent relatively to a goal).
- Trust is a mental state, a complex attitude of an agent towards another agent about a specific action relevant for a goal (the agent that feels trust is a cognitive agent

endowed with goals and beliefs, but the agent trusted is not necessarily a cognitive agent).

- Trust is a the mental counter-part of delegation (the agent that feels trust depends on the trusted agent's action, what means that the agent that feels trust is "delegating" actions or goals to the other agent; this is the relation between trust and delegation).

Following the above conditions, delegation is an action, the result of a decision, action or decision that creates a social relation among the two agents that interact and the afferent action. In these conditions, trust is a mental state, a social attitude towards another agent.

Another possibility is to consider trust as a level of risk associated with the cooperation with another agent and in this situation, it estimates how likely the agent is to fulfill its commitments. Trust can be derived both from direct interactions among agents and from reputation, built from information received from third parties. Based on trust and reputation, agents can make more informed decisions about whether to interact with others or not.

Castelfranchi and Falcone (1998) have elaborated a cognitive model that consider trust as a bet, implying risks, due to the delegating action, and than presented a quantification of trust degree, used to model the delegate decision (to delegate or not to delegate). In their opinion trust represent a mental state, a relational capital for agents that are trusted in a social network.

The main idea is that trust can be seen from two points of view: trustor's view (the agent selects the right partners for achieving its own goals) and trustee's view (the agent is selected from partners to establish with them collaboration or cooperation and take advantage from the accumulated trust).

Trust analysis as relational capital starts from a dependence social network with potential partners, in which needs, goals, abilities and resources are distributed among the agents, and than inserts the analysis of what it means for an agent to be trusted. Those conditions represent a form of power and could be used by an agent to achieve his own goals. The analysis presents the difference between relational capital and social capital, individual trust capital and collective trust capital.

In order to achieve each goal, an agent needs actions, plans and resources. Formally, let $A_t = \{A_1,...,A_n\}$ be a set of agents. Each agent $A_i \in A_t$ can have associated:

- a set of goals $G_i = \{g_{i1}, ..., g_{iq}\}$
- a set of actions $Act_i = \{\alpha_{i1}, ..., \alpha_{iz}\}$
- a set of plans $\Pi = \{p_{i1}, ..., p_{is}\}$
- a set of resources $R_i = \{r_{i1}, ..., r_{im}\}$.

The sets of actions, plans, resources owned by an agent are used to achieve a set of tasks ($\tau_1,\ldots,\tau_r$).

Considering the above notations, a Dependence Relationship between two agents A_i and A_j with respect to the goal g_{ik}, can be seen as an objective dependence or as a subjective dependence: (A_i, A_j, g_{ik}). A Dependence Network is represented by the set of dependence relationships among the agents from the set A_t at the moment t: (A_t, t).

An agent A_i has an Objective Dependence Relationship with another agent A_j if for achieving at least one of his goals, $g_{ik} \in G_i$, agent A_i needs actions, plans and resources that are owned by A_j and not owned by A_i. A Subjective Dependence Relationship represents agent's A_i point of view with respect to its dependence relationships. In this case, the dependence relationship can be modeled on the agent subjective interpretation: B_jG_i is the set of goals of the agent A_i believed by the agent A_j; B_jAct_i is the set of actions of the agent A_i believed by the agent A_j; $B_j\Pi_i$ is the set of plans of the agent A_i believed by the agent A_j, and B_jR_i is the set of resources of the agent A_i believed by the agent A_j.

For a Dependence Network (A_t, t), can be expressed a Potential for Negotiation of an agent A_i about a goal g_{ik} as:

- An Objective Potential for Negotiation:

$$OPN(A_i, g_{ik}) = f\left(\sum_{j=1}^{n} \frac{1}{1+p_{kj}}\right)$$

- A Subjective Potential for Negotiation:

$$SPN(A_i, g_{ik}) = \sum_{j=1}^{n} \frac{1}{1+p_{kj}}$$

where f is a monotonous function, n - the number of agents in the A_t set that have a dependence relation with the agent A_i with respect to the goal g_{ik} (n is the number of direct dependences), and p_{kj} - the number of agents in the set A_t set that are competitors with the agent A_i on the same actions, plans or resources owned by the agent A_j with respect to the goal g_{ik} (the agent A_j can not satisfy all the agents at the same moment, so p is the number of indirect dependences).

