Intelligence Integration in Distributed Knowledge Management

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Chapter VII
Aspects of Openness in Multi-Agent Systems:
Coordinating the Autonomy in Agent Societies

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ABSTRACT

In the distributed multi-agent systems discussed in this chapter, heterogeneous autonomous agents interoperate in order to achieve their goals. In such environments, agents can be embedded in diverse contexts and interact with agents of various types and behaviours. Mechanisms are needed for coordinating these multi-agent interactions, and so far they have included tools for the support of conversation protocols and tools for the establishment and management of agent groups and electronic institutions. In this chapter, we explore the necessity of dealing with openness in multi-agent systems and its relation with the agent's autonomy. We stress the importance to build coordination mechanisms capable of managing complex agent societies composed by autonomous agents and introduce our institutional environment approach, which includes the use of commitments and normative spaces. It is based on a metaphor in which agents may join an open system at any time, but they must obey regulations in order to maintain a suitable reputation, that reflects its degree of cooperation with other agents in the group, and make them a more desired partner for others. Coloured Petri Nets are used to formalize a workflow in the institutional environment defining a normative space that guides the agents during interactions in the conversation space.

INTRODUCTION

The management of interoperation among agents is a complex task and requires robust techniques and methodologies to be applied in the development of reliable and open *Multi-agent Systems* (MAS). Generally, this category of computational systems is used to model distributed scenarios where heterogeneous software entities, *agents*, interact to pursue particular or common goals. Even more demanding is the modeling and implementation of features that give openness to those agents, allowing them to have the ultimate choice of obeying regulations or deal with possible sanctions imposed by the MAS norms. After all agents are *autonomous* entities and the biggest challenge is to have a *coordination system* where the agents can be free to decide what to do but at the same time be encouraged or seduced to obey the regulations of the *artificial society* where they are entering.

Agent frameworks, such as JADE (Bellifemine, Poggi, & Rimassa, 2000) and Opal (Nowostawski, Purvis, & Cranefield, 2002), are developed on top of abstract architectures such as the FIPA Abstract Architecture (Fipa) that aim to offer a standard mean for message exchanging between agents and with that ease the communication process in its lowest levels. *Agent communication languages,* such as FIPA-ACL (Fipa, 2002) and KQML (Finin, Labrou, & Mayfield, 1997), are introduced to define standard semantics for dialects used during agent communication, and *interaction protocols* attempt to balance the expressive power of such languages defining patterns of behaviour that agents must follow to engage in a communicative interaction with other agents as a way of building MAS that interoperate in "predictable" ways.

The individual, local, cultural and social aspects of the communicator are significant and can often outweigh conventional concerns of software developers, such as the development of appropriate syntax, efficient coding systems, and suitable terminologies. What is necessary is an infrastructure where the agents can rely on mechanisms that will implement or offer support for interoperation with efficiency.

Our approach aims to use institutional concepts for modeling open MAS as social groups formed by agents that establish a set of regulations to interact among them. As in ordinary institutional environments, those agents assume predefined roles in the MAS and will be supervised by some authorities, defined as *system agents*. The system agents are part of the infrastructure built to manage commitments among agents, or groups of agents, and agents' reputation in the institution.

Coloured Petri Nets (CPN) (Jensen, 1997) are used to model agent roles as well as all the interactive processes in the institution. CPN brings to our approach a well-defined semantics which builds upon true concurrency, hierarchical representations and an explicit description of both states and actions. Adding to that CPN has an elaborated set of computer tools supporting their drawing, simulation and formal analysis.

From the assumption that artificial agents can be part of a structured society that follows rules, we present an approach for the use of institutional environments, commitments and reputation models to organise MAS in social structures based on roles. One major concern in our approach is to grant an institutional environment where the degree of openness the member agents experience is part of the norms that regulates the MAS.

OPENNESS CONSIDERATIONS

How does one constrain an environment as heterogeneous as a human community? In different parts of the world different rules and norms are created so that the members of that group of people can feel a sense of security and order, so that they can carry on with their lives in a more predictable way. When a person needs some kind of service they know where to go, and if not they will ask another person or consult some kind of public catalogue. Once the person chooses to go to a place and make use of some sort of service he will make use of his past experiences and knowledge to carry on with actions, autonomously, and in a more or less standard way. Rules are there to be followed as well as to guide the members of a community so that they will have their rights observed in local and global aspects.

