Norms in Distributed Organizations

Bas Testerink, Mehdi Dastani, John-Jules Meyer

Utrecht University
{b.j.g.testerink,m.m.dastani,j.j.c.meyer}@uu.nl

Abstract. Due to external requirements we cannot always construct a centralized organization, but have to construct one that is distributed. A distributed organization is a network of organizations which can locally observe and control the environment. In this paper we analyze how norms can be enforced through the joint effort of the individual local organizations. Norm violations are detected by monitoring. Sanctioning compensates the violations of norms. The main problem is to map the required data for monitoring, and the required control capabilities for sanctioning, to the local observe/control capabilities of organizations. Our investigation focuses on exploring the solution space of this problem, the properties of proper solutions and practical considerations when developing a solution.

Keywords: Normative organizations, Exogenous organizations, Distributed organizations

1 Introduction

In open multi-agent systems, organizations are used to promote global system behavior. This paper concerns normative organizations where norms are used to control and coordinate agents. Over the years there have been investigations in many aspects of organizations. This has led to different frameworks (e.g. [7],[3],[4]) and programming languages for organizations (e.g. [2],[5]). Some of the works expand organizations with roles, hierarchical structures and empowerment definitions. We consider only organizations that are exogenous to agents and the environment, and have explicit norms.

Such organizations are useful because it separates the regulation concerns from the rest of the multi-agent system (i.e. agents, middleware, etc.). This in turn allows for independent maintenance and debugging of the organization. Also the use of violable norms is often preferred over hard constraints. This is because norms preserve to a greater extent the autonomy of agents. Agents still have a choice whether or not to violate norms if they are aware of them. But also if an agent is not aware of norms then still the organization can repair or compensate violations of norms if they occur. For instance a tourist can be incarcerated for violating a law during vacation, regardless whether he or she was aware of the law. Norm-awareness is not a topic of this paper as we focus on organizations rather than agents.

There is an abundant collection of norm formalisms that allow us to specify a norm set. One of the most basic methods is to specify the desired behavior and the consequences if that specification is violated. One can implement all norms with this principle as was done in [2] and [5]. We shall also adopt this view. Monitoring is required to detect violation, which we shall capture with rules that indicate which agent behaviors should be considered as violations. Sanctioning is needed to respond to violations, i.e. to enforce norms. For enforcement we shall use rules that tie a norm violation to a consequence. We separate the rules because they can be maintained independently, which happens a lot in practice. For instance the velocity that counts-as speeding is often quite static whereas the sanction is not (usually the fines gradually get higher). Monitoring and sanctioning require two core capabilities of an organization given an environment: what can be observed and what can be controlled in that environment.

In this paper we address distributed organizations. These distributed organizations are comprised of a network of organizations each of which has their own sense and control capabilities. There are different kinds of distribution in a distributed organization. We can distribute the monitoring of a norm, the application of a sanction to repair/compensate a violation, the task of determining violations based on monitored data and the task of determining the sanction based on a norm violation.

As an example of a distributed organization we look at an application called smart roads. In the smart roads system each highway is enriched with an organization to increase the safety and throughput. For instance speed limits can be adapted to fit the current circumstances on the road. Sensors and cameras are attached to the infrastructure so the highways can be monitored. The government's regulations for traffic are adopted as norms in the organizations. To limit human intervention, the organizations are given the power to give drivers a fine whenever for instance a speed limit is violated. These organizations are geographically distributed[1]. Having a network of organizations, rather than a single organization for all roads, increases the robustness of the system and is scalable if new highways are added to the system. Because there are many agents in the smart roads application, the data that is generated by monitoring the highways can form a bottle neck if it is processed by a single organization.

The regulations for traffic are defined *independently* of the actual individual highways and their infrastructures. Similarly the norms that follow from the traffic regulations are not designed for the individual organizations. Situations can arise where only through joint effort of the organizations the norms can be enforced. As an running example we shall use a scenario from the smart roads application where joint effort is required.

In Figure 1 a scenario is schematically depicted. The organizations that make up the distributed organization are connected and have their own parts of the highway which they can monitor and influence (depicted by the dashed lines). Monitoring here entails the observation of cars and influence is for instance the

[1] Geographic distribution is not the only possibility, e.g. we could also distribute functionality.

