AI Communications 26 (2013) 317–318
DOI 10.3233/AIC-130560
IOS Press



Thesis

# Using norms to control open multi-agent systems

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**Abstract.** In this thesis we propose to use norms, which are formal descriptions of acceptable behaviours, to define control, coordination and cooperation mechanisms for multi-agent systems. Specifically, in this thesis we have developed norm-based mechanisms for open multi-agent systems at two levels: at agent level we address the problem of defining norm-autonomous agents that deliberate about norms within uncertain environments; and at multi-agent system level we propose a distributed architecture for enforcing norms in open multi-agent systems.

Keywords: Norms, multi-agent systems, agents

## 1. Introduction

Open Multi-agent systems (MAS) are formed by autonomous agents which may be designed independently according to different goals and motivations. Because of this, control, coordination and cooperation mechanisms are needed in MAS for ensuring social order and avoiding conflicts. With this aim, "social" notions, such as norms, have been introduced in MAS.

In MAS research, norms have been defined as a formal specification aimed at controlling and coordinating the life of software agents and the interactions among them. In spite of the great amount of work on the usage of norms in MAS, there are many issues that are still pending [3]. In this thesis we address the problem of controlling and reasoning about norms in Open MAS. Specifically, in this thesis we have developed norm-based mechanisms for open MAS at two levels: at agent level we address the problem of defining norm-autonomous agents that deliberate about norms within uncertain environments; and at multi-agent system level we propose a distributed architecture for enforcing norms in open MAS.

## 2. Using norms at agent level: The n-BDI architecture

Regarding the challenge of building norm-autonomous agents, in this thesis we propose the n-BDI architecture which extends a BDI agent architecture with normative notions, allowing agents to acquire norms from their environment and determine when they are relevant. The main components of the n-BDI architecture, as well as, the reasoning process carried out by n-BDI agents, have been described in [2] and [4], respectively.

We also propose techniques for allowing n-BDI agents to deliberate about the convenience of norm compliance. Deliberating about norm compliance not only implies considering reasons for and against norm fulfilment but also for and against norm violation. Specifically, in this thesis we propose a deliberation mechanism for allowing n-BDI agents to determine their willingness to comply with norms according to rational and emotional factors [6]. The way in which rational and emotional factors are combined allows different personalities to be modelled.

Agents may become members of different institutions along their life. Thus, agents need capabilities that allow them to keep track of the institutional state. This connection between the physical world and the

institutional world is defined by means of constitutive norms. In this thesis we propose an information model and associated mechanisms to enable n-BDI agents to consider the impact of their actions on the institutions and making decisions accordingly.

When a n-BDI agent decides to comply with norms, then it creates new desires to pursue an state of affairs in which the norms have been fulfilled. Similarly, when an n-BDI agent uses constitutive norms to infer changes in the institutional world, it creates new beliefs for representing these changes. Thus, norms are used by n-BDI agents to extend their cognitive elements (i.e., beliefs and desires) with new formulas. These new formulas might be in conflict with existing ones. Hence, agents should resolve contradictions before making a decision about which action to perform. To address this problem, we have proposed that n-BDI agents carry out a coherence maximization that solves the existence of conflicting formulas by calculating and selecting those formulas that maximize the coherence of the cognitive elements present in the agent theory.

To evaluate the performance of n-BDI agents in dynamic and uncertain environments we have applied this architecture into a fire-rescue case study. The experimental results illustrate that the n-BDI architecture allows to model a more dynamic behaviour since n-BDI agents are capable of self-adjusting their behaviour to the features of the rescue operation in which they are involved.

## 3. Using norms at multi-agent system level: The MaNEA architecture

Agent platforms are the software that supports the development and execution of MAS. Thus, agent platforms must implement norms in an optimized way, given that in open MAS the internal states of agents are not accessible. Therefore, norms cannot be imposed as agent beliefs or goals, but they must be implemented in the platforms by means of control mechanisms.

This thesis considers the main challenges of open MAS and points out the main deficiencies and drawbacks of agent platforms and infrastructures when supporting norms. With the aim of overcoming some of these problems, in this thesis a Norm-Enforcing Architecture, known as MaNEA, have been proposed. The main components of MaNEA as well as its evaluation have been described in [5].

MaNEA is responsible for monitoring (i.e., detecting norm fulfilments and violations) and enforcing (i.e., applying sanctions and rewards when necessary) the norms that regulate open MAS. In addition, MaNEA provides agents with information about sanctions and rewards which allows them to use this information for selecting the most suitable interaction partners. MaNEA provides support to norm enforcement in dynamic situations; i.e., the norms and instances can be created or deleted online. Finally, MaNEA is built upon a trace event system, which provides support for indirect communication in a more efficient way than overhearing approaches. As the theoretical and experimental evaluation show, the use of a tracing service reduces the number of messages required to control norms. Besides that, MaNEA can dynamically adapt to changes in the scale MAS (i.e., situations in which the number of agents or norms to be controlled changes dramatically) by performing cloning and self-deletion operations.

## 4. Conclusions

In this thesis, we focus on developing norm-based mechanisms suitable for controlling and coordinating open MAS. Specially, this thesis is aimed at developing both an agent architecture, which allows agents to reason autonomously about norms; and a norm-enforcing architecture, which allows norms to be implemented in open MAS. As future work, we will extend the n-BDI architecture for allowing agents to make collective decisions about norm compliance. The whole PhD thesis can be consulted in [1].

## References

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