One of the main goals of our approach is to define and maintain an environment were agents will interact observing a set of rules or norms but not necessarily or compulsorily will have their actions restricted via some kind of interface agent, for example, the governors, in Electronic Institution Development Environment (EIDE) (Arcos, Esteva, Noriega, Rodriguez-Aguilar, & Sierra, 2005), or the controllers in Law-Governed Interaction (LGI) (Minsky & Ungureanu, 2000). Our approach is to offer mechanisms that will seduce the agents to play a cooperative role in the agent society, but ultimately the choice of cooperating or not cooperating will be its. That choice might generate the employment of sanctions by the system agents to noncooperative agents, and with that we will be able to use a model closer to the human way of organizing their societies.

Therefore, among the empirical concerns on electronic institutions (Noriega, 2006), we are more concerned with the choice the agents will have to make when joining a institution of agents in respect to the degree of freedom of speech that institution will allow, and by that we mean that as autonomous agents, ourselves humans, we have individual goals and beliefs and those are in the autonomous artificial agents that we build. They are there because the agent-oriented paradigm aims to model the human society model and for a completely constrained environment the object-oriented paradigm is already there to be used.

Such mechanisms as governors (Arcos et al., 2005) and controllers (Minsky & Ungureanu, 2000), to our view might compromise the agents' autonomy. We otherwise want to influence agents to behave according with the rules of the environment. That is the motivation of our work, to develop an environment were agents are influenced to cooperate and follow a predefined set of rules. That environment is organized based on institutional concepts with the definition of roles to joining agents. Those concepts create an artificial environment similar to real world institutions, where people can join to obtain or offer access to services.

Autonomous agents aim to copy human reasoning or strategies when interacting with others and deciding their course of action in the electronic environment. Interaction protocols are there to be used according with the speech acts, institutional actions or illocutions identified in the dialogs executed by agents. Those interaction protocols help to predict actions and model the conversation space before it actually happens, including the possible break of expected courses of action by agents in the electronic environment. Authorities in the institutions are available to audit interactions and observe rules in the society.

The rigid control of agents' interoperation may or may not grant rigid security for MAS, but it definitely compromises the degree of agent's autonomy. If agents are only allowed to follow the rules, part of the intrinsic characteristics of the multi-agent model might be overlooked and their capability to deal with real world situations diminished. We then advocate for a model where the environment allows for the definition of norms and sanctions applicable if they are violated. The performance of the system as a whole must be observed and autonomous agents are free to misbehave, but must recognise the possibility of loosing reputation points as well, which will make them less attractive as a partner for interoperation.

INSTITUTIONAL ABSTRACTION AND DESIGN

When modeling and implementing open agent systems that allow heterogeneous agents to join the system and perform tasks we use the abstraction of *institutional environments* and *normative spaces*. As the agents that join the institution are heterogeneous the necessity of the insertion of *social norms* in the system becomes evident. Norms are introduced to balance the functioning of the system and introduce a variable mechanism of control in the environment. With that mechanism the goals of the system as a whole are observed when autonomous agents want to achieve their own goals (Aldewereld et al., 2006).

The degree of openness observed in normative systems is variable. Norms define what is legal or illegal in the system and at the same time influence the agents to behave in a desired way, much like *legal frameworks* are developed to guide humans in the real world. It is important to observe the necessity of having this control over the autonomous agents to grant a sense of order to MAS, and a degree of openness as variable as the domain modeled needs or the system designer's desire.

Interaction and coordination are identified as major concerns when designing and deploying MAS, giving a distinct approach toward the modeling and design of distributed intelligent systems (DeLoach, 2002; F. Zambonelli, Jennings, & Wooldridge, 2003). Software engineering agent-oriented methodologies, such as Gaia (Wooldridge, Jennings, & Kinny, 2000), have been developed to observe the interaction between agents as a critical design aspect when building MAS.

