A Norm-Based Approach for the Modeling of Open Multiagent Systems

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Abstract: A major challenge in the research of multiagent systems (MAS) is the design and implementation of open MAS in which norms can be effectively applied to their agents and easily managed. These tasks are arduous because norms are usually written for general purposes, hindering a more precise regulation. The motivation for this research came forth from the need to resolve this challenge, providing an approach applicable in open systems. In such systems, heterogeneity and autonomy rule out any assumption concerning the way third-party entities are implemented and behaved. In this paper, a norm-based approach for the modeling of open MAS, named DynaCROM, is presented. The paper also summarizes the result of a study that focuses on solutions for the modeling of MAS and that motivated the development of our DynaCROM approach.

1 INTRODUCTION

Three main observations form the starting point for this research. Firstly, "*autonomous agents and MAS represent a new way of analyzing, designing and implementing complex software systems*" [Jennings, 1998]. Those systems are usually formed by rich social interactions, *i.e.* by agents cooperating, coordinating and/or negotiating [Jennings, 2001].

Secondly, with the Web evolving towards a Semantic Web [Berners-Lee *et al.*, 2001], it is believed that available information will be presented in a meaningful way for allowing not only humans to process its content, but also (*software*) agents. In this scenario, agents will be able to migrate among MAS in order to obtain resources and/or services not found in their original systems. Thus, if one main contribution of Semantic Web can be singled out, it has to be *openness*. *Openness* will permit new types of applications for MAS, as ubiquitous systems [Weiser, 1991], in which dynamicity, due to internal/external events, is a key characteristic.

Thirdly, considering that MAS will be open in nature, norms play a central role in the social phenomena occurring in the MAS field, which is moving more and more from the individual, cognitive focused agent models to models of socially situated agents. In normative MAS (NMAS), the main posed question is: "*How to ensure efficiency at the level of MAS whilst respecting individual autonomy?*" [Boella, 2006]. NMAS as an area of research has become a major issue in the MAS field and it can be situated at the intersection of normative systems and MAS.

Following these three main observations, it is believed that upcoming information systems will be implemented as *open* MAS formed by several goal-oriented problem-solving entities.

Openness has consequences for the design, implementation and use of information, requiring novel modeling primitives and methods in order to make a MAS a real application. Solutions for open MAS must deal with issues inherent to open environments, namely: heterogeneity of agents; trust and accountability; exception handling (detection, prevention and recovery from failures that may jeopardize the global operation of the system); and, societal change (capability of accommodating structural changes) [Dignum *et al.*, 2007; Al-Muhtadi *et al.*, 2003].

A very dynamic, open and distributed domain – like the Semantic Web and applications for ubiquitous computing, both that can be implemented by MAS – is always subject to unanticipated events [Hewitt, 1991], caused by malicious agents that do not conform to recommendations of correct and incorrect behaviors. This risk imposes the necessity for regulatory mechanisms for preventing undesirable actions to happen and, consequently, to inspire trust for the members of the system.

In this paper, the result of a study that focuses on solutions for the modeling of MAS is presented. The study motivated the development of our DynaCROM approach (meaning *Dynamic Contextual*

Regulation information provision in Open MAS). From the individual agents' perspective, DynaCROM is an information mechanism that makes application agents aware of the norms they are bound to at a given moment. From the system developers' perspective, DynaCROM is a methodology to operationalize regulative norms in open MAS, enabling developers to embody abstract norms with domain values.

Further details about specific aspects of DynaCROM can be found in more specialized publications. In [Felicíssimo *et al.*, 2008b], the guidelines to operationalize regulative norms in NMAS by using DynaCROM are presented. Following those guidelines, concrete norms are reached from abstract ones, operationalized in NMAS. In [Felicíssimo *et al.*, 2008a] the details about how DynaCROM contextualizes norms in a NMAS, from the perspectives of individual agents and system developers are provided. In [Felicíssimo *et al.*, 2008c] a case study from the television domain and in [Felicíssimo *et al.*, 2007] a case study from the domain of multinational corporations are presented.

