Using Testimonies to Enforce the Behavior of Agents

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Abstract. Governance copes with the heterogeneity, autonomy and diversity of interests among different agents in multi-agent systems (MAS) by establishing norms. Although norms can be used to regulate dialogical and non-dialogical actions, the majority of governance systems only governs the interaction between agents. Some mechanisms that intend to regulate other agent actions concentrate on messages that are public to the governance system and on actions that are visible by it. But in open MAS with heterogeneous and independently designed agents, there will be private messages that can only be perceived by senders and receivers and execution of actions that can only be noticed by the agents that are executing them or by a group of agents that suffers from their consequences. This paper presents a governance mechanism based on testimonies provided by agents that witness facts that are violating norms. The mechanism points out if agents really violated norms.

Keywords: Open multi-agent system, governance, norms and testimonies.

1 Introduction

Open multi-agent systems are societies in which autonomous, heterogeneous and independently designed entities can work towards similar or different ends [13]. In order to cope with the heterogeneity, autonomy and diversity of interests among the different members, governance (or law enforcement) systems have been defined. Governance systems enforce the behavior of agents by establishing a set of norms that describe actions that agents are prohibited, permitted or obligated to do [3] and [18]. Such systems assume that norms can sometimes be violated by agents and that the internal state of the agents is neither observable nor controllable.

Different enforcement systems have been proposed in the literature. The majority, such as [14] and [7], focuses on regulating the interaction between agents. They usually provide governors [7] or law-governed interaction [14] mechanisms that mediate the interaction between agents in order to regulate agent messages and make them comply with the set of norms. Every message that an agent wants to send is analyzed by the mechanism. If the message violates an application norm, the message is not

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sent to the receiver. The main disadvantages of such approaches are (i) they influence the agents' privacy since those mechanisms interfere in every interaction between agents and (ii) they do not govern non-dialogical actions since they only concern about the compliance of messages with the system norm [21]. Non-dialogical actions are related to tasks executed by agents that characterize, for instance, the access to resources, their commitment to play roles or their movement in environments and organizations.

Other approaches provide support for the enforcement of norms that regulate not only the interactions between agents but also the access to resources [4] and the execution of agent's actions [21]. TuCSoN [4] provides a coordination mechanism to manage the interaction between agents and also an access control mechanism to handle communication events, in other words, to control the access to resources. In TuCSoN agents interact through a multiplicity of independent coordination media, called tuple centres. The access control mechanism controls agent access to resources by making the tuple centres visible or invisible to them. Although in TuCSoN norms can be described to govern the access to resources, the governance is restricted and only applied to resources that are inserted in tuple centre environments.

In [21] the authors claim that the governance system enforces the observable behavior of agents in terms of public messages and visible actions. They introduce a classification of norms and, according to such classification, they provide some implementation guidelines to enforce them. The main drawback of this approach is that it does not provide support for the enforcement of messages and actions that are not directly accessed by the governance system. Such an approach assumes that the governance system can enforce every norm since it can access all messages and actions regulated by a norm. But in open MAS with heterogeneous and independently designed agents, there will be private messages that can only be perceived by senders and receivers and execution of actions that can only be noticed by the agents that are executing them or by a group of agents that suffers from their consequences [1].

In this paper we propose a governance mechanism based on testimonies provided by witnesses about facts or events that they know are related to norm violations. Agents are inserted in an environment where they can perceive the changes occurred in it. Since agents can observe these changes, they can provide testimonies about actions or messages that are in violation of a norm. Note that the agents do not keep monitoring the behavior of other agents in order to provide testimonies about their violations. The agents testify if they perceive a fact or event that is violating a norm.

In our approach, private messages and also private actions can be enforced. *Private messages* that violate norms can be testified by agents that are involved in the interactions. Such agents can testify about messages they should have received or about messages they should have not received. *Private actions* that are executed in the *scope of a group* and are violating norms can be testified by any member of the group that knows such norms and has seen the actions being executed or has perceived facts or events that reflect the execution of such actions. The same can be said about actions that should have been executed but were not. Related facts or events cannot be observed and, therefore, agents can testify stating that the actions (probably) were not executed. In addition, *private actions* that are executed in the *scope of one single agent* and that are violating norms can be testified by any agent that knows the norms and that perceives facts or events that are related to the execution of such actions. The

same can be said about actions that an agent should have executed but has not. Other agents that know the norms that regulate such actions can testify if they cannot observe the related facts or events.

