

# Policy Management for Virtual Communities of Agents

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**Abstract**— In this paper we study the rational balance between local and global policies in virtual communities of agents. To study this problem we use a logical framework for modelling obligations and permissions in multiagent systems. In particular, the logical framework allows agents to trade off the decision of respecting a norm against the consequences of not respecting it: the possibility that they are considered violators and thus sanctioned. To formalize decision making we use a qualitative game theory. *n*-player games are based on recursive modelling: the bearer of a norm models the behavior of local normative authorities as agents who are in turn subject to other norms and thus model global normative agents.

## I. INTRODUCTION

Highly distributed web based environments, such as the pervasive computing architectures based on the grid [1] or peer to peer systems, are composed by disparate resource providers. In such systems, it is not possible and not even useful to have a centralized management of the resources. First of all, such centralized administration could be a too heavy burden and it can affect the core business activities of the system. Second, decentralized authorities can cope in a better way with local idiosyncratic situations: “each party of the network can decide in each circumstance whether to accept credential presented by a second party” [2]. Third, as Cole *et al.* [3] suggest, it is possible that global policies become more easily obsolete: “we observe that in real life, many policies are routinely ignored because of the perception that changing circumstances have made them redundant.” Fourth, the participants of the distributed system prefer not to give up their own power to enforce local policies for the access to the resources they control.

However, for a set of agents to be a *virtual community*, local access policies should be organized according to some global policies which define how the resources should be shared among the participants. This requirement must be traded off with the need of leaving autonomy (in the literal sense of the term: “one’s making its own norms”) to the participants.

So the problem is the rational balance of global vs local control in virtual communities. According to Pearlman *et al.* [4], “a key problem associated with the formation and operation of distributed virtual communities is that of how to specify and enforce community policies.” As [4] argue “the exercise of rights is effective only if the resource provider

has granted those rights to the community”. Since there is no plausible way to enforce the respect of global policies by constraining the architecture, it is necessary to have a *normative control mechanism* able to specify global policies about local policies.

In fact, local resource providers (such as a web server) cannot be coerced to provide their services or to deny them to users: rather they can be only motivated by rewards and sanctions (e.g., the sanction can be the exclusion from the community). So it is necessary that the local authorities are provided with incentives to implement the global policies by means of local ones. The normative system must be able to *motivate* the respect of norms at each of its levels: not only users must be provided with an incentive to respect the norms but also the local providers must be motivated to issue policies which respect the global ones.

Motivational aspects of norms have been analyzed by Boella and Lesmo [5] in the context of multiagent systems composed of heterogeneous agents: norms are useless unless they are supported by sanctions. And sanctions must be modelled as actions of the normative system, since it is not possible to presuppose that they are mere consequences of violations. Hence, Boella and Lesmo [5] attribute to the normative system the status of an agent who decides if the behavior of agents counts as a violation, and thus deserves to be sanctioned.

Inspired on [5], Boella and van der Torre [6,7] propose a logical framework for reasoning about obligations and norms based on the attribution of mental attitudes to normative system. We use this framework in [8], [9] to study the problem of modelling local and global policies for virtual communities of BDI (belief, desire and intention) agents. Proceeding in this direction, in this paper we address the following research questions: how it is possible to define global policies about local policies? How it is possible to provide local authorities with the necessary autonomy?

This paper is organized as follows. In Section II we discuss the three dimensions of the logical framework. In Section III we discuss the problem raised by decentralized control. In Section IV we present the qualitative game theory, and the definition of norms. In Section V we apply the framework to some examples.

## II. A THREE DIMENSIONAL FRAMEWORK

In this section we discuss the three dimensions of our logical framework: normative agents, mental attitudes, and the violation / sanction distinction.

The first dimension is the set of agents that are distinguished. Normative systems are “sets of agents (human or artificial) whose interactions can fruitfully be regarded as norm-governed” [10]. Normative systems do not contain one authority only but they are composed of a set of authorities.

The second dimension is the set of mental attitudes assigned to the agents. Agents’ behavior is governed by their specific balance between beliefs, desires and intentions. Moreover, norms and obligations seem to be a further ingredient in the control of agents’ behavior. Agents base their decision process on a symbolic representation of their preferences, hence we adopt a qualitative decision theory, such as the one proposed in the BOID architecture [11].

To formalize decision making in a multiagent setting we use a qualitative game theory.  $n$ -player games are based on recursive modelling: the bearer of a norm models the behavior of local normative authorities as agents who are in turn subject to other norms and thus model global normative agents.

The third dimension of our framework are the aspects of norms that are distinguished. For what concerns the possibility of not respecting obligations, we distinguish in [6] between behavior that *counts as* a violation - in the sense of the construction of social reality of Searle [12] - and sanctions.

An agent  $a_1$  is obliged by a norm of agent  $a_2$  to do  $x$  if:

- Agent  $a_2$  wants  $x$  and that  $a_1$  adopts  $x$  as its decision.
- Agent  $a_2$  wants that there is no violation, but if  $\neg x$  then it has the goal that  $\neg x$  counts as a violation.
- Agent  $a_2$  desires not to sanction, but if  $\neg x$  counts as a violation then it has as a goal that it sanctions agent  $a_1$ . This goal of the normative system expresses that it only sanctions in case of violation.
- Agent  $a_1$  has the desire not to be sanctioned.

In our model, the definition of permission makes direct reference to the definition of obligation. In fact, as law scholars [13] suggest the main role of permissions is to provide exceptions to obligations in a given context. For example, a permission to access a resource if authorized make sense only in the context of a general prohibition to access that resources with or without authorization.

Thus our definition of permission is based on a goal of the normative agent not to count a behavior as a violation: an agent  $a_1$  is permitted by a norm issued by agent  $a_2$  not to do  $x$  in a certain context  $c$  if  $a_2$  has the goal that if agent  $a_2$  believes that  $c$  is true  $\neg x$  does not count as a violation.

Note that a permission is not the mere negation of an obligation, like in most deontic logic approaches. Rather, permissions have an explicit content in that they modify the goals of the normative system concerning a corresponding prohibition.

## III. DECENTRALIZED CONTROL

Consider the following scenario: an agent  $a_2$  joined a virtual community  $a_3$ . Its contract for the participation prescribes that it should provide access to its resources to all the members of the community. Another participant agent, say  $a_1$ , tries to access the system. However, previous experiences advice agent  $a_2$  that agent  $a_1$  could damage its resource: should agent  $a_2$  grant agent  $a_1$  access to its resources?

In this scenario the management of the community is organized in (at least) two levels: the global level (agent  $a_3$ ) and the local one (agent  $a_2$ ). Agent  $a_3$  is a distinguished authority (usually called *community authorization service*) playing the role of a global authority which issues global policies and negotiates the conditions for the participation of agents to the virtual community. Agent  $a_2$  is a provider of some resource it is in control to. Moreover all the agents ( $a_3$ ,  $a_2$  and  $a_1$ ) can also play the role of users of the resources of the community. What distinguishes agents  $a_3$  and  $a_2$  is the fact that they are providers: they are in control of some resources.