The remainder of this paper is organized as follows. Section 2 gives an overview of the foundations upon the modeling of MAS. Basic theories and related research fields are analyzed in order to provide readers with a better understanding about the concepts and ideas described in this paper. Section 3 discusses the current solutions for MAS modeling presented. Section 4 briefly presents the DynaCROM approach, including its phases of concretization, contextualization, representation and composition of norms in NMAS. Section 5 finalizes the paper presenting our conclusions.

2 MODELING OF MAS

Traditional modeling of MAS often assume an individualistic perspective in the sense that agents are considered autonomous entities, pursuing their own individual goals based on their own beliefs and capabilities. Even in this perspective, global behavior emerges from individual interactions and, therefore, the modeling has to be expanded to consider not only an *agent-centric* view, but also *societal* and *organizational-centric* views. Furthermore, the overall problem of analyzing the social, legal, economic and technological dimensions of an agent organization is not normally considered when, ideally, it should be resolved.

Agent-centered approaches can be useful for closed systems, composed of a small number of agents, but they fail to design open systems [Rodríguez-Aguliar, 2001; Esteva *et al.*, 2003]. For instance, in critical applications such as those within business, environments or government agencies (hospitals, police, justice, *etc.*), the structural characteristics of the domain have to be incorporated. That is, the design of an agent society must also consider organizational characteristics such as stability over time, some level of predictability, commitment to aims and strategies, and so on.

The idea of modeling MAS as organizations was early proposed by [Gasser *et al.*, 1987; Pattison *et al.*, 1987; Corkill and Lesser, 1983; Werner, 1987] and it is still a major issue in MAS research specially in applications on the areas of Service Oriented Computing, Grid Computing and Ambient Intelligence. Recently, the subject of MAS design from the organizational perspective has been mainly discussed in the COIN workshop [COIN, URL], which has been held yearly since 2005, as a dual event co-located within large international conferences of the area in different geographic regions.

Even with this research effort, organizational approaches have not been a common use in MAS, which is usually seen as a pure aggregation of agents. The fact that organizational approaches have not been effectively adopted suggests that some work still needs to be done in providing better tools for the design and implementation of MAS in which intrinsic characteristics of the application domain (*e.g.*, society structure) can be considered. Moreover, this necessity increases when considering open systems from particular 'cultures' (*i.e.*, "*the predominating attitudes and behavior that characterize the functioning of a group or organization*" [EDictionary, URL]).

In the next subsections, two major research lines for the modeling of MAS will be presented and, then, discussed. The first research line proposes the modeling of MAS based on organizations and the second one proposes the modeling based on the *electronic institutional* aspects of organizations. By '*electronic institutional*' aspects, the authors mean an organization restricted through the definitions of all the following: related roles, common language, valid interactions and set of norms.

2.1 Electronic Agent-Based Organizations

The definition of the *organization* term usually varies between two meanings for MAS researchers. In the first meaning, an organization is often understood as an entity with identity that represents (not identical) groups of agents. In the second meaning, an organization is often understood as constraints (structures, norms and patterns) found in a social context that shapes the actions and interactions of agents [Coutinho *et al.*, 2005].

Considering the case that every organization has a social organization, the latter is materialized in the first one by the specification of the structure and objectives of the system. Thus, a social organization is envisioned by the organization as a whole and by describing the activity of the system as realized by the individual agents [Vázquez-Salceda *et al.*, 2005]. In this sense, the organizational dimension covers both the organization and the agent perspectives in the design of agent societies.

The work on MAS modeling based on the organizational dimension mainly started with the emergence of the HarmonIA [Vázquez-Salceda and Dignum, 2003] and OperA [Dignum, 2004] formal frameworks. HarmonIA provides the way to model especially highly regulated electronic organizations from the abstract level, where norms are usually defined, to the final protocols and procedures that implement those norms. The HarmonIA framework also incorporates ontologies to describe and connect different levels of norms.