The paper presents in Section 2 an overall view of the testimony-based governance mechanism. Section 3 details the judgment process used by the mechanism while Section 4 describes a case study where we apply our approach. Finally, section 5 concludes and describes some advantages and drawbacks of our proposal.

2 The Testimony-Based Governance Mechanism

The governance mechanism presented here is based on testimonies that agents provide attesting facts or events that may be norm violations. Since every agent knows sets of norms, it can report to the governance mechanism their violation. In order to interpret the norms, the agent must know the grammar (or ontology) used to describe the norms [17].

2.1 Governance Mechanism Assumptions

The testimony-based governance mechanism is funded in the following assumptions.

Assumption I: *Every agent should know every norm applied to itself.* Such as in the real world where everyone should know a code of behavior, we assume that every agent should know all norms that can be applied to their messages or actions independently of the system environment in which it is executing. When an agent enters in the environment to play a role, the environment/system must be able to provide to the agent all norms applied to this role. This is important because the mechanism assumes that an agent acting in violation of a norm chooses to do so being aware of that. The set of norms that regulates the application should by provided by an ontology.

Assumption II: *Every agent should know every norm that influences its behavior and should be able to observe violations of such norms.* Agents should know the norms that regulate the behavior of other agents when the violations of such norms influence their own execution. Therefore, when entering in an environment, agents should not only observe the norms applied to the roles they will play, but also the norms that, when violated by other agents, influence their execution. The possible violation of such norms motivates the agents to be aware of them.

Assumption III: *Every agent can give testimonies about norm violations.* Since an agent knows norms that are applied to other agents, the agent should be able to state that one of these norms is being violated. Every time an agent perceives the violation of a norm, it must be able to give a testimony to the governance mechanism. The proposed mechanism provides a component that can be used by agents to help them analyzing their beliefs in order to find out well-known facts or events that may be norms violations.

Assumption IV: *Some violations might be ignored / not observed.* The proposed mechanism does not impose that an agent must give its testimony whenever it notices a norm violation. Agents should be well motivated in order to provide their

testimonies. Besides, the mechanism does not guarantee that all violations will be observed by at least one agent. It may be the case that a violation occurs and no agent testifies about it.

Assumption V: *Agents can give false testimony.* In an open system, agents are independently implemented, i.e. the development is done without a centralized control and the governance mechanism cannot assume that an agent was properly designed. Therefore, there is no way to guarantee that all testimonies are related to actual violations. So, the governance mechanism should be able to check and assert the truthfulness of the testimonies.

Assumption VI: *The mechanism can have a law-enforcement agent force.* The mechanism can introduce agents which have the sole purpose of giving testimonies. The testimonies of those agents provided by the mechanism can always be considered to be truthful and the judgment subsystem can directly state that a norm was violated and a penalty should be assigned. Note that those agents must only testify if they are sure about the culpability of the application agents and that they can only testify about violations related to public messages and actions. They must be aware that an agent may violate a norm due some major force or to another agent fault, for instance.

2.2 The Governance Mechanism Architecture

In order to decentralize the governance of large-scale multi-agent systems, we propose to use a hierarchy of organizations where agents are executing according to their roles. Each system organization should state its own norms and implement the proposed governance system to regulate them. The mechanism's architecture proposes three subsystems. The judgment subsystem is responsible for receiving the testimonies and for providing a decision (or verdict) pointing out to the reputation and sanction subsystems if an agent has really violated a norm. The system may use different strategies to judge the violation of the different norms specified by the application. Such strategies might use the agents' reputation afforded by the reputation system to help providing the decision. It is well established that trust and reputation are important in open systems and can be used by the agents for reasoning about the reliability of other ones [16]. In [16] trust is defined as subjective probability with which agents assess that other agents will perform a particular action. We adapt this definition to our approach stating that reputation is defined as a subjective probability with which agents assess that other agent will provide trustful testimonies. The reputation subsystem [8] evaluates the reputation of agents according to the decisions provided by the judgment subsystem about violated norms and false testimonies. Finally, the third subsystem, the sanction subsystem, applies the sanctions specified in norms to the witness agents or to the defendant agents, according to the judgment decision.