The system organization as well influence the design of a MAS (DeLoach, 2002; Zambonelli, Jennings, & Wooldridge, 2001). A social setting is realized in the form of an environment where agents play roles and interact with each other pursuing individual or common goals. The organization has a defined structure, which define and enforce norms to manage the interoperations among agents. Norms are associated to roles agents assume in the system upon registration and will guide the agent behaviour in the system.

The operational use of norms in institutional environments is directly related to the context the agents interoperate is defined through ontologies (De Oliveira, Purvis, Cranefield, & Nowostawski, 2005); Grossi, Aldewereld, Vázquez-Salceda, & Dignum, 2006). Our approach is to use CPN (Jensen, 1997) to represent normative spaces that will guide agents throughout their useful existence in the institutional environment (De Oliveira, Purvis, Cranefield, & Nowostawski, 2004). Before defining the elements involved in the implementation of the institutional environment we introduce CPN in the next section.

COLOURED PETRI NETS AS A FORMALIZATION TOOL

CPN (Jensen, 1997) have some attractive properties for the representation of agents' conversations: they are expressive, have a history of successfully modeling dynamic processes, have a standard graphical presentation, as well as formal semantics. Compared to finite state machines broadly used for the representation of interaction protocols and behaviour patterns, for example, Dellarocas (2000), Artikis, Pitt, and Sergot (2002) and Arcos et al. (2005), they have the advantage of effectively representing concurrency and states together with actions that determine state change. In Cost, Chen, Finin, Labrou, and Peng (2000) a comprehensive analysis for the use of CPN to represent patterns of agent interaction is made and some agent development environments translates that assertion in reality as is the case of Duvigneau, Moldt, and Rolke (2002) and Cost et al. (2000). However, they have not applied the social model when designing MAS in their frameworks, and much less have they given the deserved consideration to the openness aspects we are interested in investigating.

Conversation policies (Bradshaw, Dutfield, Benoit, & Woolley, 1997); Elio & Haddadi, 1999) stress another existent layer of abstraction relevant to agent interoperation modeling and implementation, which suggests the relevance of cultural and social aspects of the communicator during the interaction. In Elio and Haddadi (1999) the separation of *task space* and *discourse space* goes a bit further in that direction. Our intent is to demonstrate the suitability of CPN for the modeling of institutional environments that use *social expectations* as a mechanism of control and management of open MAS.

With a static and dynamic specification of a process CPN unambiguously defines the behaviour of each net forming a foundation for formal analysis methods and allowing the development of CPN simulators. They describe explicitly both states and actions and offer a hierarchical description allowing the modeling of a large CPN by relating a number of small CPNs to each other, easing management and offering modulation. CPN simulators help to debug the net and facilitate the formal analysis of it by means of methods such as state spaces and place invariants, identifying undesired loops and deadlock conditions helping to eliminate humans errors introduced in the design process.

Figure 1 is a snapshot of a simple CPN designed with the open source CPN simulation framework JFern (Nowostawski, 2002). Figure 1 defines a very simple auction where commodities are selected as soon as they arrive in the *imput place*, the *transition* make bid do some processing with the token and the bid is put in the *outgoing arc*. For a brief introduction to the terminologies used in our CPN drawing, we define:

- **Tokens:** Represented by Java objects giving flexibility for the representation of simple structures as a *integer* or more complex ones as FIPA Messages (Fipa, 2002).
- **Places:** Net elements that represent achievable states. They are containers for tokens and are represented graphically by circles.
- **Transitions:** Net elements represented graphically by rectangles and that define actions triggered when the transitions are enabled.
- **Input Arcs:** Represented as arrows from input places to transitions. They are used to select a set of tokens from the input place, using guards and expressions.
    - **Input Arc Gards:** Boolean expression that must be evaluated to *true* for the transition to be triggered.
    - **Input Arcs Expressions:** Are used to select a set of tokens from the input place.

