Reputation and Social Network Analysis in Multi-Agent systems

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ABSTRACT

The use of previous direct interactions is probably the best way to calculate a reputation but this information not always is available. This is specially true in large multi-agent systems where interaction is scarce. In this paper we present a reputation system that takes advantage, among other things, of social relations between agents to overcome this problem.

1. INTRODUCTION

The study and modeling of reputation has attracted the interest of scientists from different fields such as: sociology, economics [7, 11], psychology [5, 10] and computer science [6, 4, 17]. According to the Oxford English Dictionary, *reputation* is "the common or general estimate of a person with respect to characteror other qualities". This estimate is necessarily formed and updated along time with the help of different sources of information. Up to now, the systems of reputation have been considering two different sources: the direct interactions and the information provided by other members of the society about experiences they had in the past [13, 14, 16, 17]. Those systems, however, forget a third source of information that can be very useful. As a direct consequence of the interactions, even in simple societies it is possible to identify different types of social relations between their members. Sociologists and psychologists have been studying these social networks for a long time in human societies. These studies show that it is possible to say a lot about the behaviour of individuals using only the information that arises from the analysis of their social network. In this paper we evolve the **Regret** [13] system to incorporate the use of social network analysis as part of the calculations for reputations.

In Section 2 we introduce the notion of social network analysis and its application to agent communities. After describing some essential concepts in Section 3, in Section 4 a scenario is presented to be used in the rest of the paper to ilustrate how the system works. Sections 5, 6, 8 and 9 describe the system in detail and finally sections 10 and 11 present the related work, conclusions and future work.

2. SOCIAL NETWORK ANALYSIS AND AGENT SOCIETIES

Social network analysis is the study of social relationships between individuals in a society. Social network analysis emerged as a set of methods for the analysis of social structures, methods that specifically allow an investigation of the relational aspects of these structures. The use of these methods, therefore, depends on the availability of relational rather than attribute data [15]. For instance, From the study of communication in Island Oceania a graph of the southern Lau trade network from the point of view of centrality was built that permitted to indentify and explain why the two main centers of trading activity were the islands of Mothe and Namuka [9].

Relational data can be handled and managed in matrix form or using graphs. Usually, the latter representation is preferred because it is more direct to make a social interpretation of a graph structure than of a matrix. A graph structure that shows social relations is called a *sociogram*. A different sociogram is usually built per each social relation under study. Depending on the type of relation, we have a directed or non-directed sociogram, with weighted edges or without.

The main question that arises at this point is: we know that social network analysis can be used to analyse human societies, could it be also is suitable for agent societies? A drawback in social network analysis is that, sometimes, the translation of human social structures into their sociological meaning is difficult and artificial due to the complexity of the individuals and their relations. The grater simplicity, in social terms, of multi-agent systems suggests that social network analysis can be applied to them with even better results.

We have exposed the pro but, of course, there is a con. Obviously, the more relational data the better network analysis. However, these data can be very difficult to obtain. Sociologists usually obtain them through public-opinion polls and interviews with the individuals. This procedure is, of course, not possible in agent societies.

Moreover, the analysis of human social structures is something that is usually done by an entity (the sociologist) external to the society. This external position gives the analyst a privileged watchtower to make this kind of analysis. In our case, as we want to use social analysis as part of the reputation system to be included in each agent, each agent has to do this analysis from his own perspective.

It is beyond the scope of this paper to propose solutions for this problem. From now on, we will assume that the agent owns a set of sociograms that show the social relations in his environment.

3. BASIC COMPONENTS

In this section we introduce the two basic concepts that constitute the foundations of our reputation system. The notion of *outcome* and the notion of *impression*.

We will note groups of agents using upper-case letters, ($\mathcal{A}$, $\mathcal{B}$,...), and agents using indexed lower-case letters, (a_2, b_3, ...). An agent noted b_i is assumed to belong to group $\mathcal{B}$. We note **G** as the set of group identifiers and **A** as the set of agent identifiers.

We define the *outcome* of a dialogue between two agents as both an initial contract to either take a particular course of action or to fix the terms and conditions of a transaction, and the actual result of the actions taken or the actual values of the terms of the transaction. An outcome is represented as a conjunction of equalities between variables and constants. The names of these variables and constants are part of the domain ontology. Variables are used to represent the outcome features and constants to represent the values of these features.[1]

For instance, the outcome of a commercial transaction between agents a and b could be: $o =$ (Delivery_date $=_c$ 10/02 $\wedge$ Prize $=_c$ 2000 $\wedge$ Quality $=_c$ A $\wedge$ Delivery_date = 15/02 $\wedge$ Prize = 2000 $\wedge$ Quality = C). This is, the agreement between a and b says that the product should arrive on 10/02, its value should be 2000, and the quality of the product be 'A'. The product actually arrives on 15/02, with a value of 2000 and quality 'C'. We note the set of all possible outcomes as **O**.