3 The Judgment Sub-system

The judgment sub-system has three main responsibilities: to receive testimonies, to judge them and to provide the decision about the violation. Three different agent types were defined to deal with these responsibilities: inspector, judge and broker

agents. The inspector agents are responsible for receiving the testimonies and sending them to judge agents. The judge agents examine the testimonies and provide decisions that are sent to broker agents. Broker agents are responsible for interacting with the reputation and sanction sub-systems to make the decisions effective. While judging the testimonies, judge agents may interact with brokers to get information about the reputation of agents.

3.1 The Judgment Process

The judgment process is composed of eight steps where six are application independent ones. Although judgment strategies cannot be completely independent of the application norms, it is possible to define some common steps to be followed by any judgment strategy. In this section we present the eight steps that compose the judgment process.

Step I: *To check if the testimony has already been judged.* Agents may send testimonies about facts that have already been testified and judged. Because of that, the first step of the judgment process checks if the testimony is related to one of the judgment processes that had occurred before and had considered the defendant guilty. If so, the testimony is discarded and the judgment process is canceled.

Step II: *To verify who the witness is.* According to assumption VI, the testimony provided by some specific agents must be considered always truth. Therefore, the second step of the judgment process verifies who the witness is. If it is the case of an always truthful witness, the judgment process is finished and the verdict stating that the agent must be penalized is provided.

Step III: *To check if the norm applies to the defendant agent.* According to assumption V, agents can lie and end up accusing other agents of violating norms that are not applied to them. In order to find out if a testimony is true, this step checks if the norm applies to the defendant agent. If the norm does not apply, the judgment process is finished and the verdict states that the defendant agent is absolved.

Step IV: *To ask the defendant agent if it is guilty.* If the norm applies to the agent, the next step is to ask it if it has violated the norm it is accused of. As it happens in the real world, if the agent confesses, the judgment process is finished and the verdict states that the defendant agent is condemned. Otherwise, the judgment process continues. In cases where the defendant confesses the violation, the applied punishment can be smaller than the one that would be applied if he hasn't confessed.

Step V: *To judge the testimony according to the norm (application dependent step).* If the agent did not confess, it is necessary to carefully examine if the agent really violated the norm. In order to determine if the testimony is truth and, therefore, if the defendant agent is guilty, it may be necessary to use different strategies for different violated norms. For instance, on one hand, if the norm regulates the payment of an item and the defendant is being accused of having not paid the witness, one possible strategy is to ask the defendant if it has the receipt signed by the witness asserting that it has received the payment. On the other hand, if the norm states that an agent should have not updated a resource, the judgment system could use the simple strategy that checks the resource log, in case it is provided. It is clear that such strategies are

application dependent ones since they depend on the norm that is being enforced. It is also possible to ask the defendant agent why it has not violated the norm. If the agent says that it was not able to do so, the judgment agent will need to investigate if such information is true. In this case, the agent should not be accused of violating the norm.

Step VI: *To ask other agents about their depositions (application dependent step).* If the application strategy could not decide if the defendant agent is guilty or not, the judgment system can still try another approach. Since there may be other agents that can also testify about the violation of the norm or facts related to it, the judgment system can explicitly ask them about their opinion about the violation. This step is an application dependent step because depending on the kind of question the judgment system makes to the agents, it may be necessary to interpret the answer according to the application norm being checked. For instance, two different kinds of questions can be asked to those agents: (i) Have you seen agent a_i violating norm n_j? (ii) What do you know about fact f_k? There are different interpretations for each of the questions and such interpretations are application dependent.