The control of resources consists not only in the fact that a given service is not provided if the provider does not want to (e.g., the files of a web server cannot be accessed if it does not provide an answer to a request). But also in the fact that an agent may influence negatively the behavior of other agents. In [14]’s terminology, other agents depend on it. In our model this is the essential precondition for the ability to issue policies. E.g., agents depend on the global level for their membership to the system. If they do not stick to its policies they are denied citizenship. At the local level agents depend on the provider for the access to the local resource.

Global policies concern the behavior of participants: for example, participants should not communicate their passwords, or distribute copyrighted files by means of the system. Or else they are banned from the community (since the membership to the system is under the control of the global authority).

At the local level policies forbid, e.g., agents to store files exceeding 1Gb on a file sharing service. Or they permit participants of the community to download copyrighted files from the web server.

As Sloman [15] argue, and as it is shown by our scenario, there are also other kinds of global policies besides these examples. There are policies that apply to other policies: global policies that constrain or permit local policies. In the scenario above agent  $a_3$  obliges agent  $a_2$  to permit members of the community to access its resources. Analogously, the global authority could oblige local ones to forbid access, permit to permit access, or permit to forbid access.

But what do these higher level policies refer to? Which are the conditions for their satisfaction? It is not sufficient that the global obligation to permit or oblige access is satisfied by the fact that the local authority issued a permission or an obligation. In fact, norms are ineffective if they are not enforced by the authority who issued them: violations of norms should be recognized as such and sanctioned.

Hence, global policies should refer not to the fact that a local norm exists but to the fact that it is enforced by the local

authority by recognizing and sanctioning violations. Thus, a global obligation by agent  $a_3$  that agent  $a_2$  obliges agent  $a_1$  to do  $x$  is expressed as an obligation that agent  $a_2$  considers  $\neg x$  as a violation and sanctions it. Since in turn the obligation of  $a_3$  is expressed in terms of goals that something counts as a violation, the global obligation by agent  $a_3$  is defined as the goal that agent  $a_2$  considers  $\neg x$  as a violation and the goal that if  $a_2$  does not do that then its behavior is considered a violation by agent  $a_3$ .

Conversely, a permission by agent  $a_3$  that  $a_2$  obliges that agent  $a_1$  does  $x$  is expressed as a permission by  $a_3$  to consider  $\neg x$  as a violation: agent  $a_3$  has the goal that agent  $a_2$  is not considered a violator by  $a_3$  if it considers  $a_1$  as a violator.

In our model we can define also the notion of *entitlement* introduced by Sadighi Firozabadi and Sergot [16] to denote a stronger notion of permission: an agent  $a_1$  is entitled to access a resource if the provider of the resource  $a_2$  is obliged to permit access by agent  $a_3$ , whatever the local policy it issued. An agent  $a_3$  obliges agent  $a_2$  to permit  $a_1$  to do  $x$  if  $a_3$  obliges agent  $a_2$  not to consider  $\neg x$  as a violation.

The local authority, however, can still violate this global policy and forbid access to users if it prefers to face the sanction with respect to permit access; in the scenario above it is possible that agent  $a_2$  does not grant agent  $a_1$  the resource it is entitled to by the global policy: facing a sanction by the global authority (e.g., being excluded by the community for a certain period of time) is preferred to the possibility that  $a_1$  damages the systems (e.g.,  $a_1$  could create a denial of service).

The argument which supports this reduction of policies about policies to obligations and permissions about considering something as a violation or not is that in our model obligations are defined in terms of goals of the normative agent. How it is possible to say that an obligation is satisfied since we cannot prove that an agent has a certain goal? The only clue we have is its behavior: whether it sanctions or it does not. Moreover, the attribution of goals and beliefs to agents is an instance of the *intentional stance* of Dennett [17]: agents behave as if they are endowed with such motivational attitudes. But nothing prevents that for simplicity reasons the implementation of the agent is not made in terms of explicit goals. So the basis for judging it can only be its behavior.

#### IV. RECURSIVE MODELLING

In this section we present a logical framework for BDI agents based on recursive modelling. This framework is extended to a qualitative game-theory for dealing with  $n$ -player games for modelling normative systems with multiple authorities: each player considers the reaction of the subsequent agent in the hierarchy. We assume that the reaction of the subsequent agent affects only the outcome of the immediately preceding agent. Hence, each agent's behavior is watched by another agent whose behavior can be in control of another one and so on in a recursive way; until the highest level of authority whose behavior is not controlled is reached.

The basic picture is visualized in Figure 1 and reflects the deliberation of agent  $a_1$  in various stages. Agent  $a_1$  is subject to some obligations, and it is deliberating about the effects of the fulfilment or the violation of the norms posed by local policies. Agent  $a_2$  is the local authority which may recognize and sanction violations. Agent  $a_1$  recursively models agent  $a_2$ 's decision (taken from its point of view) and bases its choice on the effects of agent  $a_2$ 's predicted actions. But in doing so,  $a_1$  has to consider also that  $a_2$  is subject to some obligations posed by global policies: so in modelling  $a_2$ , it considers that  $a_2$  recursively models  $a_3$ , the agent who watches over its behavior. In fact, agent  $a_3$  created some global policies concerning the local policies issued by agent  $a_2$ . Hence, agent  $a_2$  knows that agent  $a_3$  has the goal to monitor its behavior and to recognize and sanction agent  $a_2$ 's violations of the global policies.

When agent  $a_1$  makes its decision  $d_1$ , it believes that it is in state  $s_1^0$ . The expected consequences of this decision (due to belief rules  $B_1$ ) are called state  $s_1^1$ . Then agent  $a_2$  makes a decision  $d_2$ , typically whether it counts this decision as a violation and whether it sanctions agent  $a_1$  or not. Now, to find out which decision agent  $a_2$  will make, agent  $a_1$  has a *profile* of agent  $a_2$ : it has a representation of the initial state which agent  $a_2$  believes to be in and of the following stages. When agent  $a_1$  makes its decision, it believes that agent  $a_2$  believes that it is in state  $s_2^0$ . This may be the same situation as state  $s_1^0$ , but it may also be different. Then, agent  $a_1$  believes that its own decision  $d_1$  will have the consequence that agent  $a_2$  believes that it is in state  $s_2^1$ , due to its observations and the expected consequences of these observations according to belief rules  $B_2$ . Agent  $a_1$  expects that agent  $a_2$  believes that the expected result of decision  $d_2$  is state  $s_2^2$ . Finally, agent  $a_1$ 's expected consequences of  $d_2$  from  $a_1$ 's point of view are called state  $s_1^1$ . And  $a_2$  makes a similar reasoning about  $a_3$ 's decisions. Note however, that the recursion in modelling other agents stops here since agent  $a_3$  has no authority watching over its behavior. Hence it has not to base its decisions on the expected reaction of another agent.

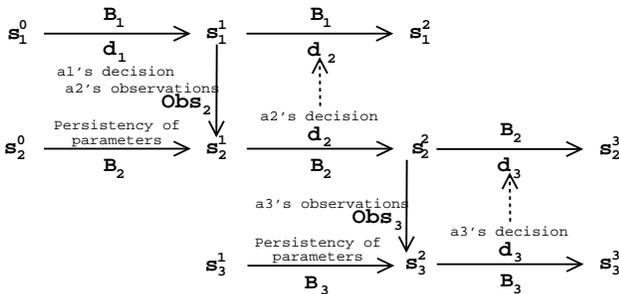


Fig. 1. A three agent scenario.