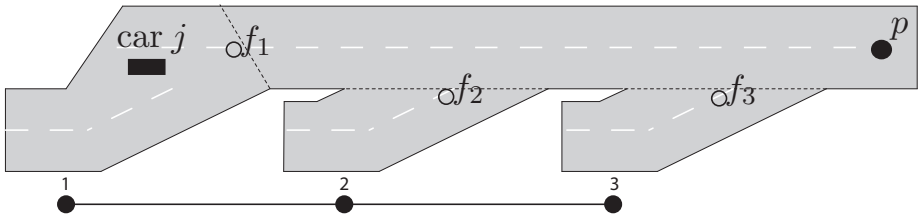

Fig. 1. Example scenario from the smart roads application. The dots 1 to 3 are connected organizations. The observation/control domains of the organizations reach to the dashed lines.

possibility to change the speed limit. Having a limited area per organization where it can monitor and influence the highway leads to different situations where it becomes problematic to monitor norms or impose sanctions. In our example scenario we will have a norm that can only be monitored if the three organizations share their local observations.

Imagine we want to increase the safety of the horizontal road part by promoting that if it is busy there, that then cars should drive slowly when approaching the horizontal road part. Consider this as the norm "if the traffic density at point p is above a certain threshold x then cars should drive less than 80km/h". Violations of this norm will be sanctioned by a fine. Point p falls out of the observation areas of each organization. In this situation the organizations have to locally observe the outgoing traffic flow (represented by f_1, f_2 and f_3) and share this information in order to determine whether a violation is occurring. In case of violation there are different choices for which organization will give the fine. We will investigate the problem of how norms can be enforced within a distributed organization.

In particular we are interested in the question whether, given a network of organizations, a set of norms *can* be enforced (e.g. are the required monitoring capabilities for detecting norm violations present?). And if we can enforce norms, what are our possibilities in terms of distributing the norm monitoring and violation sanctioning tasks? To answer these questions we will formally define norms, distributed organizations and enforcement (Section 4). Then we shall describe how the norm monitoring and violation sanctioning tasks can be distributed in the network (Section 5). But first we stress the importance of investigating distributed organizations (Section 2) and the related work on this topic (Section 3).

2 Why we should investigate distributed organizations

Centralized software systems come with plenty of disadvantages such as single point of failures, scalability issues and maintenance of always-on applications. Typically multi-agent systems are distributed by nature, with agents being distributed among platforms and entities. Imposing a centralized organization on

a multi-agent system would diminish the systems advantages that are obtained from distribution.

But it is not that distribution is just a design choice. Sometimes external factors require the use of a distributed organization. When we introduce agents in corporate business then the organization of the agents will likely be a reflection of the human organization. And human organizations are typically a network of departments, task-forces, commissions, etc., i.e. distributed organizations.

Given that distributed organizations exist, one can wonder whether the organizational theories/techniques/methodologies that we have are appropriate. We believe this question to be answered in the negative for the general case. To our best knowledge all current work on distributed organizations is focused on techniques with which one can make organizations that have some form of distribution (more in Section 3). What is not investigated is how we could distribute some given norms in a given distributed organization.

Informally, the challenges lie in the fact that organizations only have local observation and control capabilities, though norms span over the entire distributed organization. We divide the functionality of a (distributed) organization into observing - detecting violations of norms - and sanctioning - to give norms meaning. Without sanctioning there would be no point in having norms[2]. A distributed organization has a global specification of norms. The practical issue is to transfer the global specification to norms per organization, such that overall the distributed organization enforces the norms. There has not yet been an investigation to describe this problem.

Our effort is not targeted to defining a function that given norms and a distributed organization distributes the norms. Rather we want to describe the solution space of these functions. The reason is that it differs greatly per application what kind of solutions are desired. For instance, in the distributed highway organization example we have a lot of data to process because the system is huge. It can be unfeasible to let all organizations send their observation data to a central point for processing. Rather it would be preferable to distribute a set of norms among local organizations so they can enforce them locally, if possible. But if one of our external constraints is that only the police organization might impose fines on agents, then for the violations that result in fines the highway organizations should send the information to the police organization.