Step VII: *To come up with a consensus considering the depositions.* After interpreting the depositions, the judgment system must put them together to come up with a verdict. In order to do so, our approach uses the agent reputations to help evaluating the depositions. The consensus between the depositions is provided by using subjective logic [12], as detailed in Section 3.3. Such an approach evaluates the depositions considering the reputations of the agents to come up with the probability of the defendant agent being guilty of violating the norm.

Step VIII: *To provide the decision.* The judgment system can provide three decisions. It can state that (i) the defendant agent is probably guilty, (ii) the defendant is probably not guilty (the witness has lied), or (iii) the culpability of the defendant is undefined. In this case, the judge could not decide if the agent is guilty or not.

After producing the decision, it is necessary to send it to the reputation sub-system so that it can modify the reputation of the accused agent, in case the judgment system has decided that the defendant agent is guilty, or the reputation of the witness, in case the judgment system has decided that it has lied. It is also important to inform the decision to the sanction sub-system to (i) punish the agent for violating a norm and to award the witness for providing the testimony or (ii) to punish the witness for providing an untruthful testimony.

3.2 Evaluating the Testimonies and Depositions

When there are not enough evidences to be used by the judge agent to come up with a decision, it can still make use of agents' depositions to finally provide a verdict, as described in Step VI and VII. However, as stated before in assumption V, agents can give false testimonies and also false depositions. Therefore, there is a need for an approach that evaluates such testimonies and depositions considering the reliability of the agents, i.e., considering their reputations. We propose the use of subjective logic to provide a verdict stating the probability of an agent being guilty or not for violating a norm. Such an approach is used in the application independent Step VII to ponder the testimonies/depositions according to the agents' reputations and to make a consensus between them.

In [5] the authors sketched a model for e-marketplaces based on subjective logic for setting contracts back on course whenever their fulfillment deviate from what were established. Evidences from various sources are weighed in order to inform the actions that are probably violating the contracts. Subjective logic is used to support reasoning over those evidences, which involve levels of trust over parties, combining recommendations and forming consensus.

In [2], to evaluate the trustworthiness of a given party, especially prior to any frequent direct interaction, agents may rely on other agents (witnesses) who have interacted with the party of interest. The testimonies given by those witnesses are based on direct interactions and may hold a degree of uncertainty. To combine the testimonies and create a single opinion (reputation) about an agent, the authors used the Dempster-Shafer theory of evidence as the underlying computational framework.

3.2.1 Introducing Subjective Logic

Subjective Logic was proposed by Audun Jøsang based on the Dempster-Shafer theory of evidence [12]. This approach addresses the problem of forming a measurable belief about the truth or falsity on an atomic proposition, in the presence of uncertainty. It translates our imperfect knowledge about reality into degrees of belief or disbelief as well as uncertainty which fills the void in the absence of both belief and disbelief [12]. This approach is described as a logic which operates on subjective beliefs and uses the term *opinion* to denote the representation of a subjective belief. The elements that compose the frame of discernment which is a set of all possible situations are described as follows:

(i) The agent's opinion is represented by a triple $w(x) = <b(x), d(x), u(x)>$;
(ii) b(x) measures belief, represented as a subjective probability of proposition x to be true;
(iii) d(x) measures disbelief, represented as a subjective probability of proposition x to be false;
(iv) u(x) measures uncertainty, represented as a subjective probability that a proposition x to be either true or false;
(v) $b(x), d(x), u(x) \in [0..1]$ and $b(x) + d(x) + u(x) = 1$;
(vi) $w^A(x)$ represents the opinion that an agent A has about the proposition x to be true or false.

Subjective Logic operates on opinions about binary propositions, i.e. opinions about propositions that are assumed to be either true or false. The operators described above are to be applied over such opinions.

Recommendation (Discounting): The *discounting* operator ⊗ combines agent A's opinion about agent B's advice with agent B's opinion about a proposition x expressed as an advice from agent B to agent A. That means if agent B gives an advice x to agent A, and agent A has an opinion about agent B, the operator ⊗ can be used to form *agent A's opinion about agent B's advice x*:

(i) $w^A(B) = <b^A(b),d^A(b),u^A(b)>$ represents agent A's opinion about agent B;
(ii) $w^B(x)=<b^B(x),d^B(x),u^B(x)>$ represents agent B's opinion about x;
(iii) $w^{A:B}(x)= w^A(B) \otimes w^B(x)$ represents agent A's opinion about agent B's opinion about the preposition x.