## A. Agent theory

The variables of the language are either *decision variables* of an agent, whose truth value is directly determined by it, or *parameters*, whose truth value can only be determined indirectly [18].

*Definition 1 (Decisions):* Let  $A = \{a_1, a_2, \dots, a_n\}$  be a set of  $n$  distinct agents.  $A_i = \{m, m', m'', \dots\}$  (the decision variables) for  $a_i \in A$  and  $P = \{p, p', p'', \dots\}$  (the parameters) are  $n + 1$  disjoint sets of propositional variables. A literal is a variable or its negation. For a propositional variable  $p$  we write  $\bar{p} = \neg p$  and  $\overline{\bar{p}} = p$ .

A decision set is a tuple  $\delta = \langle d_1, \dots, d_n \rangle$  where  $d_i$  is a set of literals of  $A_i$  (the decision of agent  $a_i$ ) for  $1 \leq i \leq n$ . Decisions are complete, in the sense that for each decision variable  $x$  in  $A_i$ , agent  $a_i$  takes a decision about it: either  $x \in d_i$  or  $\neg x \in d_i$ .

The consequences of decisions are given by the agents' epistemic states, where we distinguish between the agents' beliefs about the world and the agents' beliefs about how a new state is constructed out of previous ones. The example in Figure 1 illustrates that we only consider games in which each agent  $a_i$  makes a decision at moment  $i$ . Second, the agents' beliefs about how a new state at moment  $t$  is constructed out of previous ones is expressed by a set of *belief rules*, denoted by  $B_i$ . Belief rules can conflict and agents can deal with such conflicts in different ways. The epistemic state therefore also contains an ordering on belief rules, denoted by  $\geq_i^B$ , to resolve such conflicts. Finally, to model the recursion the epistemic state of agent  $a_i$ , denoted by  $\sigma_i$ , includes the epistemic state of agent  $a_{i+1}$ ,  $\sigma_{i+1}$ , unless it is the last agent  $a_n$ .

In order to distinguish the value of the propositional variables in the sequence of four stages, we use superscript numbers to label the parameters and states.

*Definition 2 (Epistemic states):* Let  $P^0, P^1, \dots, P^{n+1}$  be the sets of propositional variables defined by  $P^t = \{p^t \mid p \in P \text{ and } 0 \leq t \leq n + 1\}$ . We write  $L_{A_i}, L_{A_i P^t}, \dots$  for the propositional languages built up from  $A_i, A_i \cup P^t, \dots$  with the usual truth-functional connectives. We assume that the propositional language contains a symbol  $\top$  for a tautology.

Let a rule built from a set of literals be an ordered sequence of literals  $l_1, \dots, l_r, l$  written as  $l_1 \wedge \dots \wedge l_r \rightarrow l$  where  $r \geq 0$ . If  $r = 0$ , then we also write  $\top \rightarrow l$ .

The epistemic state of agent  $a_i$ ,  $i < n$  is:

$$\sigma_i = \langle B_i, \geq_i^B, s_i^{i-2}, s_i^{i-1}, s_i^i, s_i^{i+1}, \sigma_{i+1} \rangle$$

whereas the epistemic state of agent  $a_n$  is identical except that it does not contain the epistemic state of agent  $a_{n+1}$ .  $B_i$  is a set of rules of  $L_{A_{i-1}A_iA_{i+1}P^{i-2}P^{i-1}P^iP^{i+1}}$ ;  $\geq_i^B$  is a transitive and reflexive relation on the powerset of  $B_i$  containing at least the subset relation.

$s_i^{i-2}$  is a set of literals of  $L_{P^{i-2}}$  (the state before agent  $a_{i-1}$ 's decision).

$s_i^{i-1} \subseteq L_{A_{i-1}P^{i-1}}$  (the initial state of agent  $a_i$ 's decision),

$s_i^i \subseteq L_{A_iP^i}$  (the state after the decision  $d_i$  of agent  $a_i$ ),

and  $s_i^{i+1} \subseteq L_{A_{i+1}P^{i+1}}$  (the state after the decision  $d_{i+1}$  of

agent  $a_{i+1}$ ).

Moreover, let  $s_i = s_i^{i-2} \cup s_i^{i-1} \cup s_i^i \cup s_i^{i+1}$ . All states are assumed to be complete.

The agents' epistemic states depend on what it can observe. Here we accept a simple formalization of this complex phenomena, based on an explicit enumeration of all propositions which can be observed.

*Definition 3 (Observations):* The propositions observable by agent  $a_i$ ,  $OP_i$ , are a subset of the stage  $s_{i-1}^{i-1}$  (according to agent  $a_{i-1}$ 's point of view) including agent  $a_{i-1}$ 's decision:  $P^{i-1} \cup A_{i-1}$ . The expected observations of agent  $a_i$  in state  $s_i^{i-1}$  are  $Obs_i = \{l^{i-1} \in s_{i-1}^{i-1} \mid l \in OP_i \text{ or } \bar{l} \in OP_i\}$ : if a proposition describing state  $s_{i-1}^{i-1}$  is observable, then agent  $a_i$  knows its value in  $s_{i-1}^{i-1}$ . By convention  $OP_1 = \emptyset$  and  $s_0^0 = \emptyset$ .

The observations of agent  $a_i$  depend on the state  $s_{i-1}^{i-1}$  containing the effects of the decision of agent  $a_{i-1}$  from  $a_{i-1}$ 's point of view. What is not observed persists from the initial state  $s_i^{i-2}$  from  $a_i$ 's perspective.

When an epistemic state represents the expected consequence of belief rules we say that it respects the decision and the observations:

*Definition 4 (Respect):* A set of literals is called *inconsistent* if it contains  $p$  and  $\neg p$  for some propositional variable  $p$ ; otherwise it is called *consistent*. For  $s$  a set of literals (state),  $f$  a set of literals,  $R$  a set of rules, and  $\geq$  a transitive and reflexive relation on the powerset of  $R$  containing at least the superset relation, let  $out(s, R) = \bigcup_0^\infty out^i(s, R)$  be the state obtained by  $out^0(s, R) = s$  and  $out^{i+1}(s, R) = out^i(s, R) \cup \{l \mid l_1 \wedge \dots \wedge l_n \rightarrow l \in R \text{ and } \{l_1, \dots, l_n\} \subseteq out^i(s, R)\}$ , and let  $\max(s, f, R, \geq, t)$  be the set of states obtained by:

- 1)  $Q$  is the set of subsets of  $R$  which can be applied to  $s \cup f$  without leading to inconsistency:  
 $Q = \{R' \subseteq R \mid out(s \cup f, R') \text{ consistent}\}$
- 2)  $Q'$  is the set of maximal elements of  $Q$  with respect to set inclusion:  
 $Q' = \{R' \in Q \mid \nexists R'' \in Q \text{ such that } R' \subset R''\}$
- 3)  $Q''$  is the set of maximal elements of  $Q'$  with respect to the  $\geq$  ordering:  
 $Q'' = \{R' \in Q' \mid \nexists R'' \in Q' \text{ and } R'' \geq R', R' \not\geq R''\}$
- 4)  $O$  is the set of new elements in  $out(s \cup f, R')$ :  
 $O = \{(out(s \cup f, R') \cap L_{A_{t+1}P^{t+1}}) \mid R' \in Q''\}$
- 5)  $\max(s, f, R, \geq, t)$  is the set of states in  $O$  plus some elements persisting from  $s$ :  
 $\max(s, f, R, \geq, t) = \{G \cup s''' \mid G \in O \text{ and } s''' = \{l^{t+1} \mid l^t \in (P^t \cap s) \text{ and } \bar{l}^{t+1} \notin G\}\}$

A state description  $\sigma_i = \langle B_i, \geq_i^B, s_i^{i-2}, s_i^{i-1}, s_i^i, s_i^{i+1}, \sigma_{i+1} \rangle$  respects the decision set  $\delta = \langle d_1, \dots, d_n \rangle$ , the expected observations  $Obs_i$  of agent  $a_i$  if  
 $s_i^{i-1} \in \max(s_i^{i-2}, Obs_i, B_i, \geq_i^B, i - 2)$ ,  
 $s_i^i \in \max(s_i^{i-2} \cup s_i^{i-1}, d_i, B_i, \geq_i^B, i - 1)$ ,  
 $s_i^{i+1} \in \max(s_i^{i-2} \cup s_i^{i-1} \cup s_i^i, d_{i+1}, B_i, \geq_i^B, i)$ ,  
and, if  $i < n$ ,  $\sigma_{i+1}$  respects the decision set  $\delta = \langle d_1, \dots, d_n \rangle$ , the expected observations  $Obs_{i+1}$  of agent  $a_{i+1}$ .

Note that the second state  $s_1^0$  and the last one  $s_n^{n+1}$  are obtained just by persistency from  $s_1^{-1}$  and  $s_n^n$ , respectively, since for the first agent there are no observations and the last one does not recursively model the decision of any other agent and  $B^0 = B^{n+1} = \emptyset$ .

The following example illustrates how clause 5 models the persistence of parameters that are not affected by any rules.

*Example 1:* Let  $s_1^0 = \{p^0, q^0\}$ ,  $d_1 = \{a\}$ ,  $B_1 = \{a \wedge p^0 \rightarrow \neg q^1\}$ . We have  $Q = \{\emptyset, \{a \wedge p^0 \rightarrow \neg q^1\}\}$ ,  $Q' = Q'' = \{\{a \wedge p^0 \rightarrow \neg q^1\}\}$ ,  $out(s_1^0 \cup d_1, B_1) = \{p^0, q^0, a, \neg q^1\}$ ,  $O = \{\{-q^1, a\}\}$  and, finally,  $\max(s_1^0, d_1, B_1, \geq_1^B, 0) = \{\{p^1, \neg q^1, a\}\}$ . Proposition  $p^0$  persists, since it belongs to  $s_1^0$  and  $\neg p^1$  does not belong to the elements of  $O$ .

The following example illustrates a similar situation with observations. The  $f$  component in the max operation plays the role of a constraint ([19]), in the sense that the second stage from agent  $a_2$ 's point of view respects the belief rules when it is generated from the initial state  $s_2^0$  and these belief rules, but it must be consistent with which propositions of  $s_1^1$  are observed by agent  $a_2$  ( $Obs_2$ ).

*Example 2:* If agent  $a_2$  is in state  $s_2^0 = \{p^0, q^0\}$  and there are no agent  $a_2$ 's belief rules ( $B_2 = \emptyset$ ), then agent  $a_2$  would expect a state  $s_2^1 = \{p^1, q^1\}$  given by the persistency of parameters. However, if the state  $s_1^1$  is  $\{\neg p^1, \neg q^1\}$  and  $a_2$  can observe  $p$ , i.e.,  $OP_2 = \{p\}$ , then  $s_2^1$  would amount to  $\{\neg p^1, q^1\}$ :

$\max(s_2^0 = \{p^0, q^0\}, Obs_2 = \{p\}, B_2 = \emptyset, \geq_1^B, 0) = \{\{\neg p^1, q^1\}\}$

The following example illustrates that for a given state  $s_1^0$ , there can be many states  $s_1^1$  such that the epistemic state respects the belief rules of the mental states. In the example, it is due to conflicts among applicable rules.

*Example 3:* According to agent  $a_1$ ,  $a$  achieves  $q$  unless  $p$  is true in the preceding state:  $a \rightarrow q^1$ , but  $a \wedge p^0 \rightarrow \neg q^1$ . Since the two rules have contrasting consequents they cannot belong to the same maximal set of compatible rules  $Q'$ . But if the second rule precedes the first one in the  $\geq_1^B$  ordering, then it overrides the previous in a context where  $p$  is true:

$\max(s_1^0 = \{p^0, \neg q^0\}, d_1 = \{a\}, B_1 = \{a \rightarrow q^1, a \wedge p^0 \rightarrow \neg q^1\}, \geq_1^B = \{a \wedge p^0 \rightarrow \neg q^1\} > \{a \rightarrow q^1\}, 0) = \{\{a, p^1, \neg q^1\}\}$

in fact,  $Q = \{\emptyset, \{a \rightarrow q^1\}, \{a \wedge p^0 \rightarrow \neg q^1\}\}$ ,  $Q' = \{\{a \rightarrow q^1\}, \{a \wedge p^0 \rightarrow \neg q^1\}\}$ ,  $Q'' = \{\{a \wedge p^0 \rightarrow \neg q^1\}\}$ ,  $out(s_1^0 \cup d_1, B_1) = \{p^0, \neg q^0, a, \neg q^1\}$  and  $O = \{\{-q^1, a\}\}$ .

The agent's motivational state contains two sets of rules for each agent. *Desire* ( $D_i$ ) and *goal* ( $G_i$ ) rules express the attitudes of the agent  $a_i$  towards a given state, depending on the context.

How the agents reason about obligations, and in particular how they deliberate whether they fulfill or violate them, depends not only on their interpretation of the obligations in terms of their beliefs, desires and goals, but also on their *agent characteristics*. Given the same set of rules, distinct agents reason and act differently. For example, a respectful agent always tries to fulfill the goals of the normative system, whereas a selfish agent first tries to achieve its own goals. We

express these agent characteristics by a priority relation on the rules  $\geq$  which encode, as detailed in Broersen *et al.* [11], how the agent resolves its conflicts.

*Definition 5 (Motivational states):* The motivational state  $M_i$  of agent  $a_i$   $1 \leq i < n$  is a tuple  $\langle D_i, G_i, \geq_i, M_{i+1} \rangle$ , where  $D_i, G_i$  are sets of rules of  $L_{A_{i-1}A_iA_{i+1}P^{i-2}P^{i-1}P^iP^{i+1}}$ ,  $\geq_i$  is a transitive and reflexive relation on the powerset of  $D_i \cup G_i$  containing at least the subset relation, and  $M_{i+1}$  is the motivational state that agent  $a_i$  attributes to agent  $a_{i+1}$ . The motivational state  $M_n$  of agent  $a_n$  is a tuple  $\langle D_n, G_n, \geq_n \rangle$ .