3 Distributed organizations in related work

Distributed organizations have been addressed in several works. In [5] norms are programmed per scenario, where a scenario is a coherent series of (possibly parallel) activities. Their data consists only of executed speech acts and institutional facts (prohibitions, obligations and permissions). The scene rules describe how actions from one activity can affect institutional facts concerning

[2] At least when the organization is exogenous to agents. If norms are integrated in agents then this does not hold, but then we would require no exogenous organization for control and coordination.

other activities. Scenes are independent, meaning that all relevant speech acts and institutional facts are stored in its state. In [9] the main consideration is the distribution of norms in a spatial environment. Objects and places in the environment may convey norms to agents so that they can decide to follow them. Their work does not include the monitoring system or sanctioning (other than the statement that special supervision agents might check compliance). In [8] the control mechanism is based on group interactions. Each group is governed by a law which does not span multiple groups. In [11] organizations can be programmed and run separately, but are able to communicate about environment states and brute/institutional changes which occur locally. In [1] multi-institutes, which are similar to our distributed organizations, are defined, plus an action language (InstAl) to specify them.

In the related work we see existing techniques/languages for which some form of distributive properties are described, or distributed organizations are specified by fully specifying the local organizations. None of the works however analyze the issue of distributing global norms among local organizations in order to enforce them.

What is missing from current research is an analysis of if and how we can translate a given norm set to a network of organizations, where the norm set is assumed to be developed independently of the network. Especially the issue of norms that cannot be to locally enforced (i.e. both monitoring and sanctioning of a norm cannot be done in one organization) has not been addressed properly. In this paper we move away from implementations and analyze norms in distributed organizations from a more abstract point of view. The results of our research will help to develop more general norm technologies. Also a deeper understanding of design choices when constructing a norm set will be obtained. This aids the process of designing a norm set for a distributed organization.

4 Norms, distributed organizations and enforcement

In this section we shall define norms, (distributed) organizations and enforcement. The definitions rely on environment state descriptions and observation/control capabilities. We use propositional logic to describe the state of a multi-agent system environment and organization.

4.1 Defining norms

In an open multi-agent system, active monitoring is required to detect the violation of norms, and sanctioning realizes the consequences of violations. There are many ways to represent norms using preconditions, deadlines, deontic concepts etc. For our purposes we take the most basic representation which are counts-as rules. For describing the compensations of violations we use sanction rules. The reading of a counts-as rule $\varphi \Rightarrow v$ is that the system states that satisfy φ are violated states. Or to put it differently, states that satisfy φ are forbidden states. The violation of this prohibition is identified by v. The reading of a sanction

rule $v \Rightarrow \psi$ is that violated states have to be updated with ψ to compensate for violation v. Violation atoms are considered to be institutional facts. Each norm has a unique violation atom. Counts-as/sanction rule context is omitted for simplicity. Thoughts on incorporating context in counts-as rules can be found in Section 8. A matching norm and sanction pair is a norm of which the violation is sanctioned by the sanction (Definition 1).

Definition 1. ***Matching norms and sanctions.*** *A norm is represented by a counts-as rule of the form $\varphi \Rightarrow v$, where φ is a conjunction of literals and v is a violation atom. A sanction is represented by a sanction rule of the form $v \Rightarrow \psi$, where v is a violation atom and ψ is a conjunction of literals that has to be made true in case violation v has occurred. A norm n matches a sanction s iff $n = \varphi \Rightarrow v$ and $s = v \Rightarrow \psi$, i.e. sanction s responds to violations of norm n.*

We limit the use of institutional facts to violations. Complex regulative systems often use constitutive norms to define institutional facts[10]. However, as violations are the only institutional facts, and they are already defined by counts-as rules, we do not include the use of constitutive norms.[3]

4.2 Defining (distributed) organizations

A distributed organization is a set of organizations that can communicate (Definition 2). For convenience and reasons explained in Section 4.3 we use two separate communication relations. One communication relation, which we call the regular communication, is for the communication about observations and to be imposed sanctions. The other relation is called the institutive communication and is reserved for the communication of violation atoms.

Definition 2. ***Distributed organization.*** *A distributed organization is a tuple $DO = \langle \mathbb{O}, R_r, R_i \rangle$, where $\mathbb{O}$ is a set of organizations, and $R_r, R_i \subseteq \mathbb{O} \times \mathbb{O}$ are the regular and institutional communication relations among organizations.*

Organizations in the network are described by their observation capabilities and their control capabilities (Definition 3). The specification of what exactly the observe and control capabilities are will be part of future work. We do not intend to specify an observation/control logic here, as it is besides the point. The entailment operator $\vDash_{c/o}$ can be seen as some reasoning engine that gives us the answer whether some environment state is observable or controllable. A simple example of a capability description is a set of literals that represent the observables and controllables of an organization.