We define an *impression* as the subjective evaluation made by an agent on a certain aspect (variable) of an outcome. An *impression* ι is represented then by a tuple of the form $\iota = (a, b, o, \chi, \text{time}, V)$ where $a, b \in \mathbf{A}$ are the agents who dialogue (being a who is judging), $o \in \mathbf{O}$ is the outcome, χ the variable of the outcome that is judged, time is the time when the impression is recorded and $V \in [-1, 1]$ is the rating associated to the specific aspect being evaluated from agent a's point of view. The intuitive meaning of the scale is: -1 absolutely negative, 1 absolutely positive, and 0 neutral. Using the same example, a possible impression for the outcome o could be: $(b, a, o, Delivery\_date, 16:05, -0.5)$. Note that V represents the subjective opinion of the agent who is judging, with respect to χ. For instance, the same delay for the arrival date (in this case 5 days) could be a disaster for a given agent and, hence, the value of V would be closer to -1, while in other situations it might not be a problem and the value of V could be near 0.

I is defined as the set of all possible impressions and an agent's *impressions database*, $IDB^a \subseteq I$, as the set of impressions judged by agent a. We define $IDB^a_p \subseteq IDB^a$ as the set of impressions in IDB^a that satisfy the pattern p where the general form for a pattern is

$$p ::= (a, b, o, \chi, t, V) : expr \mid p \wedge p \mid p \vee p$$

with $expr$ as a logical formula in first order logic over the components of the impression. The '_' symbol is used to represent an 'anything' value (representing a universally quantified variable) and the $\wedge$ and $\vee$ of two patterns implies the $\cap$ and the $\cup$ of the respective impressions databases, this is, $IDB_{p\wedge q} = IDB_p \cap IDB_q$ and $IDB_{p\vee q} = IDB_p \cup IDB_q$. For example, IDB^b_p with $p = (\_, a, \_, Delivery\_date, \_, \_) : true$ is the set of all b impressions over a that are related with a delivery date. Another example, IDB^a_p with $p = ((\_, b, \_, \_, \_, V) : V \geqslant 0 \vee (\_, c, \_, \_, \_, V') : V' \geqslant 0)$ is the set of all a impressions over b or c with a positive rating.

4. RUNNING EXAMPLE

The scenario for this running example is a marketplace. In this marketplace each seller is specialised in a single type of product and can be an independent seller or be part of a company that groups several sellers specialised in different products (in that case we consider they are grouped under a single brand). The buyers buy the products that they need depending on their occupancy.

To simplify, the buyers buy one product at a time (it is not possible to buy in bulk) and the elements that are taken into account for each transaction are the price, the quality and the delivery date. The buyer chooses a seller. If the seller wants to deal with that buyer, then it sends an offer. Then the buyer has to decide if he wants to accept or not the offer. If the buyer accepts it, the transaction is performed.

It is important to note that the result of the transaction is not necessarily equal to the initial offer from the seller. A swindler seller can increase the price, decrease the quality or deliver the product late. On the other hand, the buyer can decide to pay less or even not to pay at all. We consider that the process of obtaining the actual result of the transaction is atomic, this is, the buyer and the seller have to decide their strategy (to pay less, to overcharge the price, to deliver late, do things exactly as specified in the offer, etc.) before knowing the behaviour of the other. Although the latest point is not very realistic, it makes the example simpler and allows us to focus our attention only on reputation.

We can identify many types of relationships between agents in an e-commerce environment and it is beyond the scope of this paper to present a survey on all of them. We will refer just to a set of relations that can be found in our scenario and that will help the reader to go through the explanation of the system.

We assume that in our scenario the great majority of agents are rational and that have a behaviour according to their goals and affiliation (in a chaotic environment with only random or contradictory agents it has no sense to use social relationships to predict the behaviour of the agents). We note a non-directed relation of type *rel* between two agents a and b as $rel(a \leftrightarrow b)$. If the relation is directed then we use the notation $rel(a \rightarrow b)$. The three relation types that we consider are:

1) *Competition* (*comp*). This is the type of relation that appears between two agents that pursue the same goals and

[1] We'll note $=_c$ to represent the relation between a variable and its value on a contract c, and by $=$ with the value of the variable in the actual result.

need the same (usually scarce) resources. In this situation, agents tend to use all the available mechanisms to take some advantage from their competitors, for instance hiding information or lying. In our running examplem this is the kind of relation that could appear between two sellers that sell the same product or between two buyers that have the same occupancy.

2) *Cooperation* (*coop*). This relation implies a big exchange of sincere information between the agents and some kind of predisposition to help each other if it is possible. Notice that we talk about "sincere" information instead of "true" information because the information can be true only from the point of view of the agent who is giving it, but false in general. To simplify, we consider that two agents can not have at the same time a competitive and cooperative relation.

3) *Trade* (*trd*). This type of relation reflects the existence of commercial transactions between two agents.

As we said before, we assume that each agent owns a sociogram for each one of these relation types. The three sociograms are non-directed graphs with weighted edges. Weights go from 0 to 1 and reflects the intensity of the relation.

In our scenario, the variables that appear in contracts between buyers and sellers (the price, quality and delivery date) determine what sort of impressions an agent can generate and hence the reputation types. For the seller, we consider four reputation types:

R(to_overcharge): A high reputation value for this type means that the seller tends to overcharge the prices specified in contracts.

R(to_deliver_late): As the name suggest, is the reputation of delivering the products later than the delivery date specified in the contract.

R(quality_swindler): A seller with a reputation to deliver products with less quality than specified in the contract.

R(swindler): A swindler is a seller that overcharges the price and/or delivers products with a quality lower than the quality specified in the contract.

For the buyer we consider only one type of reputation:

R(defaulter): A high reputation of this type means that the buyer does not pay the products he buys.

