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Towards an integral approach of organizations in multi-agent systems: the MASQ approach

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ABSTRACT

In this chapter, we stress the importance of thinking a MAS in all its aspects (agents, environment, interactions, organizations and institutions), using a more integral vision. We show that a genuine organizational approach has to take into account both the environment and the institutional part of MAS societies. Then, we propose the MASQ (Multi-Agent System based on Quadrants) meta-model, which constitutes an abstraction of the various aspects of an OCMAS (Organization Centered Multi-Agent Systems), extending AGR (Agent/Group/Role). MASQ is based on a four-quadrant framework, where the analysis and design of a system is performed along two axes: an interior/exterior dimension and an individual/collective dimension. We give a conceptual definition of this approach and we will show that it is possible to apply it to practical models.

1 Introduction

Multi-agent systems (MAS) are often considered as collections of agents that interact together to coordinate their behavior to achieve some individual or collective goal. The research in MAS domain focuses therefore on the study of the agent-based interaction, which roughly could be divided in agent-centered interaction and mediated interaction. Agent-centered interaction is the most known and well understood as the works of FIPA (2005), the standardizing body of the MAS domain, reflect it. The interaction is considered from the perspective of a single agent communicating with another agent in isolation. The research in mediated interaction tries to complement this perspective and concentrates rather on distributed and social aspects, when many agents are in interaction. Mediated interaction is based on the idea of structuring the interaction by adding a sort of middleware responsible to manage the complexity of the interactions between many agents[1]. Depending on the kind of interaction, we can further have two types of mediated interaction: environment-based interaction and organization-centered MAS (OCMAS) interaction.

In the case of environment-based interaction research has concentrated on the physical distributed aspects of interaction. The environment is considered as a first-class abstraction at the same level as the agents, and has its own state and laws of change (Weyns, Omicini & Odell, 2007). The main reason of using an environment as a medium of interaction is to control (independently of the agents) the effects of external events or parallel actions produced simultaneously by two or more agents (Ferber & Müller, 1996). The works on environment-based interaction concentrate mainly on how to represent objects in an environment, how to specify the actions of agents and the various laws of change, and how to execute the overall system dynamics. The other problems in environment–based interaction are similar then to those of distributed systems: openness, security, coherence, load-balancing, etc.

In the case of OCMAS, an emphasis has been put on the social aspects of interaction and inspiration comes from human forms of organization. It becomes more and more accepted that the interaction can be specified and structured in terms of organizations, roles, groups and norms. (Dignum, 2004; Ferber & Gutknecht, 1998; Ferber, Gutknecht & Michel, 2004). In this view, an organization is seen as a collection of agents that can be considered together in groups, playing roles or regulated by organizational rules. For instance, in AGR model (Ferber & Gutknecht, 1998) the agents can interact only inside a group in which they play roles. An agent can play one or many roles and enter into one or many groups. A role is a general concept to which a MAS architect can associate various semantics (i.e. rights, obligations, norms, powers, patterns of behaviour, etc.). Similarly, in the family of MOISE models (Hübner, Sichman & Boissier, 2007) an organization is considered coherently under its functional, structural and deontic dimensions (for all these aspects, see also chapter 2, Modelling Dimensions for Multi-Agent Systems Organizations).

Although the initial studies of organizational interaction have not suggested explicitly the use of an organizational environment, the specification of an organization is made however independently of the participating agents and therefore at the execution time it is necessary to introduce a way to handle it. For instance, an organization could be designed architecturally as an organizational layer to keep trace of the events and information that are organizationally important. In MadKit (2004) the core layer (kernel) which implements the organizational environment has as basic functionalities to let agents join groups, associate roles to agents and let only members to the same group to interact. Another way to represent an organization is to reify it at the same level with other agents within a socially constructed agent (Boella & Van der Torre, 2004). The concept of organization becomes then a first class abstraction with a representation on its own (i.e. an organization can have its own goals and beliefs).