The agents value, and thus induce an ordering  $\leq$  on, the epistemic states by considering which desires and goals have been fulfilled and which have not.

Concerning the priorities on desire and goal rules, agents can be classified according to the way they solve the conflicts among the rules belonging to different components: desires, goals and desires and goals of the normative system that can be adopted. We defined agent types as they have been introduced in the BOID architecture [11]. Here for space reasons, we introduce only a selfish stable agent type, which bases its decisions only on its unsatisfied goals and desires.

*Definition 6 (Agent types):* Let  $U(R, s)$  be the unfulfilled rules of state  $s$ ,

$$\{l_1 \wedge \dots \wedge l_n \rightarrow l \in R \mid \{l_1, \dots, l_n\} \subseteq s \text{ and } l \notin s\}$$

The unfulfilled mental state description of agent  $a_i$  is  $U_i = \langle U_i^D = U(D_i, s_i), U_i^G = U(G_i, s_i) \rangle$ .  $s_i \leq s'_i$  iff

- 1)  $U_i^G = U(G_i, s'_i) \geq_i U_i^G = U(G_i, s_i)$
- 2) if  $U_i^G \geq_i U_i^G$  and  $U_i^G \geq_i U_i^G$  then  $U_i^D \geq_i U_i^D$

*Example 4:* Consider an agent  $a_1$  who desires that if  $p$  is true in the initial state  $s_1^0$ , then  $q$  is true in the following one, and who desires unconditionally that  $r$  is true in the final state  $s_1^2$ :  $D_1 = \{p^0 \rightarrow q^1, \top \rightarrow r^2\}$ . Given a state  $s_1 = \{p^0, q^1\}$ , we have  $U_1^D = \{\top \rightarrow r^2\}$ . In fact, the conditional desire is satisfied ( $p^0 \in s_1$  and  $q^1 \in s_1$ ) while the unconditional one is not ( $\top \in s_1$  but  $r^2 \notin s_1$ ).

We finally define the optimal decisions. It is again a recursive definition.

*Definition 7 (Optimal decisions):* A partial epistemic state is an epistemic state excluding for each agent the last three states  $s_i^{i-1}$ ,  $s_i^i$  and  $s_i^{i+1}$ . A decision problem consists of a partial epistemic state, observable propositions  $OP_i$  for all agents  $a_i$ , and a mental state  $M_1$ . A decision set is optimal for a decision problem if it is optimal for each agent  $a_i$ . A decision set is optimal for agent  $a_i$  if there is no decision set that dominates it for agent  $a_i$ . A decision set  $\delta_i = \langle d_1, \dots, d_n \rangle$  dominates decision set  $\delta'_i = \langle d'_1, \dots, d'_n \rangle$  for agent  $a_i$  iff  $d_j = d'_j$  for  $1 \leq j < i$ , they are both optimal for agent  $a_j$  for  $i < j \leq n$ , and we have  $s_i < s'_i$

- for all  $s_i$  in an epistemic state description that contains the partial epistemic state and that respects the decision set  $\delta_i$  and  $Obs_i$ , and
- for all  $s'_i$  in an epistemic state description that contains the partial epistemic state and that respects the decision set  $\delta'_i$  and  $Obs_i$  (defined on this epistemic state).

## B. Obligations and permissions

Obligations and permissions are defined in terms of goals and desires of the bearer of the norm and of the normative system. To represent violations for each propositional variable we add a *violation variable*. In [6,7], an obligation for  $x$  is defined as the belief that absence of  $x$  counts as a violation of some norm  $n$ . In this paper, we do not explicitly formalize the norm  $n$ . Instead, we write  $V_{i,j}(\neg x)$  for ‘the absence of  $x$  counts for agent  $a_j$  as a violation by agent  $a_i$ ’. Since  $x$  can be a violation variable too, we can model the fact that recognizing something as a violation or not can be considered as a violation by some other agent.

**Definition 8 (Violation variables):** Let the decision variables of agent  $a_j$  contain a set of violation variables  $V = \{V_{i,j}(x) | x \text{ a literal built from } P^i \cup P^{i+1} \cup A_i\}$ .

**Definition 9 (Obligations):** Agent  $a_i$  believes that it is obliged to decide to do  $x$  (a literal built out of a propositional variable in  $P^i \cup P^{i+1} \cup A_i$ ),  $O_{i,i+1}(x)$ , iff:

- 1)  $\top \rightarrow x \in D_{i+1} \cap G_{i+1}$ : agent  $a_i$  believes that agent  $a_{i+1}$  desires and has as a goal  $x$ .
- 2)  $\neg x \rightarrow V_{i,i+1}(\neg x) \in D_{i+1} \cap G_{i+1}$ :  $a_i$  believes that if agent  $a_{i+1}$  believes  $\neg x$  then agent  $a_{i+1}$  has the goal and the desire  $V_{i,i+1}(\neg x)$ : to recognize it as a violation of agent  $a_i$ .
- 3)  $\top \rightarrow \neg V_{i,i+1}(\neg x) \in D_{i+1}$ : agent  $a_i$  believes that agent  $a_{i+1}$  desires that there are no violations.

We extend the definition including sanctions and conditions.

**Definition 10 (Conditional obligations with sanction):**

Agent  $a_i$  believes that it is obliged to decide to do  $x$  (a literal built out of a propositional variable in  $P^i \cup P^{i+1} \cup A_i$ ) with sanction  $s$  (a decision variable in  $A_{i+1}$ ) under condition  $q$  (a proposition of  $L_{A_i P^i P^{i+1}}$ ),  $O_{i,i+1}(x, s | q)$ , iff:

- 1)  $q \rightarrow x \in D_{i+1} \cap G_{i+1}$ : agent  $a_i$  believes that in context  $q$  agent  $a_{i+1}$  desires and has as a goal  $x$ .
- 2)  $q \wedge \neg x \rightarrow V_{i,i+1}(\neg x) \in D_{i+1} \cap G_{i+1}$ :  $a_i$  believes that if agent  $a_{i+1}$  believes  $q \wedge \neg x$  then agent  $a_{i+1}$  has the goal and the desire  $V_{i,i+1}(\neg x)$ : to recognize  $\neg x$  as a violation of agent  $a_i$ .
- 3)  $\top \rightarrow \neg V_{i,i+1}(\neg x) \in D_{i+1}$ : agent  $a_i$  believes that agent  $a_{i+1}$  desires that there are no violations.
- 4)  $V_{i,i+1}(\neg x) \rightarrow s \in D_{i+1} \cap G_{i+1}$ : agent  $a_i$  believes that if agent  $a_{i+1}$  decides  $V_{i,i+1}(\neg x)$  then it desires and has as a goal that it sanctions agent  $a_i$ .
- 5)  $\top \rightarrow \neg s \in D_{i+1}$ : agent  $a_i$  believes that agent  $a_{i+1}$  desires not to sanction.
- 6)  $\top \rightarrow \neg s \in D_i$ : agent  $a_i$  desires not to be sanctioned.