5. THE REGRET SYSTEM

The **Regret** system structure is based in what we call the three *dimensions* of reputation. If an individual is considering only the direct interaction with the other members of the society to stablish reputations we say that agent is using the *individual dimension* of reputation. If it uses also the information of other members of the society and the social relations, we are talking about the *social dimension* of reputation. Previous work just explored the individual dimension [13].

On the other hand, we consider that the reputation on an individual is not a single and abstract concept but rather it is a multi-facet concept. For example, the reputation of being a good flying company summarizes the reputation of having good planes, the reputation of never losing luggage and the reputation of serving good food. In turn, the reputation of having good planes is a summary of the reputation of having a good maintenance service and the reputation of frequently renewing the fleet. The different types of reputation and how they are combined to obtain new types is what we call the *ontological dimension* of reputation. In the following sections we explain in detail each one of these dimensions.

Reputations in this paper have a temporal dimension. That is, the reputation value of an agent varies along time. We will, however, omit the reference to time in the notation in order to make it more readable. From now on, we will refer to the agent that is calculating a reputation as a (what we call the "source agent") and the agent that is the object of this calculation as b (what we call the "target agent").

6. INDIVIDUAL DIMENSION

The *individual dimension* models the direct interaction between two agents. The reputation that takes into account this dimension is the most reliable. This is because it takes into account all the peculiarities of the target agent and do not rely on behavioral trends. Therefore, even "black sheep" agents (contradictory agents or agents that do not follow the main stream of the society) can be given a reputation using this dimension. We call *subjective reputation* the reputation calculated directly from an agent's impressions database and note as $R_{a \xrightarrow{I} b}(\varphi)$ where φ is the reputation type.

To calculate a subjective reputation we use a weighted mean of the impressions' rating factors, giving more relevance to recent impressions,[2] that is $R_{a \xrightarrow{I} b}(\varphi) = \sum_{\iota_i \in IDB^a_p} \rho(t,t_i) \cdot V_i$ with t the current time, p a pattern that selects the impressions in support of φ, $\rho(t,t_i) = \frac{f(t_i,t)}{\sum_{\iota_j \in IDB^a_p} f(t_j,t)}$ and $f(t_i,t)$ a time dependent function that gives higher values to values closer to t. A simple example of this type of function is $f(t_i,t) = \frac{t_i}{t}$. Finally, given that $V_i \in [-1,1]$ and that $\rho(t,t_i)$ is a normalized value, it is easy to see that $R_{a \xrightarrow{I} b}(\varphi) \in [-1,1]$.

The subset of impressions used to calculate a given reputation type φ is domain dependent. We define a *grounding relation* as the relation that links a reputation type φ with the pattern p that allows to select the right subset of impressions from the general impressions' data base. As an example, the *grounding relation* for our scenario is defined in the following table:

φ	pattern p
to_overcharge	$p = (\_, b, \_, \text{Price}, \_)$
to_deliver_late	$p = (\_, b, \_, \text{Delivery\_Date}, \_)$
quality_swindler	$p = (\_, b, \_, \text{Quality}, \_)$

Note that we only define the *grounding relation* for the reputation types to_overcharge, to_deliver_late and quality_swindler. The reputation type swindler is a complex reputation type calculated from more basic reputations as we will see in section 8.

Besides the reputation value, it is important to know how reliable is that value. Although there are many elements that can be taken into account to calculate how reliable a subjective reputation is, we will focus on two of them: the number of impressions used to calculate the reputation value and the variability of their rating values (the impressions'

[2]There are many psychological studies that support recency as a determinant factor [10].

rating deviation). This approach is similar to that used in the Sporas system [17].

The intuition behind the number of impressions factor is that in a real society an isolated experience (or a few of them) is not enough to make a correct judgement of somebody. You need certain amount of experiences before you can say how is a person. As the number of impressions grows, the reliability degree increases until it reaches a maximum value, what we call the *intimate* level of interactions (*itm* from now on). From a social point of view, this stage is what we know as a close relation. More experiences will not increase the reliability of our opinion from then on. The next simple function is the one we use to model this:

$$Ni(IDB_p^a) = \begin{cases} \sin\left(\frac{\pi}{2 \cdot itm} \cdot |IDB_p^a|\right) & |IDB_p^a| \in [0,\text{itm}] \\ 1 & \text{otherwise} \end{cases}$$

We believe that the *itm* value is domain dependent. It depends on the interaction frequency of the individuals in that society as well as on the quality of the impressions.

The subjective reputation deviation is the other factor that our system takes into account to determine the reliability of a subjective reputation. The greater the variability in the rating values the more volatile will the other agent be in the fulfillment of their agreements.

We calculate the subjective reputation deviation as:

$$Dt(IDB_p^a) = 1 - \sum_{\iota_i \in IDB_p^a} \rho(t, t_i) \cdot |V_i - R_{a \xrightarrow{I} b}(\varphi)|$$

This value goes from 0 to 1. A deviation value near 0 indicates a high variability in the rating values (this is, a low credibility of the reputation value from the subjective reputation deviation point of view) while a value close to 1 indicates a low variability (this is, a high credibility of the reputation value).