In addition to organizational concepts, recent researches have shown the importance of other social concepts to MAS. The works on electronic institutions (Noriega, 1997; Esteva, Rosell, Rodrıguez-Aguilar & Arcos, 2004), similarly to those in OCMAS, reflect the same idea of passing through a middleware to structure the social interaction, the term institution referencing the works of North (1990) in economics. In Islander, agents can enter into « dialogical » interactions which are grounded in institutions. An institution is designed architecturally as an independent layer. Inside an institution, to each agent corresponds a governor and the interaction is defined through protocols that are called *scenes*. An institution is characterized by a set of states and the scenes characterize the transitions between states when

[1] In the agent-centered case, interaction goes also through a middleware whose main function is to provide a message transport mechanism between any two agents.

some conditions are satisfied. Norms are also used to define some deontic states and identify their violation.

Another stream of research that makes use of the term institution takes its inspiration from the philosophical work of Searle. According to (Searle, 1995) an institution establishes the rules of how commonly a human society attributes a social meaning to what happens in the physical reality. More precisely, an institution is defined as a set of count-as rules (also known as constitutive rules) that link facts from the brute reality to institutional facts. Jones and Sergot (1996) formalized the count-as operator within the perspective of institutionalized power, where agents acting in specific roles are "empowered" to create or modify institutional facts. In (Artikis, Pitt & Sergot, 2002) the concept of institutionalized power is adapted to what the authors call "electronic" or "computational" societies. For instance, they propose to associate to each member of a society a social state describing its institutional powers, permissions, obligations, sanctions, and roles. Then, according to the social laws governing the institution, the initial social state and the externally observable events, they propose a computational framework, based on event calculus, to compute the social state at a certain moment of time (see also chapter 14, *Formal Specification of Artificial Institutions Specification Using Event Calculus*). More recent works try to clarify the various aspects of the constitutive rules (procedural, declarative, normative) and use them to implement normative agent systems (Boella & Van der Torre, 2004; Cardoso & Oliveira, 2007) and show the connection to social commitments (Grossi, D., Dignum, F., Dastani, M. & Royakkers, 2005; Fornara, Viganò, Verdicchio & Colombetti, 2007)

However, these works on institutions seem to ignore the importance of environment and actions (Weyns, Van Dyke Parunak, Michel, Holvoet, & Ferber, 2005), apart from the communications (Fornara, Vigano, & Colombetti, 2007). On the other part, researches on action in environments did not grant much attention to organizational and institutional issues. Consequently, it seems that both organizations and environments should be reconciled in a general framework in order to be able to design MAS in all their dimensions.

In this chapter, we will describe a general framework and an abstract model of what constitutes a first step towards an integral view of multi-agent systems. This approach, that is called MASQ (Multi-Agent Systems based on Quadrants) is based on a four-quadrant approach and is derived from the AQAL model of Wilber (2001), which is a comprehensive map of (human) social systems. MASQ as we will see considers equally the concepts of actions, environments, organizations and institutions and propose to integrate them in the same conceptual framework.

2 AGR and beyond: adding environments to organization

In this section we present the AGR family of models, which have been thoroughly used to design organization centered MAS.

2.1 Organization centered MAS

Organizations centered MAS, or OCMAS for short, contrary to standard MAS which are oriented towards agents, are built according to the following principles (Ferber, Gutknecht & Michel, 2004):

Principle 1: The organizational level in MAS describes the "what" and not the "how". The organizational level should impose a structure into the pattern of agents' activities, but does not describe how agents behave.

Principle 2: No agent description and therefore no mental issues at the organizational level. The organizational level should not say anything about the way agents would interpret this level. Thus, reactive agents as well as intentional agents may act in an organization.

Principle 3: An organization provides a way for partitioning a MAS, each partition (or groups, spaces, etc.) constitutes a context of interaction for agents. Thus, a group is an organizational unit in which all members are able to interact freely.

Therefore, an organization may be seen as a dynamic framework where agents may be considered as kind of autonomous components. Designing systems at the organizational level may leave open some implementation issues such as the choice of building the right agent to play a specific role.