A permission not to do  $x$  is an exception to an obligation to do  $x$ .

**Definition 11 (Conditional permission):** Agent  $a_i$  believes that it is permitted to decide to do  $x$  (a literal built out of a propositional variable in  $P^i \cup P^{i+1} \cup A_i$ ) under condition  $q$  (a proposition of  $L_{A_i P^i P^{i+1}}$ ),  $P_{i,i+1}(x | q)$ , iff  $q \wedge x \rightarrow \neg V_{i,i+1}(x) \in D_{i+1} \cap G_{i+1}$ : agent  $a_i$  believes that if agent  $a_{i+1}$  believes  $q \wedge x$ , he wants that  $x$  does not count as a violation.

The permission overrides the obligation if this goal has higher priority in the agent characteristics  $\geq_{i+1}$  with respect to the goal that  $\neg x$  counts as a violation.

Finally, we define obligations and permissions concerning other obligations and permissions in order to model global policies (let  $O_{i,i+1}(x) = O_{i,i+1}(x | \top)$ ).

**Definition 12 (Obligation to oblige):** Agent  $a_{i+1}$  believes that it is obligated by agent  $a_{i+2}$  to oblige agent  $a_i$  to do  $x$  in context  $q$ ,  $O_{i+1,i+2}(O_{i,i+1}(x | q))$ , iff  $O_{i+1,i+2}(V_{i,i+1}(\neg x) | q \wedge \neg x)$  where  $V_{i,i+1}(\neg x) \in A_{i+1}$ .

**Definition 13 (Obligation to permit):** Agent  $a_{i+1}$  believes that it is obligated by agent  $a_{i+2}$  to permit agent  $a_i$  not to do  $x$  in context  $q$ ,  $O_{i+1,i+2}(P_{i,i+1}(\neg x | q))$ , iff  $O_{i+1,i+2}(\neg V_{i,i+1}(\neg x) | q \wedge \neg x)$  where  $V_{i,i+1}(\neg x) \in A_{i+1}$ .

**Definition 14 (Permission to permit):** Agent  $a_{i+1}$  believes that it is permitted by agent  $a_{i+2}$  to permit agent  $a_i$  not to do  $x$  in context  $q$ ,  $P_{i+1,i+2}(P_{i,i+1}(\neg x | q))$ , iff  $P_{i+1,i+2}(\neg V_{i,i+1}(\neg x) | q \wedge \neg x)$  where  $V_{i,i+1}(\neg x) \in A_{i+1}$ .

Since  $V_{i,i+1}(\neg x)$  is a decision variable  $V_{i+1,i+2}(V_{i,i+1}(\neg x))$  is also a decision variable: considering  $\neg x$  a violation represents a violation by agent  $a_{i+1}$  of a global policy. Given the reduction of nested obligations and permissions to obligations and permissions concerning violations it is possible to define further nestings to cope with more than two levels of authorities. This is necessary to model the management of systems which are organized in a hierarchical way. E.g., obligations by agent  $a_{i+3}$  that is obligatory for a middle authority  $a_{i+2}$  that  $a_{i+1}$  makes obligatory for  $a_i$  to do  $x$ :

$$\begin{aligned} & O_{i+2,i+3}(O_{i+1,i+2}(O_{i,i+1}(x | q))) \text{ iff} \\ & O_{i+2,i+3}(O_{i+1,i+2}(V_{i,i+1}(\neg x) | q \wedge \neg x)) \text{ iff} \\ & O_{i+2,i+3}(V_{i+1,i+2}(V_{i,i+1}(\neg x)) | q \wedge \neg x \wedge \neg V_{i,i+1}(\neg x)) \end{aligned}$$

## V. EXAMPLES

The following example illustrates an obligation to achieve parameter  $p^1$  of an agent  $a_1$  which adopts  $p^1$  only for the fear of the sanction  $s$  even if it desires not to do anything for achieving  $p^1$ . By convention we only give positive literals in states; all propositional variables not mentioned are assumed to be false.

**Example 5:**  $O_{1,2}(p^1, s | \top)$   
 $s_1^0 = \emptyset, B_1 = \{x \rightarrow p^1\}, \geq_1^B = \emptyset, x \in A_1, p^1 \in P^1,$   
 $G_1 = \emptyset, D_1 = \{\top \rightarrow \neg x, \top \rightarrow \neg s\},$   
 $\geq_1 = \{\top \rightarrow \neg s\} \geq \{\top \rightarrow \neg x\}$   
 $s_2^0 = \emptyset, OP_2 = A_1 \cup P^1, B_2 = \{x \rightarrow p^1\}, \geq_2^B = \emptyset,$   
 $V_{1,2}(\neg p^1) \in A_2, s \in A_2,$   
 $G_2 = \{\top \rightarrow p^1, \neg p^1 \rightarrow V_{1,2}(\neg p^1), V_{1,2}(\neg p^1) \rightarrow s\},$   
 $D_2 = \{\top \rightarrow p^1, \neg p^1 \rightarrow V_{1,2}(\neg p^1), V_{1,2}(\neg p^1) \rightarrow s, \top \rightarrow \neg V_{1,2}(\neg p^1),$   
 $\top \rightarrow \neg s\},$   
 $\geq_2 \supseteq \{\neg p^1 \rightarrow V_{1,2}(\neg p^1)\} > \{\top \rightarrow \neg V_{1,2}(\neg p^1), \top \rightarrow \neg s\}$

Optimal decision set:  $\langle d_1 = \{x\}, d_2 = \emptyset \rangle$

Expected state description:

$$s_1^1 = \{x, p^1\}, s_2^1 = \{x, p^1\}, s_2^2 = \{p^2\}, s_1^2 = \{p^2\}$$

Unfulfilled mental states:

$$U_1^D = \{\top \rightarrow \neg x\}, U_1^G = \emptyset, U_2^D = U_2^G = \emptyset$$

If agent  $a_1$  decides to do  $x$ ,  $d_1 = \{x\}$ , then we have  $s_1^1 \in \max(s_1^0, d_1, B_1, \geq_1^B, 0) = \{\{x, p^1\}\}$  by Definition 4 of respecting mental states. Agent  $a_1$ 's desire not to be sanctioned is fulfilled: the antecedent  $\top$  of the unconditional rule  $\top \rightarrow \neg s$  is true, and the consequent is consistent with state  $s_1^2 = \{p^2\}$  since agent  $a_2$  decides not to sanction ( $\neg s$ ) (recall that  $s \in A_2$ , so it is implicitly a variable of the last stage - Definition 2 - while  $p^2$  by persistency of the parameter  $p^1$  from  $s_2^1$  - Definition 4). In contrast, the unconditional (and hence applicable) goal  $\top \rightarrow \neg x$  is in conflict with state  $s_1^1 = \{x, p^1\}$  ( $x \in A_1$ , so it is a decision variable describing second stage) and it remains unsatisfied (see Definition 6).