Definition 3. ***Organization specification.*** *An organization is specified by a tuple $O = \langle \Gamma_{obs}, \Gamma_{con} \rangle \in \mathbb{O}$. Γ_{obs} is a specification of the observation capability of O. Γ_{con} is the specification of the control capability of O. Let φ and ψ be formulas denoting the state of the environment, $O \vDash_o \varphi$ indicates that φ can be locally observed by organization O. $O \vDash_c \psi$ indicates that ψ can be locally controlled by organization O.*

[3] More on this in Section 8.

4.3 Enforcement

For norm enforcement it is needed to have the correct observation and control capabilities available. The presence of these capabilities can be local or available through communication. If the capabilities are not local then the regular communication relation is used. In case the capabilities are present, there is also a choice which organizations do the monitoring and which organizations do the sanctioning. This leads to a distinction between centralized and decentralized enforcement. Decentralized enforcement, where monitoring and sanctioning is performed by a number of organizations, uses the institutional communication relation. By splitting communication in regular and institutional communication we can clearly describe the distribution of control and observe capabilities and the distribution of enforcement.

We will define the characteristics of each possible way that norms can be enforced in a distributed organization. We begin with defining local and global monitoring and sanctioning in an organization that is part of the distributed organization. For a norm to be applicable it means that the norm can be monitored, and for a sanction to be applicable, it means that the sanction can be imposed. We assume that the sanctioning of violations is described in terms of what organizations can do. For instance, the highway organizations can ultimately only give fines and not force agents to pay them (though not paying a fine could result in the notification of some other authority that can).

Local application in an organization can only happen if the right observation and control capabilities are locally present. If a norm or sanction is locally applicable, then no communication needs to burden the network. For a norm to be locally monitorable in an organization it must be possible to locally observe all the occurring literals in the norm. Similarly for sanctions all occurring literals in the sanction must be locally controllable.

Definition 4. ***Local monitoring and sanctioning.*** *Let N be a set of norms, S a set of sanctions and $\langle \mathbb{O}, R_r, R_i \rangle$ a distributed organization. Then, we say that $O \in \mathbb{O}$ can locally monitor N iff $\forall(\varphi \Rightarrow v) \in N : O \vDash_o \varphi$, and $O \in \mathbb{O}$ can locally sanction violations using S iff $\forall(v \Rightarrow \psi) \in S : O \vDash_c \psi$.*

Global monitoring and sanctioning concerns subparts of the network of organizations (Definition 5). An organization O can globally monitor a norm or apply a sanction if the reachable organizations for O together have the required capabilities. Given the regular communication relation among organizations, one can treat observable/controllable atoms in a connected network as distributed knowledge/controllability. Again the norm and sanctions look alike in their application. For norms the required literals for determining violation must be locally observable, or observable in a connected organization. All occurring literals in a sanction must be locally controllable or controllable in a connected organization. In the following we use $lit(\varphi)$ for the set of literals that occur in φ.

Definition 5. ***Global monitoring and sanctioning.*** *Let N be a set of norms, S a set of sanctions and $\langle \mathbb{O}, R_r, R_i \rangle$ a distributed organization. Then, we say*

$O \in \mathbb{O}$ can globally monitor N iff
$\forall(\varphi \Rightarrow v) \in N, \forall l \in lit(\varphi), \exists(O, O') \in R_r : O' \vDash_o l.$
We also say that $O \in \mathbb{O}$ can globally sanction violations using S iff
$\forall(v \Rightarrow \psi) \in S, \forall l \in lit(\psi), \exists(O, O') \in R_r : O' \vDash_c l.$

Observation 1 If R_r is reflexive, then local applicable norms and sanctions are also globally applicable because the pair $(O, O) \in R_r$ for all $O \in \mathbb{O}$ can globally apply norms/sanctions that are locally applicable by O.

To enforce norms, first monitoring takes place to determine violations. Then sanctioning takes place to compensate for the violations that occurred. There is a choice whether this process is centralized or decentralized in organizations.

Central enforcement of norms in an organization means that both the monitoring and the sanctioning of norms/violations is done by the same organization. The monitoring and sanctioning can however be either locally or globally done (Definition 6). Note that for a norm set N to be enforceable using S it must hold that for each norm $\varphi \Rightarrow v \in N$ there must be at least one corresponding sanction $v \Rightarrow \psi \in S$, otherwise the violation cannot be sanctioned.