Trust is also implied in a dependence belief (*BDep*). To believe to be dependent means both to believe not to be able to perform an action α to achieve a goal g, (*BDep1*), and to believe that an agent is able to perform an action α in order to achieve the goal g, (*BDep2*). The second type of dependence belief, (*BDep2*) is a component of trust because represents a positive evaluation of an agent as being able or competent.

The Subjective Potential for Negotiation of an agent A_i with a goal g_{ik} can be represented based on the dependence belief:

$$SPN(A_i, g_{ik}) = \sum_{j=1}^{n} \frac{B_i(DA_j * DW_j)}{1 + p_{kj}}$$

where $D(B_i(A_j))$ is a degree of ability of the agent A_j with respect to the goal g_{ik} believed by the agent A_i, $D(B_i(A_j))$ - a degree of willingness of the agent A_j with respect to the goal g_{ik} believed by the agent A_i, and p_{kj} - the number of agents in the set A_t set that are competitors with the agent A_i on the same actions, plans or resources owned by the agent A_j with respect to the goal g_{ik}.

The Subjective Trust Capital of an agent A_i about a task τ_k can be expressed as a function:

$$STC(A_i, \tau_k) = \sum_{j=1}^{n} B_i(B_j DA_i * B_j DW_i)$$

where n is number of agents that need the task τ_k, $D(B_{ij}(A_{jk}))$ - the agent's A_i degree of belief with respect the agent's A_j ability about a task τ_k, believed by the agent A_j, $D(B_{ij}(W_{jk}))$ - the agent's A_i degree of belief with respect the agent's A_j willingness about a task τ_k, believed by the agent A_j.

The cumulated trust capital of an agent A_i about a specific task τ_k is the sum of the abilities and willingness believed by each dependent agent, for all the agents that need that task in the network dependence. The subjectivity occurs because the network dependence and the abilities and willingness believed are considered from the agent's A_i point of view.

The Degree of Trust of an agent A_i on other agent A_j with respect to the task τ_k can be described:

$$DT(A_i A_j \tau_k) = B_i DA_j * B_i DW_j,$$

and the Self-Trust of the agent A_i with respect to the task τ_k:

$$ST(A_i, \tau_k) = B_i(DA_i * DW_i).$$

Based on the above notations, the Subjective Usable Trust Capital of an agent A_i about a task τ_k can be defined as:

$$SUTC(A_i, \tau_k) = \sum_{j=1}^{n} \frac{B_i(B_j DA_i * B_j DW_i)}{1 + p_{kj}}$$

where p_{kj} is the number of agents in the dependence network that can achieve the same task with a trust value comparable with agent's A_i trust value.

It should be taken into consideration that even if dependence relationship between agents in a society are important, there will not exist exchanges if trust is not present to enforce connections.

Trust can be an advantage for the trustee, but there is a disadvantage in treating social capital at individual level (relational capital). Sometimes relational capital could be in conflict with the collective capital (for an individual is better to monopolize trust, but for the community is better to distribute it among individuals).

4. NetLogo Simulations

Preferential attachment is frequently used in describing social, biological and technological networks and it represents the mechanism of formation models for such networks.

Social networks are interaction networks, where nodes are agents and links between nodes are interactions between agents. In the evolution of social networks, an important hypothesis is that highly connected nodes increase their connectivity faster than their less connected peers, called preferential attachment. Experiments reveal that the rate at which nodes acquire links depends on the node's degree, offering direct quantitative support for the presence of preferential attachment.

