A Conceptual Middleware for Adaptive Sanctioning in Normative Multi-Agent Systems

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Abstract. The use of the normative approach to govern Multi-Agent Systems has been motivated by the increasing interest in balancing between agents' autonomy and global system control. In Normative Multi-Agent Systems (NMAS), despite the existence of norms specifying the rules of how agents ought or ought not to behave, agents have the autonomy to decide whether or not to act in compliance with them. A suitable way to govern agents is using sanction-based enforcement mechanisms. These mechanisms provide agents with a certain level of autonomy while controlling them through the application of sanctions. Here we present a conceptual middleware that makes use of an adaptive sanctioning enforcement model to improve the level of norm compliance in NMAS by enabling agents to choose among several categories of sanctions.

1. Introduction

Multi-Agent Systems (MAS) are characterised by a set of heterogeneous agents that interact among themselves (e.g., cooperate, compete, and negotiate) in order to perform their tasks and achieve their goals [Wooldridge 2009]. An important characteristic of agents in MAS is the capability to operate autonomously. If not properly governed, however, such autonomy may result in degraded emerging properties of the system [Johnson et al. 2012].

For the last two decades, the normative approach has attracted the attention of the scientific community as a means to tackle the issue of MAS governance. Such interest is due to the fact that norms have been recognised as playing a key role in regulating humans' behaviours and maintaining the social order in the human society [Castelfranchi 1995, Castelfranchi 2000, Conte et al. 1998, Verhagen 2000, Boella et al. 2006, Boella et al. 2008, Hollander and Wu 2011, Andrighetto et al. 2013]. In agreement with Boella *et al.* [Boella et al. 2006], we refer to norms as "a principle of right action binding upon the members of a group and serving to guide, control, or regulate proper and acceptable behaviour", and to normative as a qualifier of something "conforming to or based on norms". Normative Multi-Agent Systems (NMAS) are then the integration of normative concepts into MAS. This approach has been motivated by the increasing interest in balancing between agents' autonomy and control in MAS [Verhagen 2000].

Norms by themselves, however, do not guarantee that agents will comply with them. Agents have autonomy to decide whether or not to comply with or violate such norms. A possible form to govern NMAS is by using enforcement mechanisms that

may motivate agents to comply with or prevent agents from violating norms. Here we propose the use of sanctioning as an enforcement mechanism. Sanction is a reaction or response to a norm violation or compliance used as a means to achieve social order [Castelfranchi 2000]. Sanctions may be either direct (material) or indirect (social). Direct sanctions have an immediate effect on the resources of the target agent (e.g., by imposing fines), whereas indirect sanctions may affect future interactions of the sanctioned agent (e.g., by affecting its reputation) [Cardoso and Oliveira 2009].

There are two complementary sanctioning approaches. One is the *trust and reputation* approach in which given two agents, A and B, A may sanction B by performing any action that, positively or negatively, affects B's reputation. The other is the *norm enforcement* approach in which a non-complaint behaviour is negatively sanctioned and a compliant behaviour positively sanctioned by the institutions in the NMAS [Nardin 2015].

A considerable amount of sanction enforcement mechanisms may be found in the literature. Some examples of these mechanisms are presented in [Cardoso and Oliveira 2009, Centeno et al. 2011, Centeno et al. 2013, Criado et al. 2013, Daskalopulu et al. 2002, De Pinninck et al. 2010, Luck et al. 2003, Mahmoud et al. 2012a, Mahmoud et al. 2012b, Modgil et al. 2009, Villatoro et al. 2011]. However, they lack the support of at least one of the following: multiple categories of sanctions; potential association of multiple sanctions with multiple norms; or the decision-making to determine the most adequate sanction to apply depending on different contextual factors. As shown in [Nardin 2015], these are all desirable requirements for sociotechnical systems, all of which we intend to address with the middleware proposed in this work.

Here we propose a middleware to enforce norms in NMAS using sanctions in order to achieve increased levels of norm compliance. The remaining sections are organised as follows: Section 2 briefly describes the adaptive sanctioning enforcement model used in the middleware; Section 3 introduces the proposed middleware; and Section 4 reports future works.