Definition 6. ***Centralized enforcement.*** *Let N be a set of norms, S a set of sanctions and $\langle \mathbb{O}, R_r, R_i \rangle$ a distributed organization. $O \in \mathbb{O}$ can centrally enforce N by S iff O can locally or globally monitor N and O can locally or globally sanction violations using S.*

Decentralized enforcement entails that monitoring and sanctioning can happen in two different organizations. Though the organizations do have to be able to communicate about the detected violations (Definition 7).

Definition 7. ***Decentralized enforcement.*** *Let N be a set of norms, S a set of sanctions and $\langle \mathbb{O}, R_r, R_i \rangle$ a distributed organization. $O \in \mathbb{O}$ and $O' \in \mathbb{O}$, $O \neq O'$, can decentrally enforce N by S iff $(O, O') \in R_i$ and O can locally or globally monitor N and O' can locally or globally sanction violations using S.*

Observation 2 If R_i is reflexive, then centrally enforceable norms and sanctions are also decentrally enforceable, because the pair $(O, O) \in R_i$ for all $O \in \mathbb{O}$. So if O can locally or globally monitor N and locally or globally sanction using S, then the pair (O, O) can do this decentrally.

A distribution of a set of norms and sanctions is a set of pairs that contain a subset of the norms and a subset of the sanctions. To be correctly enforced, each possible detection of a violation must be present in the distribution (i.e. all occurring norms must together be the set of all norms). But it must also be the case that if a violation is monitored, that then the sanction concerning that violation will always be imposed when the violation occurs. Thus for each norm and sanction concerning the same violation there must be a pair in the distribution such that both the norm and the sanction occur in the pair (Definition 8).

Definition 8. ***Distribution.*** *Let (N, S) be a pair consisting of a set of norms N and a set of sanctions S. A distribution of (N, S) is a set $\{D_0, \ldots, D_n\}$, where $D_i = (N_i, S_i)$, $N_i \subseteq N$ and $S_i \subseteq S$. Furthermore, for each matching norm-sanction pair (n, s), $n \in N$, $s \in S$, we require the existence of $D_i = (N_i, S_i)$ in the distribution such that $n \in N_i$ and $s \in S_i$.*

We have defined enforcement of norms and their sanctions for a specific organization or a pair of organizations, but not yet for the distributed organization as a whole. In Definition 9 we define whether norms and their sanctions are enforceable in a distributed organization. This is the case if there is a distribution such that each of the norm subset and sanction subset pairs in that distribution are enforceable by some organization or pair of organizations.

Definition 9. ***Global enforcement.*** *Let N be a set of norms, S a set of sanctions and $\langle \mathbb{O}, R_r, R_i \rangle$ a distributed organization. $\langle \mathbb{O}, R_r, R_i \rangle$ can globally enforce N by S iff there is a distribution $\{D_0, \ldots, D_n\}$ of (N, S) such that for each D_i there either exists an organization $O \in \mathbb{O}$ that can centrally enforce D_i or there exists a pair of organizations $(O, O') \in R_i$ such that (O, O') can decentrally enforce D_i.*

4.4 Subtypes of enforcement

We have discussed local/global availability of observe and control capabilities, and we have discussed centralized versus decentralized enforcement. In Definition 9 we required a distribution for which each element was either centralized or decentralized enforced, and each norm/violation was either locally or globally monitored/sanctioned. But we can get some interesting properties of enforcement by ruling out types of enforcement and the types of norm and sanction application. We do this by restricting the communication.

Global monitoring and sanctioning (Definition 5) is impossible if $R_r = \emptyset$, so only local monitoring and sanctioning (Definition 4) then remains. This is useful if the data for norm monitoring is very big in an application. The communication of violation atoms is likely to be very cheap.

Decentralized enforcement (Definition 7) is impossible if $R_i = \emptyset$, so only centralized enforcement (Definition 6) then remains. This kind of enforcement is useful because we do not need to create an institutional infrastructure. It also increases security as important data concerning enforcement (the violations) cannot be intercepted.