For what concerns agent  $a_2$ 's attitudes, its unconditional desire and goal that agent  $a_1$  adopts the content of the obligation  $\top \rightarrow p^1$  is satisfied in  $s_2^1$ . Analogously are the desires not to prosecute and sanction indiscriminately:  $\top \rightarrow \neg V_{1,2}(\neg p^1)$  and  $\top \rightarrow \neg s$  (recall that states are complete - Definition 2 - so  $\neg V_{1,2}(\neg p^1)$  and  $\neg s$  are true in  $s_2^2 = \{p^2\}$ ). The remaining conditional attitudes  $\neg x \rightarrow V_{1,2}(\neg p^1)$ , etc. are not applicable and hence they are not unfulfilled.

Whatever other decision agent  $a_2$  would have taken, it could not satisfy more goals or desires, so  $d_2 = \emptyset$  is a minimal and optimal decision - Definition 7. E.g.  $d_2'' = \{s\}$  leaves  $\top \rightarrow \neg s$  unsatisfied:  $\{\top \rightarrow \neg s\} \geq_2 \emptyset$  (in fact,  $\geq_2$  contains the subset relation) and then  $U_2''^D = \{\top \rightarrow \neg s\} \geq U_2^D = \emptyset$ .

Had agent  $a_1$ 's decision been  $d_1' = \emptyset$ , agent  $a_2$  would have chosen  $d_2' = \{V_{1,2}(\neg p^1), s\}$ . The unfulfilled desires and goals in state  $s_1' = s_2' = \{V_{1,2}(\neg p^1), s\}$ :  $U_1'^D = \{\top \rightarrow \neg s\}$ ,  $U_1'^G = \emptyset$ ,  $U_2'^D = \{\top \rightarrow p^1, \top \rightarrow \neg V_{1,2}(\neg p^1), \top \rightarrow \neg s\}$ ,  $U_2'^G = \{\top \rightarrow p^1\}$ .

How does agent  $a_1$  take a decision between  $d_1$  and  $d_1'$ ? Since it compares which of its goals and desires remain unsatisfied (Definition 6):  $U_1^G = U_1'^G = \emptyset$  but  $U_1^D = \{\top \rightarrow \neg s\} \geq U_1'^D = \{\top \rightarrow \neg x\}$ . And hence, the optimal state (Definition 7) is  $s_1: s_1 = \{x, p^1, p^2\} \leq s_1' = \{V_{1,2}(\neg p^1), s\}$ .

We consider now a case of entitlement: agent  $a_1$  desires to have a given file ( $p^1$ ) by downloading it ( $x$ ): it is entitled to do  $x$  in context  $q$  by agent  $a_3$ ; in fact, agent  $a_3$  has issued a global policy which obliges agent  $a_2$  to permit agent  $a_1$  to do  $x$ :  $O_{2,3}(P_{1,2}(x|q^1))$ . But the resource  $x$  is in control of agent  $a_2$  who locally forbids access:  $O_{1,2}(\neg x, s)$ . Agent  $a_2$  has to decide whether to stick to the global policy and let  $a_1$  do  $x$  without sanctioning it or to make  $a_1$  to respect the local policy, thus sanctioning  $a_1$ . Moreover, to consider a different situation where agent  $a_2$  believes that agent  $a_1$  can make damage, let  $r$  mean that agent  $a_1$  is possibly dangerous and  $o^1$  mean that agent  $a_1$  damaged agent  $a_2$ .

*Example 6:*  $O_{1,2}(\neg x, s)$  and  $O_{2,3}(P_{1,2}(x|q^1))$ , i.e.,  $O_{2,3}(\neg V_{1,2}(x)|q^1 \wedge x)$   
 $s_1^0 = \{q^0\}$ ,  $B_1 = \{x \rightarrow p^1\}$ ,  $\geq_1^B = \emptyset$ ,  $x \in A_1, p, q \in P$ ,  
 $G_1 = \emptyset$ ,  $D_1 = \{\top \rightarrow p^1, \top \rightarrow \neg s\}$ ,  $\geq_1 = \{\top \rightarrow p^1\} > \{\top \rightarrow \neg s\}$ ,  
 $s_2^0 = \{q^0\}$ ,  $OP_2 = A_1 \cup P^1$ ,  $B_2 = \{r^1 \wedge x \rightarrow o^1\}$ ,  
 $\geq_2^B = \emptyset$ ,  $V_{1,2}(x) \in V \cap A_2$ ,  $s \in A_2$ ,  
 $G_2 = \{\top \rightarrow \neg x, x \rightarrow V_{1,2}(x), V_{1,2}(x) \rightarrow s, \top \rightarrow \neg V_{2,3}(V_{1,2}(x)), \top \rightarrow \neg o^1\}$ ,

$D_2 = \{\top \rightarrow \neg x, x \rightarrow V_{1,2}(x), V_{1,2}(x) \rightarrow s, \top \rightarrow \neg V_{1,2}(x), \top \rightarrow \neg s, \top \rightarrow \neg o^1\}$ ,  
 $\geq_2 \supseteq \{\top \rightarrow \neg o^1\} > \{\top \rightarrow \neg V_{2,3}(V_{1,2}(x))\} > \{x \rightarrow V_{1,2}(x)\} > \{\top \rightarrow \neg V_{1,2}(x), \top \rightarrow \neg s\}$ ,

$s_3^1 = \emptyset$ ,  $OP_3 = A_2 \cup P^2$ ,  $V_{2,3}(V_{1,2}(x)) \in V \cap A_3$ ,

$G_3 = \{q^1 \wedge x \rightarrow \neg V_{1,2}(x), V_{1,2}(x) \rightarrow V_{2,3}(V_{1,2}(x))\}$ ,

$D_3 = \{q^1 \wedge x \rightarrow \neg V_{1,2}(x), V_{1,2}(x) \rightarrow V_{2,3}(V_{1,2}(x)), \top \rightarrow \neg V_{2,3}(V_{1,2}(x))\}$ ,

$\geq_3 \supseteq \{V_{1,2}(x) \rightarrow V_{2,3}(V_{1,2}(x))\} > \{\top \rightarrow \neg V_{2,3}(V_{1,2}(x))\}$ ,

Optimal decision set:  $\langle d_1 = \{x\}, d_2 = \emptyset, d_3 = \emptyset \rangle$

Expected state description:

$s_1^1 = s_2^1 = \{x, q^1, p^1\}$ ,  $s_3^3 = s_2^2 = s_1^2 = \{q^2, p^2\}$ ,  $s_3^3 = s_2^2 = \{q^3, p^3\}$

Unfulfilled mental states:  $U_1^{D1} = U_1^{G1} = \emptyset$ ,

$U_2^{D2} = U_2^{G2} = \{\top \rightarrow \neg x, x \rightarrow V_{1,2}(x)\}$ ,  $U_3^{D3} = U_3^{G3} = \emptyset$

Since agent  $a_1$  decides to do  $x$ , then  $s_1^1 = \max(s_1^0, d_1, B_1, \geq_1^B, 0) = \{x, q^1, p^1\}$ : hence its unconditional (and hence applicable) goal  $\top \rightarrow p^1$  is achieved in state  $s_1^1$ . Also its desire not to be sanctioned is fulfilled: the antecedent  $\top$  of the unconditional rule  $\top \rightarrow \neg s$  is true, and the consequent is consistent with state  $s_1^2$  since agent  $a_2$  decides not to sanction.