2. Sanctioning Model

Our conceptual middleware is based on the sanctioning enforcement model proposed by Nardin and colleagues [Nardin et al. 2016, Nardin 2015]. This enforcement model is based on the social approach in which the agents themselves are responsible for performing an adaptive and auto-organised peer control. For such purpose, agents are endowed with mechanisms to monitor their peers, assess their behaviours, and apply sanctions whenever necessary.

The model is comprised of a *sanctioning enforcement process* and a *sanctioning evaluation model*. The sanctioning enforcement process enables agents to reason about and adapt their behaviour regarding possible sanctions (Figure 1). It has four stages: (i) violation detection; (ii) sanction determination; (iii) sanctioning process; and (iv) assimilation. Five capabilities (Detector, Evaluator, Executor, Controller, and Legislator) enact these stages by using two data repositories (De Jure and De Facto).

The repositories are centralised and used to store information about norms and sanctions. The De Jure repository stores norms and sanctions, as well as links between
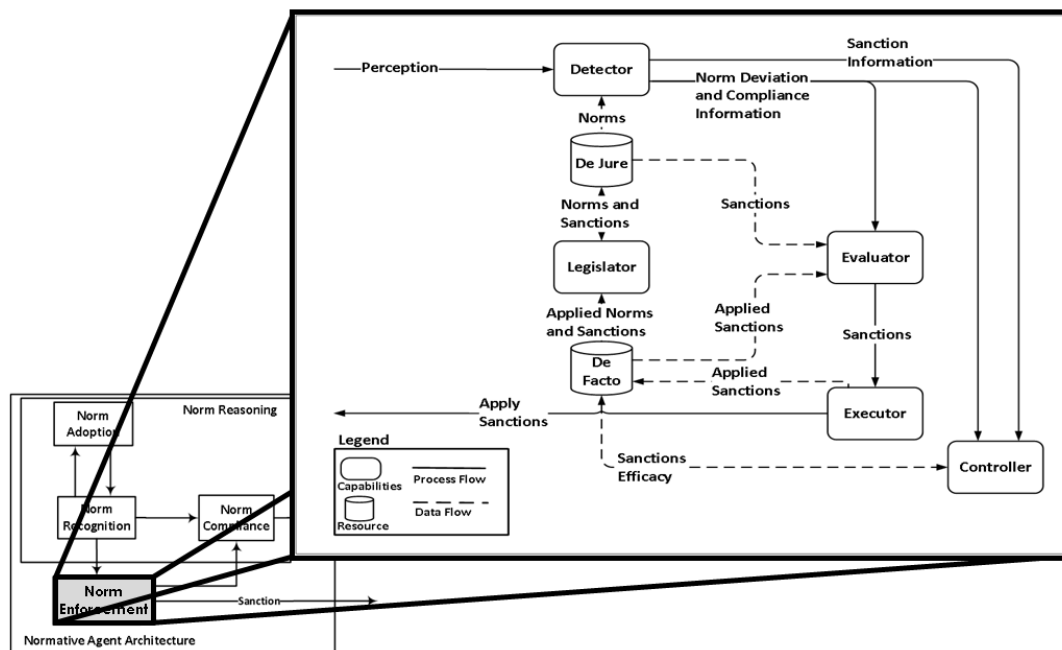
Figure 1. Sanctioning enforcement process model [Nardin 2015].

them, which are also known by the agents. One norm may be related to s different sanctions, whereas one sanction may be triggered by n different norms, as shown in Figure 2. The De Facto repository stores information about the applied sanctions and other relevant information used to assess their efficacy.
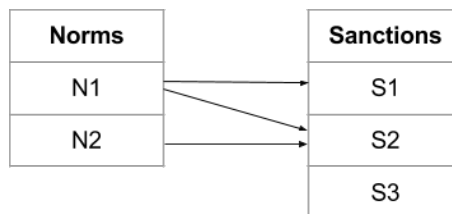

Figure 2. Relationship of norms and sanctions in the De Jure repository.

The five capabilities of the sanctioning enforcement process are:

- **Detector** – perceives the environment and detects any norm violation or compliance, and sanctions applied by other agents;
- **Evaluator** – obtains information from De Jure and De Facto to determine whether and which sanctions to apply;
- **Executor** – applies a sanction;
- **Controller** – monitors the outcomes of applied sanctions to evaluate their efficacy and records information about sanctions applied by other agents;
- **Legislator** – updates De Jure based on an assessment of De Jure and De Facto.