If both global monitoring and sanctioning, and decentralized enforcement are impossible, i.e. $R_r = \emptyset$ and $R_i = \emptyset$ then there is no communication needed for enforcement. This kind of enforcement is needed if we want to implement norms using a language that does not allow for inter-organizational communications (such as 2OPL[2] and NPL[6]).

Observation 3 If $\langle \mathbb{O}, R_r, \emptyset \rangle$ can globally enforce N by S then no subsets of N and S can be decentrally enforced. If $\langle \mathbb{O}, \emptyset, R_r \rangle$ can globally enforce N by S

then only local monitoring and sanctioning of N and S respectively is possible. If $\langle \mathbb{O}, \emptyset, \emptyset \rangle$ can globally enforce N by S then only local monitoring and sanctioning of N and S respectively is possible and only centralized enforcement.

5 Assigning norms and sanctions to organizations

In an organization each norm has to be monitored. This requires computational effort. Similarly, each sanction to be imposed costs computational effort as well. In a distributed organization we have the possibility to distribute this computational effort in the network of organizations. We want to assign to organizations norms and sanctions that they must monitor/impose.

The assignment of a global set of norms and sanctions to local organizations should provide the information about which organization exactly monitors which norms and which sanctions. We define this by creating two sets of pairs. The first set couples organizations with norms, the second set couples organizations with sanctions. All the given norms and sanctions must be assigned to at least one organization. Furthermore, all assigned norms must be monitorable in the organizations to which they are assigned. And equally all assigned sanctions must be imposable by the organizations to which they are assigned. Lastly it is needed that each detectable violation can reach the sanction that handles that violation.

Definition 10. ***Assignment.*** *Let (N, S) be a pair consisting of a set of norms N and a set of sanctions S and $\langle \mathbb{O}, R_r, R_i \rangle$ a distributed organization. An assignment A is a pair (A_N, A_S), where $A_N \subseteq \mathbb{O} \times N$ and $A_S \subseteq \mathbb{O} \times S$. For every $(O, n) \in A_N$ and $(O, s) \in A_S$, n can be monitored locally or globally by O and s can be locally or globally used by O to sanction. Furthermore for each matching norm-sanction pair (n, s), $n \in N$, $s \in S$, either there exists an $O \in \mathbb{O}$ s.t. $(O, n) \in A_n$ and $(O, s) \in A_S$ and O can centrally enforce n by s, or there exists $(O, O') \in R_i$ s.t. $(O, n) \in A_n$ and $(O', s) \in A_S$ and (O, O') can decentrally enforce n by s.*

Observation 4 Let N be a set of norms, S a set of sanctions and $\langle \mathbb{O}, R_r, R_i \rangle$ a distributed organization. (A_N, A_S) is an assignment if and only if $\langle \mathbb{O}, R_r, R_i \rangle$ can globally enforce N by S. An assignment can be transformed into a distribution $\{D_0, \ldots, D_n\}$ by creating for each matching norm-sanction pair (n_i, s_i), $(O, n_i) \in A_N$, $(O, s_i) \in A_S$, a distribution element $D_i = \{(\{n_i\}), (\{s_i\})\}$. Likewise the distribution $\{D_0, \ldots, D_n\}$ that is required for global enforcement can be transformed in an assignment. We know that for each matching norm pair (n, s) there exists a $D_i = (N_i, S_i)$ and $n \in N_i$ and $s \in S_i$. We also know that there exists an organization O s.t. O can centrally enforce n by s or two organizations O, O' s.t. they can decentrally enforce n by s. In the first case the assignment will contain $(O, n) \in A_N$ and $(O, s) \in A_S$. In the second case the assignment will contain $(O, n) \in A_N$ and $(O', s) \in A_S$.

6 Example revisited

In Section 1 we described a distributed organization to regulate the traffic on highways. The example norm was that if the traffic stream is dense at a certain point p (determined by the density at that point being above a certain threshold), then traffic should slow down to maximally 80 km/h. Violations of this norm are sanctioned through fines. The density at point p is determined by the outgoing flows of the three organizations. The distributed organization is formally $\langle \mathbb{O}, R_r, R_i \rangle$ where
$\mathbb{O} = \{O_1 : \langle \Gamma^1_{obs}, \Gamma^1_{con} \rangle, O_2 : \langle \Gamma^2_{obs}, \Gamma^2_{con} \rangle, O_3 : \langle \Gamma^3_{obs}, \Gamma^3_{con} \rangle\}, R_r, R_i \rangle$ and
$R_r = \mathbb{O} \times \mathbb{O}$ and $R_i = \mathbb{O} \times \mathbb{O}$