(iv) $w^{A:B}(x)=<b^{A:B}(x),d^{A:B}(x),u^{A:B}(x)>$ and is evaluated as follows:
   a. $b^{A:B}(x) = b^{A}(b)\ b^{B}(x)$;
   b. $d^{A:B}(x) = b^{A}(b)\ d^{B}(x)$;
   c. $u^{A:B}(x) = d^{A}(b) + u^{A}(b) + b^{A}(b)\ u^{B}(x)$

Consensus: The *consensus* of two possibly conflicting opinions is an opinion that reflects both opinions in a fair and equal way, i.e. when two observers have beliefs about the truth of x, the consensus operator $\oplus$ produces a consensus beliefs that *combines the two separate beliefs into one*:

(i) $w^{A}(x) = <b^{A}(x),d^{A}(x),u^{A}(x)>$ represents agent A's opinion about x;
(ii) $w^{B}(x) = <b^{B}(x),d^{B}(x),u^{B}(x)>$ represents agent B's opinion about x;
(iii) $k = u^{A}(x) + u^{B}(x) - u^{A}(x)u^{B}(x)$;
(iv) $w^{A,B}(x) = w^{A}(B) \oplus w^{B}(x)$ represents the consensus between agent A's opinion about x and agent B's opinion about x.
(v) $w^{A,B}(x)= <b^{A,B}(x),d^{A,B}(x),u^{A,B}(x)>$ is calculated as follows for $k\neq 0$:
   a. $b^{A,B}(x)=(b^{A}(x)u^{B}(x)+b^{B}(x)u^{A}(x))/k$;
   b. $d^{A,B}(x)=(d^{A}(x)u^{B}(x)+d^{B}(x)u^{A}(x))/k$;
   c. $u^{A,B}(x)=(u^{A}(x)\ u^{B}(x))\ /\ k$

3.2.2 Applying Subjective Logic in Our Approach

Our goal is to come up with a consensus between the different testimonies and depositions about the violation of a norm considering the reliability of the witnesses. In order to do so, it is important to understand what a testimony/deposition is in the context of subjective logic. The testimony or deposition given by agent A attesting something about a proposition x can be seen as the *A's opinion about x, i.e.,* $w^{A}(x)$.

Second, it is necessary to state that the testimonies (or the opinions of the agents about facts) will be evaluated by the judge agent according to its own opinion about the agents, for instance, $w^{J}(a)$ where A is one of the witnesses. Such an opinion is directly influenced by the reputation of the agent.

After evaluating the judge's opinions about the agents that have given their testimonies and depositions, it is necessary to evaluate the judge's opinions about testimonies and depositions given by those agents. In order to do so the *discounting operator* will be used. Finally, after having the judge's opinions about all testimonies and depositions, it is necessary to put them all together to form the judge point of view about the violated norm. The *consensus operator* is therefore used.

Judge's Opinions About the Agents:
The reputation provided by the reputation system reflects how much the judge believes in the agent, i.e. $b^{J}(a)$, and not its whole opinion about such agent, i.e $w^{J}(a)$.

Judge's Opinions About Testimonies and Depositions Given by the Agents:
The judge's opinion about a testimony/deposition given by an agent, i.e $w^{J:A}(x)$, depends on the judge's opinion about the agent, $w^{J}(a)$, and the agent's opinion about fact x that is related to the testimony/deposition, $w^{A}(x)$. In order to evaluate the judge's opinion we use the discounting operator presented in Section 3.2.1 as described in equation (1):

$$w^{J:A}(x) = w^{J}(a) \otimes w^{A}(x) = < b^{J:A}(x),\ d^{J:A}(x),\ u^{J:A}(x)> \quad (1)$$