OperA is a formal specification framework that focuses on the organizational dimension, properly modeling not only organizational structures in an agent society (that structures the global behavior of the society), but also the aims and behavior of the agents from the agent perspective. The framework also explicitly provides a solution for ontological descriptions of agent interactions.

In [Vázquez-Salceda *et al.*, 2005], the *Organizational Model for Normative Institutions* (OMNI) framework is presented, resulting from the combination of some aspects of the HarmonIA and OperA frameworks. The OMNI framework focuses on the organization dimension (that also structures the global behavior of the society), on the behavior of the agents from the agent perspective, on agent interactions and on a normative structure that is separate from the agents that will populate the MAS.

In order to support the development of closed systems and open, flexible environments, OMNI presents a rigid specification of its structure, defining particular fields for the description of scenes, roles and groups of roles. There are no normative aspects further than the ones for organizations, roles, group of roles, agent interactions and agents (only norms for roles, group of roles, scene and transition can be specified). The organization entity is not explicitly present. An organization is formed by listing all its institutional roles (*e.g.*, managers, directors, president, *etc.*) and represented when agents play those roles. Currently, OMNI does not provide a solution for the implementation and integration of its specifications in a given MAS.

Another important line of research, based on organizational models for MAS, is mainly proposed by Sichman, Boissier and their colleagues with their work started with $\mathcal{M}$OSE [Hannoun *et al.*, 2000]. $\mathcal{M}$OSE is an organizational model for MAS based on three major concepts: the roles which constrain the individual behaviors of agents, the organizational links that regulate social exchanges between agents and the groups which constrain the layout of agents involved in strong interactions.

In [Hübner *et al.*, 2002], the work on $\mathcal{M}$OSE evolved resulting in the $\mathcal{M}$OISE$^+$ model. $\mathcal{M}$OISE$^+$ permits the specification of a MAS organization along the structural and functional dimensions, which can be specified independently of one another. Furthermore, $\mathcal{M}$OISE$^+$ makes explicit the deontic relation which exists between both dimensions. In short, the $\mathcal{M}$OISE$^+$ organizational model enables the declaration of the MAS organizational structure (roles, groups and links), functioning (a set of global goals and plans), obligations and permissions.

2.2 Electronic Agent-Based Institutions

The idea of modeling MAS as institutions came from the observation that human institutions [North, 1990] have been successfully mediating human interactions for centuries and, so, EI (meaning *Electronic Institution(s)*) may cope with a similar responsibility within agent societies. The aim of the proposal is to promote a natural extension of human institutions by permitting not only humans, but also autonomous agents to interact with one another in a reliable way. This way, EI can be seen as the electronic counterpart of a human institution in which interactions between agents are articulated through a role-based multiagent protocol specification.

The work on formalization of EI has been done for years and it is extensively presented mainly in [Noriega, 1997], [Rodríguez-Aguilar, 2001] and [Esteva, 2003]. In [Noriega, 1997], the different components of an institution are introduced by using a typical trading institution – the fish market auction houses – as a motivating example. Noriega proposes that an institution is defined by: (i) a set of roles and relationships within them, (ii) a common ontology and communication language which allow heterogeneous agents to exchange knowledge, (iii) the valid interactions that agents may have structured in conversations, and (iv) a set of rules of behavior which determine the actions that agents must take under certain circumstances.

In [Rodríguez-Aguilar, 2001], the formalization of EI presented by Noriega was extended and refined, resulting in the definition of ways of realizing EI. Rodríguez-Aguilar proposes an infrastructure to implement EI that can be realized by making use of a special type of mediator agents, the so called *interagents* [Martín *et al.*, 2000]. Each agent involved in a conversation is connected to an interagent, which mediates the agent's interactions in one-to-one conversations.

In [Esteva, 2003], the previous work done by [Noriega, 1997, and Rodríguez-Aguilar, 2001] on the formalization of EI was continued. In his work, Esteva provides support for the specifications of EI, their automatic verification and also their realization. His main concrete result, the ISLANDER graphical editor, was developed as a generic infrastructure which could be used for the deployment and verification of the specified institutions.