The density of point p was not locally observable by any of the organizations. Let us assume that each organization O_i can observe the outgoing flow f_i (i.e. $O_i \vDash_o f_i$) and that the conjunction of those flows represents whether the density is above x at point p. For a car j the atom $speed_j > 80$ is introduced, stating that j's speed exceeds 80km/h. We use $fine_j$ for "car j has a fine". The norm set is represented as $\{f_1 \wedge f_2 \wedge f_3 \wedge speed_j > 80 \Rightarrow v_j\}$ and the sanction set is $\{v_j \Rightarrow fine_j\}$. Car j is on the road of organization O_1 so $O_1 \vDash_o speed_j > 80$. Also each organization O_i can give a fine ($O_i \vDash_c fine_j$).

The norm is not locally monitorable as no organization can observe f_1, f_2 and f_3 all locally. Therefore there can be no local monitoring. The sanction is locally imposable in any organization. The norm is centrally and decentrally enforceable as all organizations together can observe all used literals and the closure of the communication relation connects all organizations. For norm assignments there are several options. Each organization can by communication detect the violation so the norm can be assigned to any organization, likewise for the sanction. However from all the possible assignments there will be some more preferable in practice. As an illustration, if we assign the norm and the sanction to O_1 then the communication costs will be minimal.

7 Towards practice

So far we have defined norms, distributed organizations, the enforcement of norms and the assignment of norms to local organizations. To put this into practical use we would need assignment functions that given a norm set and a distributed organization provide an assignment of the norms (or multiple candidate assignments). It is not our goal to provide such functions but we will give some examples of how they are related to our definition of norm and sanction assignments.

The solution space of assignment functions is the set of all possible assignments as per Definition 10. Depending on the requirements of a distributed organization, the used distribution function can access a subset of the solution space. For instance let (A_N, A_S) be an assignment of norms consider the following restrictions:

1. $\forall n \in N : \exists!(O, n) \in A_N$ and $\forall s \in S : \exists!(O, s) \in A_S$

2. $\forall n \in N : \exists (O, n) \in A_N, (O', n) \in A_N : O \neq O'$ and
   $\forall s \in S : \exists (O, s) \in A_S, (O', s) \in A_S : O \neq O'$

Assignments under the first restriction have no redundancy in the assignment of norms and sanctions, which increases efficiency. Assignments under the second restriction have at least two organizations per norm and sanction. This increases robustness of the distributed organization. If one organization fails then the norms are still properly enforced. It depends on the designer of the distributed organization which kind of properties should hold for assignments. Having a clear definition of assignments helps to think about what properties are possible.

If the accessed subset of the assignment solution space is not a singleton set, then an ordering is needed to determine the best assignments. For instance if we have a low bandwidth in the communication channels among organizations then those assignments are preferred where as little as possible communication is needed. Such a preference can be captured by for instance counting the amount of norm assignments where the norm cannot be locally monitored.

In our definition of global monitoring and sanctioning (Definition 5) we have not touched upon the issue of how to exactly get information from one organization to another. We stated the conditions such that it is possible. In an implementation it would be required to use a distribution annotation such that organizations know where to get which information. Future research can expand upon these issues.

8 Future work

Our work is to be a basis for further investigations of distributed organizations. In this paper we have described their nature and some considerations when one designs a distributed organization. There are still many research opportunities.

Norms were our main focus in this paper. We can also incorporate other organizational aspects. For instance there are interesting aspects to the use of constitutive norms when it comes to distribution. Constitutive norms relate brute facts to institutional facts. E.g. certain vehicles will count as trucks. The brute facts that are required for applying constitutive norms can also be locally or globally acquired. For monitoring and sanctioning in an organization the applicability of norms/sanctions would depend on whether the used institutional facts in those norms/sanctions can be derived by that organization.

We represented norms with counts-as rules that do not have context. Usually counts-as rules have the form $A \Rightarrow B \ in \ C$, where C is the context in which A counts as B. Context specifies under which circumstances obligations hold. For instance an obligation to have a maximum velocity of 120/km might only hold at daytime. Adding context to our framework would require a description of how the context is evaluated and how the required information for this is gathered. If the information is possibly distributed then the applicability of norms and sanctions can alter.