Finally, we define the reliability of a subjective reputation as a convex combination of the function Ni and the impressions' rating deviation Dt.

$$RL_{a \xrightarrow{I} b}(\varphi) = (1 - \mu) \cdot Ni(IDB_p^a) + \mu \cdot Dt(IDB_p^a)$$

7. SOCIAL DIMENSION

Although direct interaction is the most reliable source of information, it is not always available. Not only because the agent can be a newcomer to a society but also because the society can be very large. Therefore, when the interactions with another agent are scarce it is not possible to assign him a reputation based just on direct experiences. In these situations is when the *social dimension* of an agent may help, this is, to use information coming from other agents. In the **Regret** system we use three types of social reputation —depending on the information source:

- *Witness Reputation.* Based on the information about the target agent coming from other agents. We note this reputation as: $R_{a \xrightarrow{W} b}(\varphi)$
- *Neighbourhood Reputation.* Uses the social environment of the target agent, this is, the neighbours of the target agent and their relations with him. Noted as: $R_{a \xrightarrow{N} b}(\varphi)$
- *System Reputation.* It is a default reputation value based on the role played by the target agent. Noted as: $R_{a \xrightarrow{S} b}(\varphi)$

Each one of these reputations requires a different degree of knowledge of the agent society and the target agent. The *System Reputation* is the easiest to calculate. We are assuming that the role an agent is playing is always "visible" information that is available to all the agents in the society. However, the role alone does not convey enough information to compute a reputation on all imaginable aspects. Also, the reliability of this type of reputation tends to be low because it doesn't take into account the peculiarities of the individual and its environment. This is the kind of reputation that an agent can use when it is a newcomer and there is an important lack of interaction with the other agents in the society. The *Witness Reputation* and the *Neighbourhood Reputation*, on the other hand, demand from the agent a moderate to hard knowledge of the social relations in the agent community. We explain below how to calculate these reputation values.

7.1 Witness reputation

Beliefs about the reputation of others can be shared and communicated by the members of a society. The reputation that an agent builds on another agent based on the beliefs gathered from society members (witnesses) is what we call *witness reputation.* In an ideal world, with only homogeneous and trusty agents, this information is as relevant as the direct information. However, in the kind of scenarios we are considering, it may happen that:

The information can be false. Either because the other agent is trying to lie, or because the information he owns is not accurate.

Agents can hide information. An agent cannot assume that the information coming from the other agents is complete.

Besides that, the information that comes from other agents can be correlated (what is called the "correlated evidence problem" [12]). This happens when the opinions of different witnesses are based on the same event(s) or when there is a considerable amount of shared information that tends to unify the witnesses' way of "thinking". In both cases, the trust on the information shouldn't be as high as the number of similar opinions may suggest. Because the event(s) that have generated the opinions for each agent are hidden, the agent cannot identify directly which agents are correlated. Schillo et. al [14] propose a method based on the analysis of "lying" as a stochastic process to implicitly reconstruct witness observations in order to alleviate this problem. We take a different approach based on the social relations between agents. Analysing these relations, an agent can obtain useful information to minimize the effects of the correlated evidence problem.

Exchanging a set of outcomes or impressions would solve the correlated evidence problem, because then, assuming that the information is true, the agent would have enough information to detect correlated agents. However, we consider that it is not realistic in a competitive environment because the set of outcomes/impressions contains sensitive information about the witness. We consider that a more reasonable model is to assume that the information to be exchanged between agents is a tuple where the first element is the reputation value of the target agent from the point of view of the witness, and the second element is a value that reflects how confident is the witness about the reputation value. As we said before, the witness can give wrong

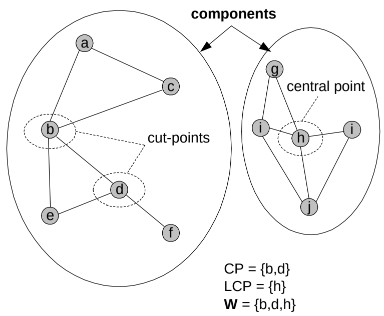

Figure 1: Witness selection within Regret.

values or simply can decide not to give his opinion even if he has enough information to do so. We will note the tuple as $\langle R_{c\to b}(\varphi), RL_{c\to b}(\varphi)\rangle$, where c is the agent giving the information to a.

7.1.1 *Identifying the witnesses*

The first step to calculate a witness reputation is to identify the set of witnesses ($\mathbf{W}$). The initial set of potential witnesses might be the set of all agents that have had a trade relation with the target agent in the past. This set, however, can be very big and its members probably suffer from the correlated evidence problem.

We take the stance that grouping agents with frequent interactions among them and considering each one of these groups as a single source of reputation values minimizes the correlated evidence problem. Moreover, assuming that asking for information has a cost, it has no sense to ask the same thing to agents that we expect will give us more or less the same information. Grouping agents and asking for information to the most representative agent within each group reduces the number of queries to be done. A sociogram based on the cooperative relation is what **Regret** uses to build these groups and to decide who is their most representative agent.