Judge's Point of View About the Violated Norm:
Given that there may exist more then one agent testifying about the same fact (proposition x), all testimonies and depositions can be combined using the consensus operator to produce the judge's own opinion about the proposition x. The consensus puts together all testimonies and depositions while considering the reputation of the witnesses. For instance, let's suppose that A, B and C are agents that provided their testimonies and depositions, the consensus is formed by using equation (2):

$$w^{J:(A,B,C)}(x) = (w^{J}(a) \otimes w^{A}(x)) \oplus (w^{J}(b) \otimes w^{B}(x)) \oplus (w^{J}(c) \otimes w^{C}(x)) \quad (2)$$

3.2.3 Analyzing the Use of Subjective Logic

When there is not enough evidences about a fact stated in a testimony, the greatest challenge about judging it is to set an opinion (verdict) based on facts observed by agents and based on how trustful those agents are. Trust, in this work, represents a degree of reliability of a statement made by an agent. Subjective Logic was used since it is an approach that deals with binary propositions (i.e. true or false propositions) that carry some degree of uncertainty or ignorance, represented, in this work, by the confidence in an agent.

Judging a testimony requires collecting information from different sources, evaluating how trustful the information is and combining the difference sources in a fair and equal way. Subjective Logic offers two operators that can be used to accomplish these tasks, the Recommendation and Consensus operators. The Recommendation operator evaluates the information based on the confidence on the source of the information. The Consensus operator combines all the collected information to make a single opinion (verdict) about the fact stated in the information.

The main advantage about using Subjective Logic is that it offers a formal representation that allows a decision making based on the combination of many evidences (consensus operator) evaluates how confident these evidences are (recommendation). This work uses the agent's reputation as a mean to evaluate the trustworthiness of an agent's statement, which are used as evidences.

The main disadvantage of this method of judgment is that, since its result is expressed in terms of probability, there may be cases where the defendant is convicted while not being guilty in fact, and cases where the defendant is absolved while being, in fact, guilty. Subjective Logic has been used in many works like confidence analysis [9], authentication [11], legal reasoning [10], e-market places [5] and invasion detection systems [20].

4 A Case Study: Cargo Consolidation and Transportation

In order to validate our approach we present a case study based on the real-life cargo consolidation and transportation domain. Cargo consolidation is the act of grouping together small shipments of goods (often from different shippers) into a larger unique unit that is sent to a single destination point (and often to different consignees). Such practice makes possible to the enterprises that provide transportations to reduce the rate of shipping. Importers and exporters that want to ship small cargos may look for consolidator's enterprises that provide cargo consolidation to ship their goods.

An open multi-agent system approach is entirely adequate for developing applications on this domain because such applications mostly involve interactions between different autonomous partners playing different roles in order to accomplish similar objectives. Such applications are governed by several rules that are used to regulate the behavior of the heterogeneous and independently designed entities that reinforce the open characteristic of the systems. In this paper we will contemplate examples of two different norms that are regulated by the proposed mechanism.

Norm I: *The consolidator agent must not change its shipment schedule once it has been presented.*

Norm II: *The consolidator agent must deliver the cargo at the destination on the date established in the transportation agreement.*

4.1 Norm I

In this section we present the judgment process that judge testimonies stating that norm I was violated. We detail the two application dependent steps (Steps V and VI) and also the application independent Step VII that makes a consensus between the testimonies. Let's suppose that a testimony was provided by one of the application agents (an importer, for instance) stating that the agent consolidator has violated norm I. After checking that the testimony is not about a fact that has already been judged (Step I), that the witness is not a law-enforcement agent (Step II), that norm I really applies to the defendant agent (Step III) and that the defendant did not confess that it has violated the norm (Step IV), it is necessary to judge the testimony according to the particular characteristics of norm I (application dependent Step V).

In order to judge testimonies stating violation of norm I, such testimonies must inform shipment schedule firstly defined by the consolidator agent and the actual shipment schedule. One possible application strategy to judge such testimonies is described below. It supposes that there is a system's resource that stores the shipment schedules. The resource is analyzed with the aim to compare the information provided in the testimony with the stored information. If the schedule provided by the resource is equal to the first schedule available in the testimony, the schedule was not changed and the testimony is discarded. If the schedule provided by the resource is different to the actual schedule provided by the testimony, the testimony is also discarded because the testimony describes a fact that cannot be confirmed. In both cases the witness is providing a false testimony. The judgment process is finished and the defendant is considered 100% innocent (Step VIII).