Figure 1. Simple auction

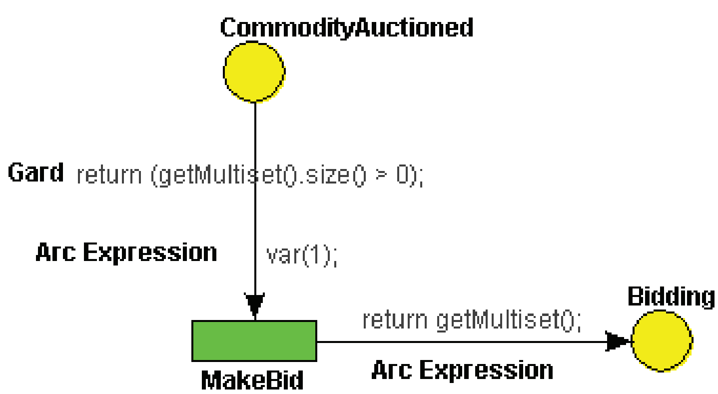
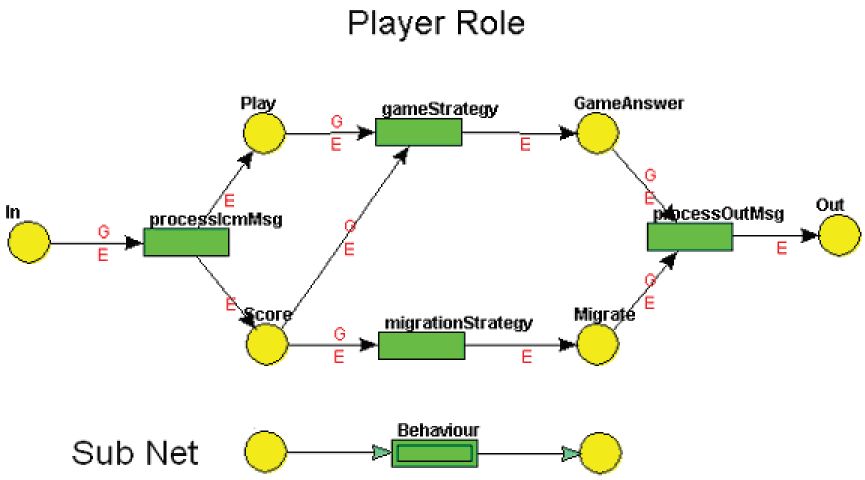


Figure 2. Player role and sub net



- **Output Arcs:** Represented as arrows from transitions to output places.
  - **Output Arcs Expressions:** These are used to generate output tokens which are being placed into output places.
- **Sub Nets:** Represented as double rectangles that specify a link from a higher hierarchy net to a lower hierarchy net; see Figure 2.

INSTITUTIONAL ENVIRONMENTS

In an institutional environment a group of persons agree to follow a set of regulations in order to develop a fruitful relationship with the others participating in the institution. That set of regulations is formed based on the actions each individual can perform in the institutional environment, according to the role they play. In other words, institutional actions (Colombetti, Fornara, & Verdicchio, 2002) taken by agents in an agent society must follow the rules imposed by a certain set of regulations defined by an institution. Those institutional actions are in fact the speech acts identified in the context of an institution that are used as illocutions in conversations and are used here to predefine courses of actions and build interaction protocols.

Institutional Acts

The institutional environment represents well defined groups of agents that together form organizations that follow a set of regulations, which specify how agents should undertake activities in a specific domain. Therefore, we use institutional actions to identify standard dialogs that take place in an institutional environment and define CPNs that will manage the interaction protocols necessary to achieve the wanted outcomes. Some examples of institutional actions would be to bid in an electronic auction institution, buy in an electronic commerce institution or to kick in an electronic soccer game institution.

The process of identification of the institutional acts in a domain requires analysis and evaluation of all the elements defined in that context. For that, we specify ontologies that define the concepts identified in that specific domain and relationships among them. We prefer to use ontological models graphically represented by UML diagrams, due to the easier reading and object deployment capabilities that those models offer. Those ontologies can be extracted from ontology servers as in Cranefield, Nowostawski, & Purvis (2002) and Cranefield & Purvis (2002), or from representations that are found in the semantic Web (Lee, Hendler, & Lassila, 2001).

Systems Elements

A significant characteristic of our approach is its open and distributed nature. Elements are organised in such a way that they are not compelled to report their actions to any other participating agent in the structure. We define our Institutional Environment (IE) as:

$IE = (O_s, N_s, I_a)$

Where:

- O_s stands for system ontology;
- N_s stands for normative space; and
- I_a stands for institutional actions.