There are many heuristics that can be used to find groups and to select the best agent to ask. In the **Regret** system we use a heuristic based on the work by Hage and Harary [8]. Taking the agents that had a trade relation with the target agent, and their cooperative relations, as the initial graph, the heuristic that **Regret** follows is:

1. To identify the *components* of the graph. A *component* is defined as a maximally connected subgraph.
2. For each component, to find the set of *cut-points* (CP). A *cut-point* is a node whose removal would increase the number of components by dividing the sub-graph into two or more separate sub-graphs between which there are no connections. A cut-point can be seen from a sociological point of view as indicating some kind of *local centrality*. Cut-points are pivotal points of articulation between the agents that make up a component [15].
3. For each component that does not have any cut-point, to choose as a representative for that component the node with the larger degree. If there is more than one node with the maximum degree, choose one randomly. The degree can be regarded also as a measure of *local centrality* [15]. We refer to this set of nodes as LCP.
4. The set of selected nodes is the union between the set of *cut-points* and the set of LCP. This is, $\mathbf{W} = CP \cup LCP$.

Figure 1 shows an example of the application of the heuristic. At this point, the agent has to ask for information to all the agents in the so calculated set of witnesses $\mathbf{W}$.

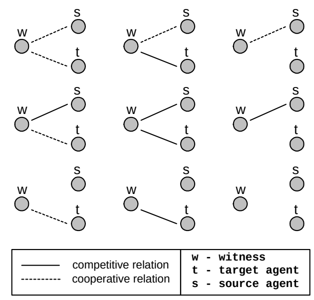

Figure 2: Relevant social structures.

7.1.2 *Who can I trust?*

Once the information is gathered we obtain $\{\langle R_{w_i\to b}(\varphi), RL_{w_i\to b}(\varphi)\rangle \mid w_i \in \mathbf{W}' \subseteq \mathbf{W}\}$, where $\mathbf{W}'$ is the subset of agents that answered a's query. The next step is to aggregate these values to obtain a single value for the *Witness Reputation*. However, as we said before, it is possible that this information be false so the agent has to be careful to give the right degree of importance and reliability to each piece of information.

We define $socialTrust(a, w_i, b)$ as the trust degree that agent a assigns to w_i when w_i is giving information about b and taking into account the social structure among a, w_i and b.

Regret uses fuzzy rules [18, 19] to determine how a social structure provides a reliability degree on the information coming from a given agent in that structure. The antecedent of each rule is the type and degree of a social relation and the consequent is the reliability of the information from the point of view of that social relation. On our scenario, a possible rule would be:

IF coop($w_i \leftrightarrow b$) is high
THEN socialTrust(a, w_i, b) is moderate

this is, if the level of cooperation between w_i and b is high then the trust from the point of view of a on the information coming from w_i related to b is moderate. The heuristic behind this rule is that a cooperative relation implies some degree of complicity between the agents that share this relation so the information coming from one of them about the other is probably biased.

From the set of social relations in our scenario, only the cooperative relation and the competitive relation are relevant to calculate a measure of reliability. Which relations are relevant to calculate the reliability depends on the meaning that has each relation in the specific agent society. In our scenario, for instance, a trade relation cannot cast any light on the reliability of an agent from the point of view of social analysis. In other societies, however, this could be the other way around.

Hence, together with the "no relation" possibility and with the fact that the most relevant links are between the witness and the agent and the witness and the target, there are 9 social structures to be considered. Figure 2 shows this set of social structures.

Figure 3 contains the fuzzy set values for the variables coop($w_i \leftrightarrow a$), coop($w_i \leftrightarrow b$), comp($w_i \leftrightarrow a$), and comp($w_i \leftrightarrow b$), and figure 4 the fuzzy set values for the variable socialTrust(a, w_i, b). Table 1 shows the set of fuzzy

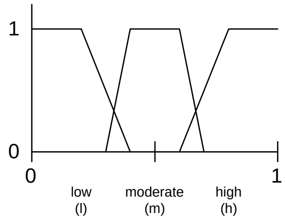

Figure 3: Intensity of a social relation.

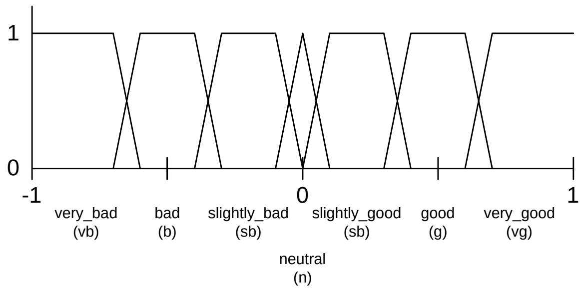

Figure 4: Fuzzy sets for reputation.

rules. The variable no_rel is boolean. Table 1 shows the set of fuzzy rules. Note that a great percentage of the rules tend to be "pessimistic". This is because in those cases where it is not clear that the behaviour is going to be good, it seems preferable. Although for the moment the kind of influence of each social structure is static and based in human common sense, we plan in the near future to improve the system with a mechanism to learn these rules and modify them at run time.