The limitation of the Rodríguez-Aguilar's work in which only one-to-one conversations could be mediated by interagents was improved in Esteva's work. There, for each conversation, a governor agent (an evolution of the interagent one) has two queues, one for the messages received from its associated agent and another one for the messages received from the social layer agents. As a case study, Esteva evolved the previous examples of Noriega and Rodríguez-Aguilar on fish markets, now regarding multi-market institutions instead of only single-market ones.

Many other publications of EI have appeared recently [*e.g.*, Esteva *et al.*, 2004; García-Camino *et al.*, 2005 and 2006; Grossi *et al.*, 2007], expanding the work on the subject.

In [Esteva *et al.*, 2004], the AMELI agent-based middleware is proposed as an infrastructure that mediates agents' interactions while enforcing institutional norms. The combination of ISLANDER and AMELI supports the design and development of open MAS adopting a social perspective.

In [García-Camino *et al.*, 2005], a distributed architecture for EI is proposed in order to endow MAS with a social layer in which normative positions are explicitly represented and managed via rules for regulation. In [García-Camino *et al.*, 2006] the rule-based language from the authors is better detailed as a declarative normative language that can represent distinct flavors of deontic notions and relationships. Every external agent from the architecture has a dedicated governor agent linked to it that enforces the norms of executed events.

In [Grossi *et al.*, 2007], the work on formalization of EI is continued, focusing on both institution and its components (abstract and concrete norms, empowerment of agents and roles). Yet, a formal relation between institutions and organizational structures is also defined in such a way that institutional norms can be refined to construct – organizational structures – which are closer to an implemented system. Thus, the gap between abstract norms and concrete system specifications is better bridged.

Despite all work done, a MAS implemented as an EI is still understood as a type of dialogical system that simply structures agent interactions by establishing the commitments, obligations and rights of participating agents. However, the solution not only structures interactions, but also enforces individual and social behaviors by obliging every agent to act according to the defined norms.

The following current limitations of EI are outlined: (i) there are no normative aspects further than the ones for roles, agent interactions and agents; (ii) the specification of an EI is often too *society-centric* in the sense that it completely fixes agent interactions in rigid protocols and interfaces; (iii) external agents have no room for autonomous behavior, *i.e.*, they blindly follow defined protocols with the only autonomy to accept or reject them; (iv) all possible interactions among agents have to be defined; (v) it is difficult, if not impossible, to describe indirect interactions; this is due to the fact that all interacting activity taking place in an EI is purely dialogic by means of direct communication between the agents; and, (vi) the structure of an EI is static and, so, cannot evolve at system runtime.

3 DISCUSSION

The models used to describe or design an organization are classically divided into the *agent-centered* or *organizational-centered* perspectives [Lemaître and Excelente, 1998]. In the first perspective, system developers try to analyze and/or design a whole MAS that shows a non-accidental and non-chaotic global behavior starting from the agents (parts of the system).

In the open MAS scenario, the basic problem with the *agent-centered* idea is that the system developer has no control anymore over the creation of the agents. Thus, at any time, external heterogeneous agents can join or leave an open MAS and, then, disrupt the existing order. As long as open MAS are highly desirable to face today's increasingly distributed and interconnected computing demands, this wish poses problems that still need concrete solutions.

In the last few years, one promising path of research and development has been an *organizational-centered* analysis and design of MAS (second perspective). In this attempt, system developers proceed in a top-down fashion, explicitly defining both the organization entity (external to the agent level) and the organization statutes that agents must comply with. The statutes of an organization indicate, at the most abstract level, the main objectives of the organization and the values that direct the fulfilling of its objectives. Moreover, statutes also point to the context in which the organization will have to perform its activities [Vázquez-Salceda *et al.*, 2005].