Also empowerment as investigated in [1] forms an interesting topic in the context of distributed organizations. If only a selection of organizations is em-

powered to determine a institutional fact, then this poses limits to the possible assignments of norms. Also information access among organizations can differ. We can filter out solutions where certain organizations need to acquire information for an observation to which they have no access. A topic that is related to empowerment is the notion of hierarchies among organizations. For instance it might be interesting to let organizations delegate monitoring and sanctioning tasks to other organizations.

In the future we want to move the work from the abstract level to more concrete levels such as programming frameworks for organizations. When doing so we want to also include organizational dynamics. A given infrastructure does not have to be permanent. We can imagine some distributed organization to be expandable with new organizations and communication relations among them. For instance the highway network can be expanded with new highway organizations, or become connected to other organizations. It would be interesting to investigate enforcement under the possibility of a dynamic distributed organization. Our final goal is to have a running network of organizations that in case of failing organizations or dynamic circumstances can restore itself and keep enforcing the norms.

9 Conclusions

To keep up with the decentralizing trend in software engineering it is important to investigate the use of distributed organizations. A distributed organization is described as a network of organizations. Each organization has observation capabilities to observe the environment and control capabilities to manipulate the environment. Norms have to be monitored for determining whether violation has occurred, and their violations have to be sanctioned to be enforced.

We have described the possible ways in which the enforcement overhead of norms can be distributed in a distributed organization. There are different approaches for the enforcement of norms. With centralized enforcement an organization applies both the norms and the sanctions. With decentralized enforcement a pair of organizations together enforces norms by letting one monitor the norms and the other impose the sanctions. Using these definitions we have described what proper norm assignments are. The result can be used as a basis for further investigations of distributed organizations and as a guideline for functions that produce assignments of norms for distributed organizations. In future work we plan to move the results to other organization aspects beside norms and towards a more concrete level.

Acknowledgments

This research is funded by Next Generation Infrastructures.
URL: http://www.nextgenerationinfrastructures.eu

References

1. O. Cliffe, M. De Vos, and J. Padget. Specifying and reasoning about multiple institutions. In *AAMAS'06: Workshop on Coordination, Organization, Institutions and Norms in agent systems (COIN-2006)*, 2006.
2. M. Dastani, N. Tinnemeier, and J.-J. Ch. Meyer. A programming language for normative multi-agent systems. In V. Dignum, editor, *Multi-Agent Systems: Semantics and Dynamics of Organizational Models*, pages 397–417. 2008.
3. V. Dignum. *A model for organizational interaction: based on agents, founded in logic*. PhD thesis, Universiteit Utrecht, 2004.
4. M. Esteva. Islander: an electronic institutions editor. In *AAMAS'02: Proceedings of the First International Conference on Autonomous Agents and Multiagent systems*, pages 1045–1052. ACM Press, 2002.
5. D. Gaertner, A. Garcia-camino, P. Noriega, and W. Vasconcelos. Distributed norm management in regulated multi-agent systems. In *AAMAS'07: Proceedings of the 6th International Conference on Autonomous Agents and Multiagent Systems*, pages 624–631, 2007.
6. J.F. Hübner, O. Boissier, and R.H. Bordini. A normative programming language for multi-agent organisations. *Annals of Mathematics and Artificial Intelligence*, 62:27–53, 2011.
7. J.F. Hübner, J.S. Sichman, and O. Boissier. Moise+: towards a structural, functional, and deontic model for mas organization. In *AAMAS'02: Proceedings of the first International Conference on Autonomous Agents and Multiagent Systems*, pages 501–502, New York, NY, USA, 2002.
8. N.H. Minsky and V. Ungureanu. Law-governed interaction: A coordination and control mechanism for heterogeneous distributed systems. *TOSEM, ACM Transactions on Software Engineering and Methodology*, 9:273–305, 2000.
9. F.Y. Okuyama, R.H. Bordini, and A.C. da Rocha Costa. A distributed normative infrastructure for situated multi-agent organisations. In *AAMAS'08: Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems - Volume 3*, pages 1501–1504, Richland, SC, 2008.
10. J. Searle. *The Construction of Social Reality*. Free Press, 1995.
11. B. Testerink and M. Dastani. A norm language for distributed organizations. In *BNAIC'12:Proceedings of the 24th Belgium-Netherlands Conference Artificial Intelligence Conference*, pages 234–241, 2012.