IF	coop($w \leftrightarrow a$) is l	THEN	socialTrust(a, w_i, b) is g
IF	coop($w \leftrightarrow a$) is m	THEN	socialTrust(a, w_i, b) is vg
IF	coop($w \leftrightarrow a$) is h	THEN	socialTrust(a, w_i, b)t is vg
IF	comp($w \leftrightarrow a$) is l	THEN	socialTrust(a, w_i, b) is sb
IF	comp($w \leftrightarrow a$) is m	THEN	socialTrust(a, w_i, b) is b
IF	comp($w \leftrightarrow a$) is h	THEN	socialTrust(a, w_i, b) is vb
IF	coop($w \leftrightarrow b$) is l	THEN	socialTrust(a, w_i, b) is sb
IF	coop($w \leftrightarrow b$) is m	THEN	socialTrust(a, w_i, b) is b
IF	coop($w \leftrightarrow b$) is h	THEN	socialTrust(a, w_i, b) is vb
IF	comp($w \leftrightarrow b$) is l	THEN	socialTrust(a, w_i, b) is sb
IF	comp($w \leftrightarrow b$) is m	THEN	socialTrust(a, w_i, b) is b
IF	comp($w \leftrightarrow b$) is h	THEN	socialTrust(a, w_i, b) is vb
IF	no_rel($w \leftrightarrow b$)	AND THEN	no_rel($w \leftrightarrow a$) socialTrust(a, w_i, b) is g

Table 1: Witness reputation fuzzy rules.

A second way to calculate the degree of trust of an agent is using the *subjective trust reputation* ($R_{a \xrightarrow{I} b}$(trust)). The *subjective trust reputation* is calculated like any other subjective reputation (see section 6). In our running example the *grounding relation* for this reputation type could be:

φ	pattern p
trust	$p = (\_, b, \_, \text{Price}, \_) \vee (\_, b, \_, \text{Quality}, \_) \vee$ $(\_, b, \_, \text{Delivery\_Date}, \_)$

In this example we consider that an agent that respect the price, the quality and the delivery date in a contract is a trusty agent and the other way around.

The trust values calculated using a subjective trust reputation are usually more useful than those based on social relations (socialTrust). This is because a subjective trust reputation is based on the individual and takes into account his particularities while the analyses of social structures rely on global expected behaviours. However, in those situations where there is not enough information to calculate a reliable subjective trust reputation, the analysis of social relations can be a good solution. Usually social relations are easier to obtain than a set of impressions (necessary to calculate a subjective trust reputation) specially if the agent has just arrived to a new scenario. Given that, we define the a's trust degree for an agent w_i when it is giving information about b as:

$$\begin{aligned} trust(a, w_i, b) \quad = \quad & RL_{a \xrightarrow{I} w_i}(trust) \cdot R_{a \xrightarrow{I} w_i}(trust) + \\ & (1 - RL_{a \xrightarrow{I} w_i}(trust)) \cdot socialTrust(a, w_i, b) \end{aligned}$$

This is, the agent uses the trust reputation based on direct interactions if it is reliable, if not, it uses the social trust.

Now we have the necessary tools to calculate the *witness reputation* and its reliability considering that the information coming from the witnesses can be false. The formulae we propose to calculate these values are:

$$R_{a \xrightarrow{W'} b}(\varphi) = \sum_{w_i \in \mathbf{W}} \omega^{w_i b} \cdot R_{w_i \to b}(\varphi)$$

$$RL_{a \xrightarrow{W'} b}(\varphi) = \sum_{w_i \in \mathbf{W}} \omega^{w_i b} \cdot \min(trust(a, w_i, b), RL_{w_i \to b}(\varphi))$$

where $\omega^{w_i b} = \frac{trust(a, w_i, b)}{\sum_{w_j \in \mathbf{W'}} trust(a, w_j, b)}$

These formulae require some explanations. To calculate the *witness reputation* the agent uses the normalized trust of the witness to weight each opinion in the final value. For the reliabilty, we want that in the final reliabilty value, the contribution of each individual reliabilty be in the same proportion that its related reputation. Therefore, the agent uses the same weights in the reliability formula that in the reputation formula. Finally to calculate the reliabilty of an individual reputation, the agent uses the minimum between the trust of the witness that sent the reputation and the reliabilty that the witness himself gives to that reputation. We use this method to model the idea that if the witness is a trusty agent, then we can use his own measure of reliability for the reputation, if not, we cannot rely on his information and we have to calculate our own measure of trustworthiness for that reputation based on our impressions and the social relations of that witness.

7.2 Neighbourhood reputation

The reputations of the individuals that are in the neighbourhood of the target agent and the relation with him are the elements used to calculate what we call the *Neighbourhood Reputation.* The main idea is that the behaviour of these neighbours and the kind of relation they have with the target agent can give some clues about its possible behaviour. The set of neighbours of an agent b is noted as $\mathbf{N}_b = \{n_1, n_2, \cdots, n_n\}$.

To calculate a *Neighbourhood Reputation* we use fuzzy rules. These rules, that are domain dependent, relate the subjective reputation of the target from the neighbour's point of view and some kind of relation between the target and the neighbour. The application of these rules generates a set of *individual neighbourhood reputations* noted as $R_{a \xrightarrow{n_i} b}(\varphi)$. For instance, using again our running example, one rule could be:

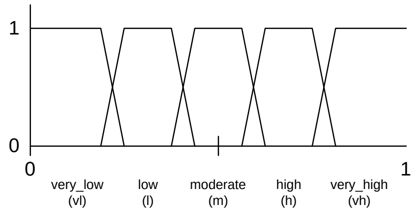

Figure 5: Fuzzy sets for reliability.

IF $R_{a \to n_i}$(swindler) is X AND coop($b \leftrightarrow n_i$) $\neq \perp$
THEN $R_{a \xrightarrow{n_i} b}(swindler)$ is X
IF $RL_{a \to n_i}$(swindler) is X' AND coop($b \leftrightarrow n_i$) is Y'
THEN $RL_{a \xrightarrow{n_i} b}(swindler)$ is T(X', Y')

In other words, we are saying that if the neighbour of the target agent is a swindler and there is a relation of cooperation between the target and this neighbour, then the target is also a swindler. The fuzzy sets for the reliability were shown in figure 5.