Nevertheless, if the schedule provided by the resource is equal to the actual schedule provided by the testimony, the judgment process should continues in order to find out if the schedule was really changed. Since the application does not have logs to inform when resources are updated, the alternative to find out if the consolidator agent has really changed the schedule is to ask other agents about their opinions (application dependent Step VI). The information provided by the witness is confronted with the information provided by other agents, in this case, with the opinion of two others importers and two exporters about the violation of norm I.

The decision (Step VII) is established based on the information provided by the testimony, the defendant statement and the importers' and exporters' depositions by using subjective logic. Such testimonies and depositions are analyzed from the point

of view of the judge and, therefore, there is a need for evaluating how much the judge believes in each agent. As stated before, the reputation of the agent (provided by the reputation system) reflects how much the judge believes in the agent; $b^{J}(a) = rep(a)$.

The judge's beliefs are used to evaluate the judge's opinion about the testimonies and depositions provided by the agents. Such opinions ($w^{J:W}(x)$, $w^{J:C}(x)$, $w^{J:I1}(x)$, $w^{J:I2}(x)$, $w^{J:E1}(x)$ and $w^{J:E2}(x)$), evaluated by using equation (2), are depicted in Table 1. We are supposing that the two importers and the two exporters, together with the witness, have stated that the defendant is guilty ($w^{A}(x)$).

The verdict, i.e the judge point of view about the violated norm, can be provided by applying the consensus operator (equation (2)). In this example the verdict (equation (3)) states that the probability of the consolidator agent has violated norm I is 84%.

$$w^{J} = w^{J:W}(x) \oplus w^{J:C}(x) \oplus w^{J:I1}(x) \oplus w^{J:I2}(x) \oplus w^{J:E1}(x) \oplus w^{J:E2}(x) = \mathbf{<0.84}, 0.06, 0.1> \quad (3)$$

Table 1. Judge's opinion about the violation of norm I

	Statement	$\mathbf{w^{A}(x)}$	$\mathbf{b^{J}(a)}$	$\mathbf{w^{J}(a) \otimes w^{A}(x) = w^{J:A}(x)}$
Witness	Guilty	<1,0,0>	0.54	$w^{J:W}(x) = <0.54,0,0.46>$
Consolidator Agent	Innocent	<0,1,0>	0.33	$w^{J:C}(x) = <0,0.33,0.67>$
Importer1	Guilty	<1,0,0>	0.75	$w^{J:I1}(x) = <0.75,0,0.25>$
Importer2	Guilty	<1,0,0>	0.53	$w^{J:I2}(x) = <0.53,0,0.47>$
Exporter1	Guilty	<1,0,0>	0.57	$w^{J:E1}(x) = <0.57,0,0.43>$
Exporter2	Guilty	<1,0,0>	0.66	$w^{J:E2}(x) = <0.64,0,0.34>$

4.2 Norm II

In this section we also focus on the two application dependent steps (Steps V and VI) and on Step VII while illustrating the judgment process of norm II. As in Section 4.1, we assume that the judge system could not provide a verdict before executing Step V.

In order to judge testimonies stating violations of norm II, such testimonies must contain the transportation documents called House Bill of Landing (HBL) and Master Bill of Landing (MBL). A bill of landing is a document issued by the carrier (the consolidator agent, in this case) that describes the goods, the details of the intended transportation, and the conditions of the transportation. The difference between HBL and MBL is that the MBL describes several small cargos consolidated in a single shipment and the HBL describes each small cargo.

Therefore, in step V, the judge must first ensure that the exporter has really delivered the cargo at the place designated by the consolidator on the appropriated date. When this task is accomplished, the consolidator gives a copy of the HBL (related to the cargo delivered by the exporter) to the exporter. The judge can, therefore, ask the exporter about his copy of the HBL. If the exporter does not have this document, the judgment process is finished, the witness' testimony is considered false and the defendant is considered 100% innocent (Step VIII). The consolidator agent has not delivered the cargo because the exporter has not delivered its cargo to the consolidator agent.