The N_s is defined as:

$N_s = (R_s, R_e, O_c, W_f, L)$

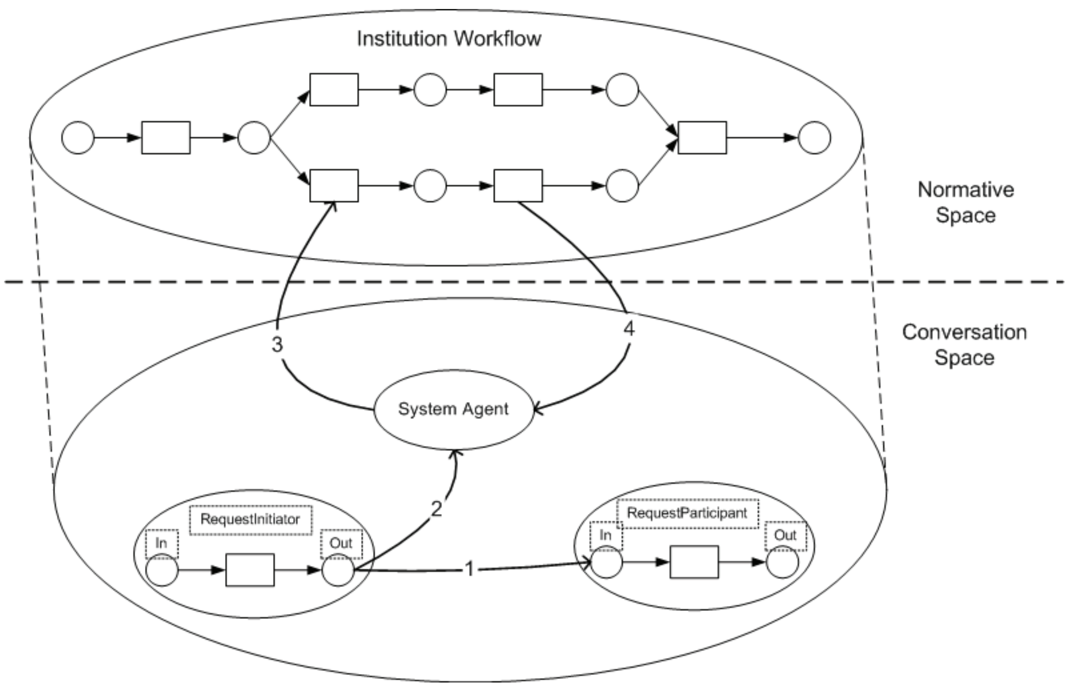
Where:

- R_s stands for system roles;
- R_e stands for external roles and correspond to roles available to be played by agents that register to the institutional environment;
- O_c stands for context ontology;
- W_f stands for workflow; and
- L stands for content language and represents the language expressed in the content attribute of the FIPA messages exchanged among agents in the N_s.

The system level infrastructure identifies system agents that assume roles from R_s and are deployed to manage the interactions in the normative space; see Figure 3. Following is the description of such agents.

Institution Agent: The first step for an agent to get into the institution is to register with the Institution Agent and assume a role in the artificial society. Upon registering, the agent will gain

Figure 3. Normative space and conversation space



access to a representation of W_f in the form of a CPN that represents a suggested path or course of actions the recently registered agent should follow in order to obey the norms that regiment the institutional environment. The W_f can be as constrained as the MAS developer wants, it depends on the degree of restrictions, security or access he wants to deploy in the system, for example, demanding the use of monitored interactions for certain activities. It is important to mention here that the member agents will have their own goals and strategies to obtain them, and even though they have knowledge about the $W_{f,}$ they still can participate freely in conversations without compulsorily following it, but everybody knows the rules of the game, though.

Monitor Agent: This system agent represents a monitoring authority in the institutional environment. It monitors certain activities, defined as institutional actions, according with the norms defined in the normative space by the W_f. The monitoring is done through the use of commitments and observation by the monitor agent of the commitments' life cycle. Once in the artificial society, the agent can commit itself with other agents to perform tasks and request other agents to make commitments to perform tasks for it. In the case that the agent does not have an acceptable level of trust of the agent with which it is starting the interoperation process, it can ask for a monitored interaction, where the monitor agent will audit the commitment shared by the agents engaged in interaction. That interaction is stored in a database of audited interactions for later examination, if requested to the monitor agent. It is important to mention here that the system agents will always follow the W_f and with that the norms that regulate the institutional environment. But again, knowing the rules, some groups of agents might be formed without the use of any monitoring in their interaction only based in the trust they developed with one another.