Finally table 2 shows a possible set of values for function T in the reliability rule.

X'\ Y'	l	m	h
vl	vl	vl	vl
l	vl	vl	l
m	vl	l	m
h	l	m	h
vh	m	h	vh

Table 2: Function T used in reliability rules.

The general formulae we use to calculate a *neighbourhood reputation* and its reliability are:

$$R_{a \xrightarrow{N} b}(\varphi) = \sum_{n_i \in N_b} \omega^{n_i b} \cdot R_{a \xrightarrow{n_i} b}(\varphi)$$

$$RL_{a \xrightarrow{N} b}(\varphi) = \sum_{n_i \in N_b} \omega^{n_i b} \cdot RL_{a \xrightarrow{n_i} b}(\varphi)$$

where $\omega^{n_i b} = \frac{RL_{a \xrightarrow{n_i} b}(\varphi)}{\sum_{n_j \in N_b} RL_{a \xrightarrow{n_j} b}(\varphi)}$

In this case we are using the reliability of each *individual neighbourhood reputation* to weight the contribution to the final result, both for the reputation and for the reliability.

7.3 System reputation

The idea behind *System reputations* is to use the common knowledge about *institutional structures* and the role that the agent is playing for that *institutional structure* as a mechanism to assign default reputations to the agents. An *institutional structure* is a social structure the members of which have one or several *observable* features that unambiguously identify them as members of that social structure. The fact that there are *observable* features to identify its members is what differentiates an institutional structure from other social structures. Examples of institutional structures in human societies are the police, a company, a club, or a family. We assume that the role that an agent is playing and the institutional structure it belongs to is something "visible" and trustworthy for each agent.

Each time an agent performs an action, we consider that it is playing a single role within the institutional structure. An agent can play the role of buyer and seller but when it is selling a product only the role of seller is relevant. Although we can think up some situations where an agent can play two or more different roles at a time, we consider that there is always a predominant role and the others can be disregarded.

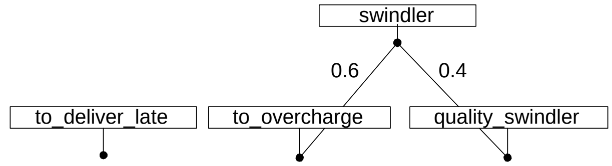

Figure 6: Ontological structure for a seller.

In **Regret** the reputations associated to each role within an institutional structure are domain dependent and part of the initial knowledge of the agent. The value for these reputations can be different depending on which institutional structure the agent belongs to. This models the idea that groups (in our case institutional structures) influence the point of view of their members [10]. Another important point is that an institutional structure does not always associate a reputation value to each aspect present in the leaves of the ontological tree.

System reputations are calculated using a table for each institutional structure where the rows are the possible roles, and the columns the leaves of the *ontological dimension.*

Table 3 shows an example of *system reputations* for agents that belong to company B from the point of view of an agent of company A. As you notice, in this case the opinion of company A towards agents in company B is not very good.

	defaulter	to_overcharge	to_deliver_late	quality_swindler
seller	0.7	-	-	-
buyer	-	0.5	0.9	0.7

Table 3: Example of *system reputations.*

Using a similar table we would define the reliability for these reputations.

System reputations are noted as $R_{a \xrightarrow{S} b}(\varphi)$ and its reliability as $RL_{a \xrightarrow{S} b}(\varphi)$. Hence, for example, using the table defined before, we have that $R_{a \xrightarrow{S} b}(defaulter) = 0.7$ where b is a seller that belongs to company B. Given that this is a default value for reputation used when other information sources are missing the reliability has to be necessarily moderately low.

8. ONTOLOGICAL DIMENSION

Along the individual and social dimensions, reputation is always linked to a single behavioural aspect. With the ontological dimension we add the possibility to combine reputations on different aspects to calculate complex ones. To represent the *ontological* dimension we use graph structures. Figure 6 shows an *ontological dimension* for a seller in the running example. In this case, the reputation of being a swindler is related with the reputation of overcharging prices and the reputation of delivering products with less quality than specified in the contracts. For the owner of this ontological structure, the delivery date is something that is not relevant to be considered a swindler.

Hence, to calculate a given reputation taking into account the *ontological dimension*, an agent has to calculate the reputation of each one of the related aspects that, in turn, can be the node of another subgraph with other aspects associated. The reputation of those nodes that are related with an atomic aspect of the behaviour (in the example: to_deliver_late, to_overcharge and quality_swindler), are calculated using the individual and social dimensions. The reputation of an internal node ψ in an ontological graph is computed as follows (the computation of leaves remains as presented before):

$$R_{a\rightarrow b}(\varphi) = \sum_{\psi \in children(\varphi)} \omega_{\varphi\psi} \cdot R_{a\rightarrow b}(\psi)$$

$$RL_{a\rightarrow b}(\varphi) = \sum_{\psi \in children(\varphi)} \omega_{\varphi\psi} \cdot RL_{a\rightarrow b}(\psi)$$

For instance, using the ontological structure in figure 6 we can calculate the reputation of b as a swindler from a's perspective using the formula:

$$\begin{aligned} R_{a\rightarrow b}(swindler) &= 0.6 \cdot R_{a\rightarrow b}(to\_overcharge) + \\ & \quad 0.4 \cdot R_{a\rightarrow b}(quality\_swindler) + \end{aligned}$$

Note, that the importance ($\omega_{\varphi\psi}$) of each aspect is agent dependent and not necessarily static. The agent can change these values according to his mental state.