On the other hand, if the exporter has its copy of the HBL the judge must execute step VI, continuing the judgment process to come to a verdict. Since, the witness'

cargo has been consolidated with others cargos, the judge may ask all other importers mentioned in the MBL if their cargos have been delivered in the correct date and place. After receiving the importers depositions, the judge needs to execute step VII, where it puts together all statements while considering the reputations of consolidator agent and all importers of the mentioned shipment. We are supposing that there were three cargos consolidated in this shipment. Table 2 depicts the judge's opinion about the testimony and depositions provided by the witness, the consolidator agent and the two importers ($w^{J:C}(x)$, $w^{J:I1}(x)$, $w^{J:I2}(x)$ and $w^{J:I3}(x)$).

The verdict, i.e judge point of view about the violated norm, can be provided by applying the consensus operator, as shown in equation (4). In this example the verdict states that the probability of the consolidator agent has violated norm II is 76%.

$$w^{J} = w^{J:W}(x) \oplus w^{J:C}(x) \oplus w^{J:I1}(x) \oplus w^{J:I2}(x) = \mathbf{<0.76}, 0.18, 0.06> \quad (4)$$

Table 2. Judge's opinion about the violation of norm II

	Statement	$\mathbf{w^{A}(x)}$	$\mathbf{b^{J}(a)}$	$\mathbf{w^{J}(a) \otimes w^{A}(x) = w^{J:A}(x)}$
Witness	Innocent	<0,1,0>	0.75	$w^{J:W}(x) = <0,0.75,0.25>$
Consolidator Agent	Guilty	<1,0,0>	0.23	$w^{J:C}(x) = <0.23,0,0.77>$
Importer1	Guilty	<1,0,0>	0.47	$w^{J:I1}(x) = <0.47,0,0.53>$
Importer2	Guilty	<1,0,0>	0.92	$w^{J:I2}(x) = <0.92,0,0.08>$

The approaches that governs only the interactions between agents, such as [14] [7], could not govern norm I since this norm govern the access to a resource. As stated in Section 1, there are approaches that govern the public messages and visible actions, both in the system point of view. Such approaches could only be used to enforce norm I and II if we consider (i) that the shipment schedules of a consolidator agent are public resources and, therefore, every action done in such resource are visible actions and (ii) that the deliveries done by the consolidator agent are public messages, that is not usually the case. Moreover, note that both strategies presented in sections 4.1 and 4.2 are simple examples that can be used to judge the testimonies related to norms I and II. Other more complex and completely different strategies could have been implemented to judge the same testimonies.

5 Conclusion

In this paper we present a governance mechanism based on testimonies given by agents that have perceived norm violations. Since a violation of a norm influences (injures) the execution of an agent, perceiving it will be a natural consequence of the regular execution of that agent. The mechanism judges the testimonies it receives trying to differentiate true and false testimonies in order to provide a verdict. The governance mechanism was implemented as a framework that supports, by now, the judgment and reputation sub-systems (section 2.2). The main advantages of the proposed mechanism are: (i) it does not interfere in the agents' privacy; (ii) it can be used to enforce norms associated not only with interactions but also with the execution of

different actions, such as the access to resources; and (iii) it does not assume that the system can do all the work of finding out the violations and enforcing the norms.

Whereas we believe that the advantages of our proposed mechanism are really important, it has some potential weaknesses. First, it may be difficult to distinguish if a testimony is true or false and, therefore, to provide a good verdict. We proposed to solve this problem by using probability based on subjective logic while providing the verdicts. Second, violations that go without testimonies will not be punished. This could lead to an undesired system state. One way to overcome this issue is motivating the agents to give their testimonies by using an agent rewards program, for instance. Another important drawback is that the effort to implement an agent under the proposed governance system may increase since it needs not only to perceive facts, but also to associate them with possible norm violations. To minimize this impact, the judgment subsystem provides a mechanism that can be used by the agents to associate facts with norms violations. In order to improve our work we are in the way of adding some argumentation aspects to the judgment process. This will improve the set of evidences used for and against a verdict.

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