The evolving network models are mostly based on two important hypothesis, growth and preferential attachment. The growth hypothesis sustains that networks continuously expand through new nodes and links between the nodes, and the preferential attachment hypothesis sustains that the rate with which a node with *k* links acquire a new link is a monotonically increasing function of *k*.

4.1 Preferential Attachment in NetLogo

This model shows a way of arising networks, when there are a few hubs that have many connections, while the others have only a few. The model starts with two nodes connected by an edge. A new node is added at each step. A new node picks an existing node to connect to randomly, but there is a tendency observed: a node's chance of being selected is directly proportional to the number of connections it already has. In our simulations, we are going to endow agents with two attributes, "reputation" and "intelligence".

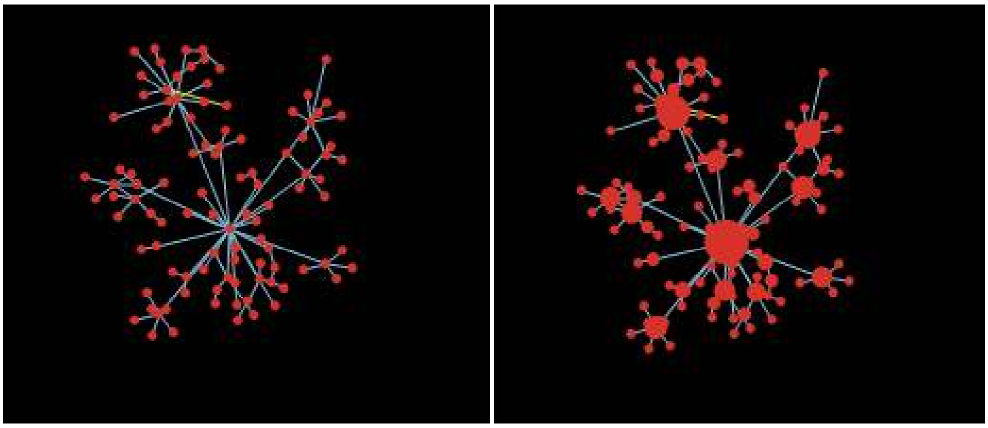

Figure 1 a) **Figure 1 b)**

We can observe that there are two nodes that have many connections, while the most of them have only a few ((figure 1 b) shows resized nodes, for clearance). Experiences have shown that the popular nodes will acquire new links faster than the other ones ((figure 1 a) and figure 1 b)).

4.2 Simulations

The forthcoming simulations will try to show agents' behavior assuming that they are endowed with two attributes, reputation and intelligence. We propose a representation of reputation as a variable over the range [-1, 1] and intelligence as a variable over the range [1, 100].

The first agent's intelligence is a random value between 1 and 100. Agents are going to be linked each other only if their intelligence is varying with less than 10. For example, if an agent has intelligence 92, it could have connections only with agents that have intelligence between 82 and 100.

Figure 2 a) presents the intelligence values for the agents. The maximum intelligence value is 100 and the minimum intelligence value is 80, but the difference between them is amplified by the growing number of agents.

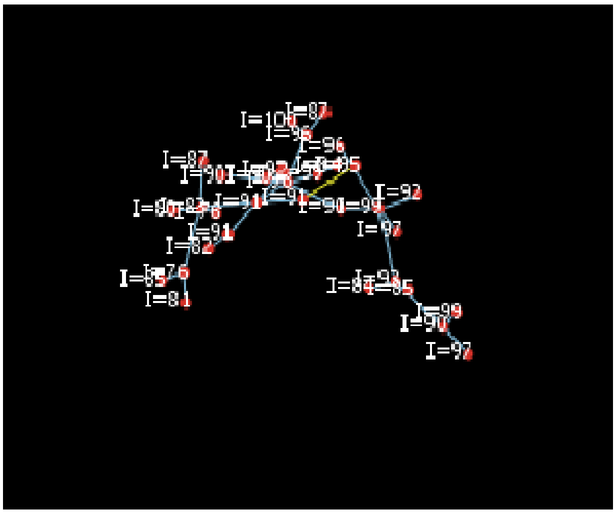

Figure 2 a)

We can notice that agents make links with those agents that have the closest value of intelligence. For example, if there are two agents, one with intelligence 92 and the other with intelligence 95, a third agent with intelligence 87 will choose to connect to the agent with the closest intelligence, the agent with intelligence 92.