9. PUTTING ALL TOGETHER: THE REGRET SYSTEM.

The **Regret** system is an experimentation tool where the reputation of the participating agents is modeled taking into account all the aspects mentioned in this paper. In particular it defines a reputation measure (and its reliability) that takes into account the *individual dimension*, the *social dimension* and the *ontological dimension* as:

$$R_{a\rightarrow b}(\varphi) = \begin{cases} \sum_{i \in \{I,W,N,S\}} \xi_i \cdot R_{a \overset{i}{\rightarrow} b}(\varphi) & \text{if } \varphi \text{ is a leaf} \\ \sum_{\psi \in Children(\varphi)} \omega_{\varphi\psi} \cdot R_{a\rightarrow b}(\psi) & \text{Otherwise} \end{cases}$$

$$RL_{a\rightarrow b}(\varphi) = \begin{cases} \sum_{i \in \{I,W,N,S\}} \xi_i \cdot RL_{a \overset{i}{\rightarrow} b}(\varphi) & \text{if } \varphi \text{ is a leaf} \\ \sum_{\psi \in Children(\varphi)} \omega_{\varphi\psi} \cdot RL_{a\rightarrow b}(\psi) & \text{Otherwise} \end{cases}$$

As we have argued, the most reliable reputation is the *subjective reputation* followed by the *witness* and the *neighbourhood* reputations and finally by the *system reputation.* Therefore, we want that the agent gives more relevance to the *subjective reputation* in detriment of the others. If the *subjective reputation* has a low degree of reliability (for instance because the agent does not have enough information) then he will try to use the *witness* and the *neighbourhood* reputations. Finally, if its knowledge of the social relationships is short, he will try to use the *system reputation.* Given that, to calculate the factors $\{\xi_I, \xi_W, \xi_N, \xi_S\}$ in the general formulae we use:

$$\begin{aligned} \xi_I &= RL_{a \overset{I}{\rightarrow} b}(\varphi) \\ \xi_W &= RL_{a \overset{W}{\rightarrow} b}(\varphi) \cdot (1 - \xi_I)/2 \\ \xi_N &= RL_{a \overset{N}{\rightarrow} b}(\varphi) \cdot (1 - \xi_I)/2 \\ \xi_S &= 1 - (\xi_I + \xi_W + \xi_N) \end{aligned}$$

10. RELATED WORK

The idea of using the opinion of other agents to build a reputation is not new. The work of Michael Schillo, Petra Funk and Michael Rovatsos[14] and the work of Bin Yu and Munindar P. Singh [16] are good examples of this. In both cases they use a trust-net for weighting the other agents' opinions. Our structure to calculate the witness reputation can be considered also a trust-net. In our case, however, besides the previous experiences with the witnesses we consider also the information of social relations between them.

The model described in [16] merges information that comes from agents that have good reputation. In [14] the same agents that can provide you with information are also competing with you. Although agents are assumed to never lie, they can hide information or bias it to favour their goals. We go one step further and consider that the agents also can lie.

In electronic marketplaces, the reputation that a user has is the result of aggregating all the impressions of the other users that interacted with him/her in the past. Amazon Auctions [1], eBay [2] and OnSale Exchange [3], for instance, are online auction houses where users buy and sell goods. Each time a new transaction is finished, the buyer rates the seller. These ratings are used to build the reputation of a seller. Sporas [17] is an evolved version of this kind of reputation models. Sporas introduces the notion of reliability of the reputation and is more robust to changes in the behaviour of a user than reputation systems like Amazon Auctions, based on the average of all the ratings given to the user. In all these systems each user has a global reputation shared by all the observers instead of having a reputation biased by each observer. Histos [17], also oriented to electronic commerce, is a more personalized reputation system where reputation depends on who makes the query, and how that person rated other users in the online community.

Finally, we would like to stress that unlike **Regret**, all the previous models consider reputation as a single concept instead of a multi-facet concept.

11. CONCLUSIONS AND FUTURE WORK

In this paper we have presented how social network analysis can be used in a reputation system that takes into account the social dimension of reputation. The system also has a hierarchical ontology structure that allows to consider several types of reputation at the same time. The combination of complementary methods that use different aspects of the interaction and social relations, allows the agent to calculate reputation values at different stages of his knowledge of the society.

The use of the social network analysis techniques as part of a reputation system opens a new field for experimentation. Our first objective is to validate the system in an as real as possible e-commerce environment where social relations are an important factor. To be able to exploit all the capabilities of the **Regret** system we need environments more sophisticated than the actual e-markets like Amazon Auctions or eBay. We are working in several tools that allow the specification and implementation of these kind of e-markets.

Once you introduce the social dimension in reputation systems and the agents start to take into account social relations, it becomes more and more important to consider not only which is the reputation of the other agents, but what can an agent do to get and maintain a good reputation. Using the **Regret** system, we want to study reputations from this new perspective.

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