Analyzing several *organizational-centered* models found in the literature (*e.g.*, OMNI [Vázquez-Salceda *et al.*, 2005], ISLANDER [Esteva *et al.*, 2002], $\mathcal{M}$OISE^{+} [Hübner *et al.*, 2002]), we find two main sources of difficulties presented in [Coutinho *et al.*, 2008]. The first one is that the very notion of organization admits and is frequently used with slightly different interpretations. Sometimes, the organization term refers to "*collectivities oriented to the pursuit of relatively specific goals and exhibiting relatively highly formalized social structures*" [Scott, 1998]. Other times, the term refers to stable social patterns/structures of joint activity that constrains and drives the actions and interactions of agents towards a purpose. The second source of difficulty is that the organization entity can be described in several modeling dimensions (*e.g.*, in the structural and functional ones).

These two sources of difficulties are important and should be considered because each proposal of an organizational model makes a particular ontological commitment in regard to them.

A proposal for an integrated ontology, which is developed in a bottom-up manner from the existing organizational models, is presented in [Coutinho *et al.*, 2008]. The main purpose of such ontology is the creation of an interoperation mechanism that can be used by heterogeneous organizational models for handling interoperability among open *organizational-centered* MAS. However, the proposal is an ongoing work and, therefore, needs to be concluded.

In [Vázquez-Salceda *et al.*, 2005], some drawbacks of current approaches for MAS modeling also are pointed out, as follows. MAS modeling are too *agent-centric* or too *organizational-centric*. Some methodologies (*e.g.*, GAIA [Wooldridge, 2000]; Prometheus [Winikoff and Padgham, 2004]) are too *agent-centric* in the sense that they are mainly focused on the model of single agents and give limited support to model the dynamic interactions of the agents in the agent society. Other methodologies (*e.g.*, SODA [Omicini, 2001] and ISLANDER) are too *society-centric* in the sense that they completely fix agent interactions in rigid protocols and interfaces in such a way that the agents cannot exercise their characteristic of autonomy.

Roles and *agents* are usually treated without an explicit distinction. This distinction is important in order to establish a difference between organizational values and individual (agent) values.

Normative aspects are not often considered or, when considered, they are either too theoretical or too practical. Few agent methodologies cover normative aspects and they usually do it by trying to model the whole normative environment in only one level of abstraction, either too theoretical (by means of computationally hard logics) or too practical (by means of the usage of policies or protocols).

Ontologies are often seen as an external (accessory) component, while in fact they should be tightly coupled with the rest of the system when used to model most of its elements.

4 CONTEXTUALIZING MAS

4.1 From Abstract to Concrete Norms

A major challenge in NMAS is how norms can be effectively applied to their agents and, then, easily managed and evolved. These tasks are arduous because norms are usually written for general purposes, hindering a more precise regulation.

In [Gaertner *et al.* 2007], the authors of the paper propose to extend the coordination level of a MAS with a normative level, so that, norms can be integrated during the design and execution time of the system. Our DynaCROM approach follows their proposition but, furthermore, it also proposes to extend the normative level with, what is called, a *contextual normative level*. In this level, abstract norms are concretized (*i.e.*, embodied) with domain values according to the context wherein they hold.

The proposition for contextual classification of norms follows the ideas first proposed by Dignum in [Dignum, 2002] and, then, refined in [Grossi and Dignum, 2004]. However, their works mainly address formal issues while DynaCROM provides an implemented solution as a proof-of-concept for the ideas proposed.

Considering a negotiation activity, from a simplistic supply-chain scenario, the following norm is considered in order to exemplify the DynaCROM *contextual normative level*:

> *A Payment Norm for Effecting a Negotiation*: Negotiations are obliged to be paid by using the national currency of the seller's country.