In figure 2 b) are shown the reputation values, ranging between [-1, 1].

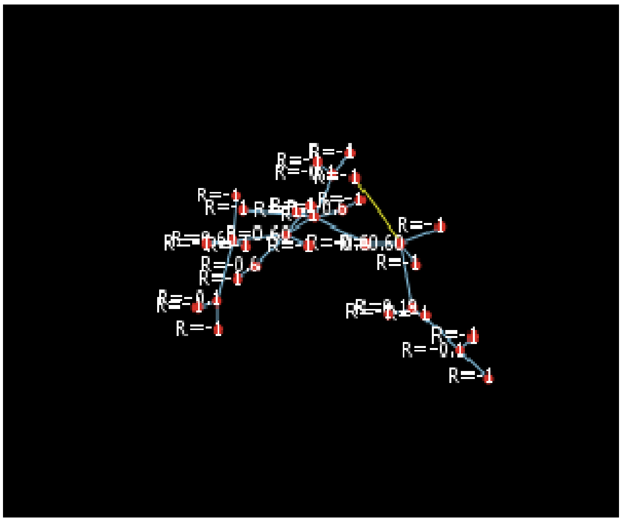

Figure 2 b)

Agent's reputation is determined by the number of connections that agent has with other agents. The more connections an agent has, the reputation value is closer to 1.

The first agent has frequently reputation value 1 because it is the agent with the higher number of connections.

Figure 2 c) shows agents endowed with the two attributes, reputation and intelligence.

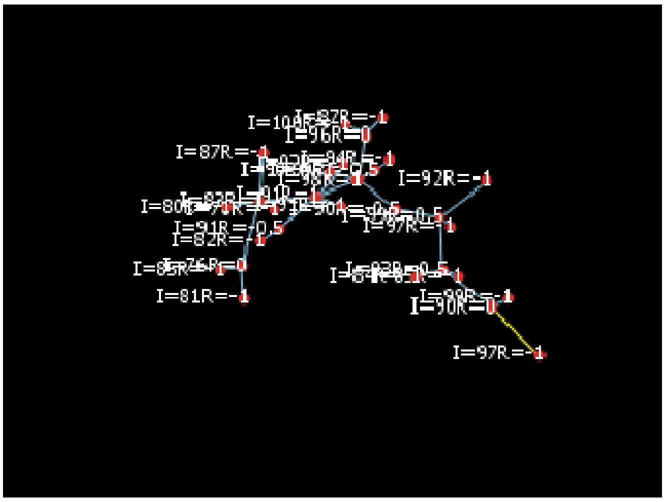

Figure 2 c)

An agent prefers to connect with another agent that has a high level of reputation, but in the same time with the closest value of intelligence.

5. Conclusions

The organizational behavior field is interested in studying organizations as complex adaptive systems. Trust is a decisive source of social capital within complex adaptive systems. Most of the theories from this field explore individual and collective human behavior within organizations and their central activities try to identify the determinants of intra-organizational cooperation. Managing collective intelligence within an organization implies combining all tools, methods and processes that can lead to connection and cooperation among individual intelligences.

Individual intelligence can not face all the problems in today's world. To successfully deal with problems we need to develop collective intelligence as a global civilization. Collective intelligence can improve competitiveness within organizations in the context of a global market and collective performance has become a critical factor in the organization's development. In this situation creating, developing and sustaining trust among members within teams is the core that leads to performance.

Our future work will focus on extending the NetLogo simulations by adding new attributes or characteristics to the agents, and furthermore, developing a model of trust and reputation that would lead to an increase of the collective intelligence in organizations.

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