3. Proposed Middleware

Here we propose a middleware to implement the adaptive sanctioning enforcement model for NMAS briefly described in Section 2. This middleware will be developed as artefacts in the JaCaMo platform [Boissier et al. 2013].

The JaCaMo platform introduces a new promising programming paradigm called "multi-agent oriented programming" by integrating three orthogonal programming paradigms. It puts together agent-oriented programming, organisation-oriented programming, and environment-oriented programming in a synergistic way while preserving separation of concerns. A system built with JaCaMo is given by an agent organisation programmed in $\mathcal{M}\text{OISE}^+$ [Hübner et al. 2007], autonomous agents programmed in *Jason* [Bordini et al. 2007], and shared distributed artefact-based environments programmed in CArtAgO [Ricci et al. 2009]. Artefacts are building-blocks which provide services in addition to functions that make individual agents work together in a MAS and shape the agent environment according to the system needs. We chose JaCaMo due the high-level first-class support it provides for developing agents, environments, and organisations in synergy.

The middleware architecture is shown in Figure 3. The figure shows a couple of sample agents (*Agent A* and *Agent B*) in an environment. These agents may possess the five capabilities aforementioned (Detector, Evaluator, Executor, Controller, and Legislator) and are able to use the De Jure and De Facto repositories available on the environment. *Judge X* and *Legislator Y* represent two special artefacts provided by the middleware. *Judge X* is responsible for applying formal and direct sanctions. For example, suppose *Agent A* reports to *Judge X* a possible norm violation caused by *Agent B*. *Judge X*, based on De Jure and De Facto repositories, decides whether a sanction is appropriate and, if so, chooses which sanction to apply and its level of severity. *Legislator Y* is responsible for updating norms and sanctions in De Jure based on the assessment of the De Jure and De Facto repositories.
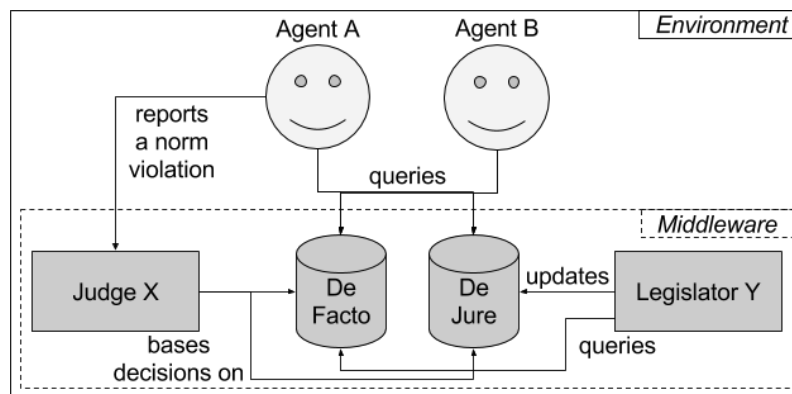
Figure 3. Middleware architecture.

The main advantage of our proposed middleware is the focus on flexibility and adaptability. By using our middleware, agents are free to choose the best way to sanction a violator or complier agent. In addition to being able to decide between formal or informal sanctions, they may also determine the level of severity of the informal ones. Due to the fact that these decisions are all dependent on the current context and historic facts, our middleware can, therefore, assure high level of flexibility and adaptability for norm enforcement in NMAS.

As direct consequence of the flexibility provided, the main disadvantage of our middleware is the limited control and predictability of the final results. As the sanctioning

mechanism depends on system's history and evolution, this influences how agents will learn and apply sanctions.

4. Future Works

This work is at an early stage of development and still in its conceptual phase. A first possible step would be to create a $\mathcal{M}$OISE$^+$ model, whose roles correspond to the five capabilities of the normative enforcement process. A next step would be to perform tests with the current architecture. Next, we intend to decentralise the De Facto repository meaning that every agent will have its own De Facto while De Jure remains centralised like the "penal code" in an environment-level of the NMAS.

Acknowledgements

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