The payment norm presented above is abstract and vague, and therefore, applied for general purposes. In order to cause any effect in a regulated system, abstract norms must be translated into concrete norms [Grossi and Dignum, 2004]. Thus, the abstract payment norm might be contextualized, by the system developer of a DynaCROM NMAS, as an environment norm and, then, concretized in his system. For example, in the *American* and *Japanese* supply-chain domains, the environment norm is concretized with the following instantiations:

> *A Concrete Environment Norm for Effecting a Negotiation:* Negotiations are obliged to be paid (i) in *USA*, with *American dollars (USD)*; and, (ii) in *Japan*, with *Japanese Yen* (*JPY*).

In the contextual normative level, the classificatory reading of *counts-as* from [Grossi *et al.*, 2006] is applied. The reading states that if "A counts-as B in context c", then, it is interpreted as "A is a sub-concept of B in context c". In this sense, *counts-as* statements work as *contextual classifications*.

Considering the payment norm exemplified above, its reading is done as follows: "*USD* counts-as a *valid currency* in the context of the *USA environment*"; and its interpretation is done as follows: "*USD* is a sub-concept of a '*valid currency*' concept in the context of the *USA environment*".

4.2 Contextual Norm Classification

In order to help the system developer in his task of norm contextualization, DynaCROM follows directions taken by research into context-aware applications that suggest top-down architectures for classifying contextual information [Khedr and Karmouch, 1995; Henricksen and Indulska, 2005].

DynaCROM defines that norm information should be classified in a MAS according to the following contexts: *Environment*, *Organization*, *Role* and *Interaction*, which are differentiated by the boundaries of their data (*i.e.*, norms). *Environment Norms* are applied to all entities in a regulated environment. Likewise, *organization norms* are applied to all entities in a regulated organization; *role norms* are applied to all agents playing a regulated role; and, *interaction norms* are applied to all agents involved in a regulated interaction.

The four predefined normative contexts of DynaCROM are not targeted to a particular application domain; by so, they rather represent a basic set for a general regulation in NMAS. For a more precise regulation, this set should be improved through additions and refinements of application domain normative contexts and their respective norms. An example of a domain normative context and its norm might be, in the *Catholic* domain, a *Religious* concept that holds a (religious) norm stating that "*marriage is prohibited in the case that the man and/or the woman to be married made perpetual vows of chastity in a religious institute*".

4.3 Contextual Norm Representation

DynaCROM proposes a *contextual normative ontology* for declarative specifications of norms, providing information with a common understanding about well-defined system regulation to heterogeneous agents.

An *ontology* is a conceptual model that embodies shared conceptualizations of a given domain [Gruber, 1993]; a *contextual ontology* is an ontology that represents localized domain information [Bouquet *et al.*, 2003] (*e.g.*, *USD* is the national currency of *USA*); and, a *contextual normative ontology* is a contextual ontology that has a *Norm* concept as its central asset. The *Norm* concept should be instantiated with norms contextualized differently according to basic MAS entities (*i.e.*, environments, organizations, roles and agent interactions) or specific domain entities.

The DynaCROM ontology is an extensible one, *i.e.*, its basic concepts can be extended and/or new domain concepts can be created, both for representing classified contextual domain information. More precisely, the representation of a concrete norm in a DynaCROM ontology should be done by extending existing concepts or by creating new ones, then, instantiating the concept with norm information and, at last, linking the regulated instances to its related abstract norm (represented in the created norm instance).

4.4 Contextual Norm Composition

After classifying and representing norms in precise levels of abstractions, contextual norms can be composed during system execution since, at any given moment, an agent may be related to norms defined at one or more normative contexts. Compositions of related contextual norms result in sets of independent norms, in which the semantic of one norm can influence the semantics of the others. For instance, the environment norm presented below is considered:

> *A Concrete Environment Norm for Calculating Prices:* a state corporate income tax rate of *6.25* in *Missouri* is obliged to be imposed on all sales.

DynaCROM uses rules to compose contextual norms. DynaCROM rules are *ontology-driven rules*, *i.e.*, they are created by the system developer, according to the ontology structure, and they are limited to the related concepts to which each concept is linked to.