For what concerns agent  $a_2$ 's attitudes, its unconditional desire and goal that agent  $a_1$  fulfills the obligation  $\top \rightarrow \neg x$  is not satisfied in  $s_2^1$  and also the conditional attitude  $x \rightarrow V_{1,2}(x)$  is not satisfied. In contrast, the desires not to prosecute and sanction indiscriminately are satisfied:  $\top \rightarrow \neg V_{1,2}(x)$  and  $\top \rightarrow \neg s$ .

Had agent  $a_2$ 's decision been  $d_2' = \{V_{1,2}(x), s\}$   $a_1$ 's unfulfilled desires would have been:  $U_1^{D1} = \{\top \rightarrow \neg s\}$ .

How does agent  $a_2$  take a decision between  $d_2$  and  $d_2'$ ? It compares which of its goals and desires remain unsatisfied under the light of agent  $a_3$ 's reaction: in fact, if agent  $a_2$  decided for  $d_2'$ ,  $d_3'$  would have been  $\{V_{2,3}(V_{1,2}(x))\}$ . In this situation  $U_2'^{G2} = \{\top \rightarrow \neg V_{2,3}(V_{1,2}(x))\}$  but  $U_2'^{D2} = \{\top \rightarrow \neg V_{2,3}(V_{1,2}(x))\} \geq U_2^{G2} = \{\top \rightarrow \neg x, x \rightarrow V_{1,2}(x)\}$ .

What happens instead if  $r^1$  is true in  $s_2^2$ ?  $r$  can be interpreted as the fact that a hacker is accessing the resource and agent  $a_2$  believes it will damage ( $o^1$ ) the system (since  $r^1 \wedge x \rightarrow o^1 \in B_2$ ). In this case agent  $a_2$  prefers to be considered a violator by agent  $a_3$  with respect to not considering a violator  $a_1$  and thus punishing it.

In the last example, we describe a more complex local policy of agent  $a_2$ : it forbids access to a resource  $x$  to agent  $a_1$  unless it is in a context  $q^1$ , where agent  $a_2$  permits  $a_1$  to access resource  $x$ ; this permission as exception is in contrast with the global policy issued by agent  $a_3$  to unconditionally forbid access. However, given the fact that agent  $a_3$  considers agent  $a_2$  as a violator if it does not prosecute agent  $a_1$  then  $a_2$  complies with the global policy also in context  $q^1$  and thus it sanctions agent  $a_1$ .

*Example 7:*  $O_{1,2}(\neg x, s)$  and  $P_{1,2}(x|q^1)$   $O_{2,3}(O_{1,2}(\neg x))$ ,  
i.e.,  $O_{2,3}(V_{1,2}(x)|x)$

$$s_1^0 = \{q^0\}, B_1 = \emptyset, \geq_1^B = \emptyset, x \in A_1, q \in P,$$

$$G_1 = \emptyset, D_1 = \{\top \rightarrow x, \top \rightarrow \neg s\}, \geq_1 = \{\top \rightarrow x\} > \{\top \rightarrow \neg s\},$$

$$s_2^0 = \{q^0\}, Obs_2 = A_1 \cup P^1, B_2 = \emptyset, \geq_2^B = \emptyset, V_{1,2}(x) \in V \cap A_2, s \in A_2,$$

$$G_2 = \{\top \rightarrow \neg x, x \rightarrow V_{1,2}(x), V_{1,2}(x) \rightarrow s, x \rightarrow \neg V_{1,2}(x), \top \rightarrow \neg V_{2,3}(\neg V_{1,2}(x))\},$$

$$D_2 = \{\top \rightarrow \neg x, x \rightarrow V_{1,2}(x), V_{1,2}(x) \rightarrow s, x \rightarrow \neg V_{1,2}(x), \top \rightarrow \neg V_{1,2}(x), \top \rightarrow \neg s\},$$

$$\geq_2 \supseteq \{\top \rightarrow \neg V_{2,3}(\neg V_{1,2}(x))\} > \{x \rightarrow \neg V_{1,2}(x)\} > \{x \rightarrow V_{1,2}(x)\} > \{\top \rightarrow \neg V(x), \top \rightarrow \neg s\},$$

$$s_3^1 = \emptyset, Obs_3 = A_2 \cup P^2, B_3 = \emptyset, \geq_3^B = \emptyset, V_{2,3}(V_{1,2}(x)) \in V \cap A_3,$$

$$G_3 = \{x \rightarrow V_{1,2}(x), V_{1,2}(x) \rightarrow V_{2,3}(\neg V_{1,2}(x))\},$$

$$D_3 = \{x \rightarrow V_{1,2}(x), V_{1,2}(x) \rightarrow V_{2,3}(\neg V_{1,2}(x)), \top \rightarrow \neg V_{2,3}(\neg V_{1,2}(x))\},$$

$$\geq_3 \supseteq \{V_{1,2}(x) \rightarrow V_{2,3}(\neg V_{1,2}(x))\} > \{\top \rightarrow \neg V_{2,3}(\neg V_{1,2}(x))\},$$

Optimal decision set:  $\langle d_1 = \{x\}, d_2 = \{V_{1,2}(x), s\}, d_3 = \emptyset \rangle$

Expected state description:

$$s_1^1 = s_2^1 = \{x, q^1\}, s_2^2 = s_1^2 = \{V_{1,2}(x), s, q^2\}, s_3^3 = s_2^3 = \{q^3\}$$

Unfulfilled mental states:

$$U_1^{D_1} = \{\top \rightarrow \neg s\}, U_1^{G_1} = \emptyset,$$

$$U_2^{D_2} = \{x \rightarrow \neg V_{1,2}(x), \top \rightarrow \neg V_{1,2}(x), \top \rightarrow \neg s\}, U_2^{G_2} = \{x \rightarrow \neg V_{1,2}(x)\},$$

$$U_3^{D_3} = U_3^{G_3} = \emptyset$$

## VI. SUMMARY AND CONCLUDING REMARKS

In this paper we consider the problem of regulating virtual communities by means of local and global policies.

The relevant property of our approach is that it is not a preventative control system: agents are not constrained to respect local policies and to implement global policies, instead they can decide whether to do that or not under the light of a rational balance between the advantage of non respecting a norm and the disadvantage of being sanctioned. In this way the autonomy of the local providers is maintained, while at the same time enabling the regulation of a virtual community. Moreover, multiple levels of global policies can be defined.

We introduce a qualitative decision theory for reasoning about decision making of BDI agents constrained by global and local policies.

There are several issues for further research. For example, the hierarchical relations among authorities [20] and the analysis of when is rational to introduce norms [21]. In [7], we address the problem of structuring the normative system by means of different roles. Moreover we are interested in studying the distinction between enacting a permission and granting an authorization. While these two notions seem similar, they are distinct when we consider that permissions are meaningful only if there is a possibility to forbid the permitted behavior.

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