Reputation Agent: The agents in the open MAS have access to a system agent called the Reputation Agent. This agent is responsible for giving information about other agents that have been present at some time in the society and have developed a reputation. The agents are not obliged to report nor to consult the Reputation Agent prior to every interoperation they take part in. This offers flexibility and the possibility of open MAS implementations with verifying degrees of agent autonomy.

Agent Roles and the Conversation Space

In our approach, CPN are used to represent agent roles and agents conversations. Those two concepts together define what we call the Conversation Space of an institution; see Figure 3. In that way, we visualize an agent's role as part of a CPN that describes the messages exchanged by a specific group of agents in the institution. The overall institution conversations are represented as a CPN that has specific access points, where smaller CPNs, representing roles of individual participating agents, can be plugged in. With that approach, an agent will be involved in the part of the conversation appropriate for its role in the institution. Figure 2 depicts a CPN that represents a player role in the prisoners' dilemma game.

Every agent in the institutional environment will have a local state that concerns to its role in the whole system. By distributing the state representation among a set of tokens, it is easier to represent the local state of an individual agent role (in the context of a larger institution), and this can be useful for local management of individual agents.

We use the Opal (Nowostawski et al., 2002) framework for lower level FIPA communication services and JFern (Nowostawski, 2002) for CPN creation, simulation and deployment. Opal modularity and scalability through its micro-agents kernel (Nowostawski et al., 2002) allows for the development of agent templates as message processors that implement patterns of behaviour.

COMMITMENTS

In our approach, a commitment is an object created at the agent level and handled by the Auditor agent involved in the interaction. The Debtor is the agent that makes the commitment, and the Creditor is the agent relative to which the commitment is made.

We have adapted a model defined in Colombetti et al. (2002) to our needs. The commitment states used are: unset, pending, cancelled, active, violated, fulfilled and not fulfilled. The not fulfilled commitment state is introduced to differentiate a state identified when the commitment's task does not have a deadline associated with it and the commitment is never violated nor fulfilled, because commitment violation is directly related to a deadline.

The Monitor Agent is the system agent that manages the commitments in the MAS. We have defined a CPN that represents the auditor role and manages the commitment object from its instantiation to its storage in the commitment log, a data base of commitments that have reached one of its final states (cancelled, violated, fulfilled or not fulfilled).

The Monitor Agent will observe the normative space when monitoring interactions. Operations on commitments reflect in its state and together with the norms defined in the W_f a monitored agent can have from a change in its system reputation for better or worse or in an extreme case could lead to the banishment of the agent from the institutional environment.

The audit process performed by the Monitor Agent can be visualised as the proof given by the debtor agent that he performed some task. That would have the form of a commitment with condition equal to "true," acknowledging some information about a task the debtor should perform. Basically, the debtor would be committing itself formally to an authority in the MAS (represented by the Monitor Agent) that it did something. If an agent commits itself too often to false statements, the Monitor Agent should receive many complaints about that agent, which would lead the Monitor Agent to use its power to update the reputation of agents in the MAS.

The normative space guides the Monitor Agent during the monitoring process; its role is a commitment management protocol that manages commitment objects according to their life cycle. Participating agents can decide to break the protocol, but the normative space defines the level of tolerance to those actions, and depending on the application domain that the institutional environment is implementing, agent acts can decrease its reputation to such a level that other agents which consult the Reputation Agent will cease to communicate with the untrustworthy agent. The time factor is an important element in the representation of commitments. To express a commitment formally, it is necessary to find a representation mechanism able to handle the constraints of time found in the definition of commitments. We represent the idea of commitment's *timeout* and *deadline*. The timeout is related to the period of time available for the commitment to become active, and the deadline is related to the amount of time available for the commitment to be fulfilled.