Code 1 presents an example of rule that recursively compose the norms of hierarchical environments as, for instance, the norms of the *Missouri* and *USA* environments. More precisely, considering *Missouri* as an example of the given environment, the following composition process is executed: in (4), the '*?OEnv*' variable is instantiated with the *USA* inferred value, when the '*?Env*' variable is instantiated with the *Missouri* given value; in (3), the

'*?OEnvNorms*' variable is instantiated with the *OblToPayWithNationalCurrency* inferred value; and in (2), the inferred norm is added as a new norm of *Missouri*.

The result of the norm composition process is that, in *Missouri*, all negotiations are obliged to be paid with *USD* and increased by a state corporate income tax of *6.25*.

Code 1: A DynaCROM rule to compose the norms of hierarchical environments.

```
(1)[DynaCROMRule_EnvWithOEnvNorms:
(2)  hasNorm(?Env,?OEnvNorms)
(3)   <- hasNorm(?OEnv,?OEnvNorms),
(4)       belongsTo(?Env,?OEnv)]
```

For the composition process, DynaCROM uses an inference rule engine that executes the following tasks: (i) read an ontology instance to get data (*i.e.*, concept instances and their relationships), (ii) read a rule file to retrieve the information about how concepts must be composed; and then, (iii) infer an ontology instance based on the previous readings.

Once the domain ontology and/or rule file change(s), updated information is automatically forwarded to agents in the next DynaCROM execution. This makes it possible for managements in the system to be done at runtime, providing the dynamicity and flexibility necessary for regulation and also regarding social changes characteristic of MAS. These achievements for norm management are gotten because all norms provided by DynaCROM are applicable at a given moment.

4.5 DynaCROM Incorporation in Agents

Agents executing in NMAS are heterogeneous, implemented by different third-party developers, with code that is inaccessible. A viable solution for regulation in NMAS should not be hard coded inside agents' original codes and it must allow some flexibility for updating data (*e.g.*, norms) during the system execution [Grizard *et al.*, 2006].

DynaCROM was implemented as a behavior that should be added by agents for them become aware of the applicable system norms, according to their current contexts. This way, DynaCROM is a non-invasive approach in the sense that agents are developed independently of it. Only a normative behavior is spontaneously added inside agents, thus, the DynaCROM code is not scattered inside agents or regulated NMAS, fostering modularity.

5 CONCLUSION

Three main assumptions underlie this research. Firstly, MAS has emerged as a concrete solution to develop complex software systems in which monolithic architectures (based on objects) have been replaced by distributed ones (based on agents). Secondly, with the advent of the Semantic Web, agents will be able to process information from different sources and, so, they will be able to move around other MAS looking for resources and/or services not found locally. In this scenario, openness will be an intrinsic and mandatory characteristic of upcoming systems. However, openness without control leads to chaotic scenarios. The use of norms in MAS is a promising approach for achieving openness in a reliable way. So, the final assumption of this work is that MAS should be normative.

However, despite all efforts made to move theory and practice of MAS from closed to open agent societies, current solutions do not yet explicitly support openness and its consequences. More precisely, methodologies, modeling languages and tools (*e.g.*, frameworks, platforms), needed for implementing open MAS, do not conveniently cover the aspects of regulation and domain representation for society differentiation.

A study done on solutions for the modeling of MAS led to the development of the DynaCROM methodology that operationalizes regulative norms in MAS. The DynaCROM methodology includes the phases of concretization, contextualization, representation and composition of norms.

The top-down classification for norms proposed by DynaCROM facilitates the tasks of elicitation, organization and management of norms. The DynaCROM contextual normative ontology supports heterogeneous agents with a common understanding about the system norms. The norm composition process defined by DynaCROM makes it easy to update system regulation by both evolving norms in a unique resource (an ontology) and/or by customizing particular rules for different compositions of contextual norms.

Nevertheless, a regulated NMAS should verify if a performed action is legal or illegal based on its defined norms, which might be enforced. Thus, DynaCROM also can be integrated with third-party enforcers for enforcing contextual norms in each application agent [Felicissimo, 2008b].

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