Reputation Influence in the Institutional Environment

All the requisite institutional information is given to the agents upon their registration in the institutional environment, and will be available from the Institution Agent for consultation at any time. However, the Institution Agent does not maintain any control over the registered agents. In fact, it is the reputation that the agent has in the MAS that will determine its useful existence in the institution. Based on the trust the agents have for each other, they will interact or not. With time and the development of a number of interactions, agents can build up trust networks and establish trust relationships with each other.

The reputation the agent develops in the institutional environment, together with restrictions of the normative space, defined in the W_f, may restrict levels of access to certain resources. Such concepts as level of access to resources and services can be modeled in the normative space through the context ontology O_c and implemented in the W_f. Therefore, as all the agents are aware of the rules of the institutional environment they know that their actions might not only affect their reputation, but diminish the level of access to resources in the system.

We define a trust relationship ontology that defines the concept of trust and reputation and how they influence the system agents and can be used by external agents to compose their own definition of trust. That ontology is available for the agents that are joining the institutional environment to understand the information managed by the Reputation Agent.

The reputation update model sometimes needs to express characteristics of the context in which the institution was developed, and different reputation update models can be attached to the Reputation Agent CPN to express that. Another important aspect of that approach is that the external agents can have their own definition of trust and use the one defined by the institution to add information to it, or simply ignore it. The agents are not compelled to use the Reputation Agent before every transaction. They can have, for example, a history of their conversations internally and their own information about other agents and choose to refuse certain kinds of interactions from some agents, that they might not trust, but in case they are willing to use the information agent, it is available. Being aware of the W_f, they can calculate the risk of losing privileges in the institutional environment and act as they will.

DISCUSSION

Multi-agent system coordination methods are a research topic that has gained quite a portion of the research community's attention in the past years due to its suitability to design and build complex systems (Zambonelli et al., 2003). Usually, the MAS methodologies are based on agent-oriented foundations and are agent-centred instead of community- or socially-centred. Those methodologies focus more on the individual aspects of the agents, which bring very good contributions for the designing of agents, but lack in feasibility for the implementation of agent interactions in an organized way.

Agent infrastructures such as DARPA COABS (Kahn & Cicalese, 2003) and FIPA compliant platforms such as JADE (Bellifemine et al., 2000) and OPAL (Nowostawski et al., 2002), deal with many issues that are essential for open agent interactions. They use standards to manage communication, identification, synchronization and matchmaking. That infrastructure is necessary, but lies at a lower layer of abstraction than the one our model here presents.

An important development in the area of electronic institutions has been done in Arcos et al. (2005) Minsky and Ungureanu (2000) and Ricci and Omicini (2003). Even though, along with Arcos et al. (2005), we have the goal of implementing social centred frameworks to develop open MAS, our approach differs in many aspects from theirs. We adapt the work done in Colombetti et al. (2002) and Singh (1999) in the definition of our commitment-based infrastructure and use it to define objects whose active state changes according to the agent interactions with which it is associated. Again, in our architecture the three kinds of operational agent present use the concept of trust for better accommodating the openness that we claim to have in our model because we do not rely on interface agents to implement norms in our institutional environment. Instead of having a special operational agent, such as the governor (Arcos et al., 2005) and controller (Minsky & Ungureanu, 2000), which forces the agents to comply with the interactions in the institution, we use the concept of trust among agents and normative spaces so that different levels of security and other important constraints can be implemented in a way that the agent itself will decide which strategy to use in order to comply with the societal norms and avoid being penalized by losing reputation points, in a first instance, going to losing access to system resources until the banishment of the agent.

Another important aspect of our approach is that we do not use finite state machines to represent an electronic institution and the conversations in the institution. Our approach is the use of CPNs to represent the institution's normative space and conversation space, which includes the roles played by agents in the institution. By that, we seek the use of a formalism defined over concurrency concepts and powerful semantics relating states and actions.

CONCLUSION

Agent autonomy is an important aspect of the multi-agent paradigm. When coordinating the autonomy in MAS norms in institutional environments, bring a flexible mechanism for the definition of legality and illegality in an artificial social environment, as its use eases the coordination of open MAS composed by heterogeneous agents, allowing for the adaptation of degrees of openness according to the context being modeled.

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