2.2 From AGR to AGRE: adding environments to organizations

In order to show how these principles may be actualized in a computational model, we have proposed the Agent-Group-Role model, or AGR for short (Ferber, 2004) also known as the Aalaadin model (Ferber & Gutknecht, 1998) for historical reasons, which complies with the organization centered general principles that we have proposed in the previous section. The AGR model is based on three primitive concepts, *agent*, *group* and *role,* which are structurally connected and cannot be constructed from other primitives.

Agent: an agent is an active, communicating entity playing *roles* within *groups*. An agent may hold multiple roles, and may be member of several groups. An important characteristic of the AGR model is that no constraints are placed upon the architecture of an agent or about its mental capabilities. Thus, an agent may be as reactive as an ant, or as clever as a human being.

Group: a group is a set of agents sharing some common characteristics. A group is used as a context for a pattern of activities, and is used for partitioning organizations. Two agents may communicate if and only if they belong to the same group, but an agent may belong to several groups. This feature will allow us to give the definition of organizational structures.

Role: the role is the abstract representation of a functional position of an agent in a group. An agent must play a role in a group, but an agent may play several roles. Roles are local to groups, and a role must be requested by an agent. A role can be played by several agents.

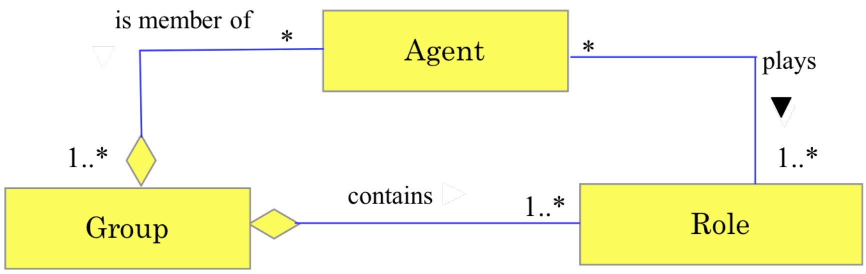

Figure 1. A simplified UML representation of AGR

The simplicity of the AGR model comes from its minimalism and its generic aspect. There is only a minimal set of concepts to describe the main aspects of organizations. In AGR, by defining its groups, its roles and their relations, an organization may be seen as a framework for activities and interactions. By avoiding the strictly "agent-centered" approach, and by focusing on the organization, it may be possible to describe an application at an abstract level. Organizations can be seen as dynamic frameworks (where 'framework' is used in its object-oriented meaning), where agents may be placed in the 'holes' of the framework, where roles of the organization stand for the 'holes'. An organization can then be described only from its structure, i.e. the way groups and roles are arranged to form a whole. Several diagrams may be used to describe an organization in the AGR context.

The AGR meta-model is represented in Figure 1 in UML (To see a view of the complete metamodel, see chapter 2, *Modelling Dimensions for Multi-Agent Systems Organizations*). A group type (or group structure), situated at the organizational level describes a particular type of group, how a group is constituted, what are its roles, its communication language, and the possible norms that apply to this type of group. A group is thus a kind of instance of a group type. A role type is part of the description of a group structure and describes the expected behavior of an agent playing that role. Role types may be described as in (Zambonelli, Jennings & Wooldridge, 2003) by attributes such as the cardinality (how many agents may play that role). It is also possible to describe interaction protocols and structural constraints between roles. A structural constraint describes a relationship between roles that are defined at the organizational level and are imposed to all agents. A role, which is part of a group, is an instance of a role type defined for an agent. We can see the role as a representative of an agent or as a kind of social body that an agent plays when it is a member of a group, the interface by which an agent is able to communicate and more generally to perform actions in a group.

Several notations may be used to represent organizations. In (Ferber, Gutknecht & Michel, 2004) we have proposed a set of diagrams to represent both static and dynamic aspects of organizations, such as the "cheese-board" diagram where a group is represented as an oval that looks like a board. Roles are represented as hexagons. Agents are represented as skittles that stand on the board and sometimes go through the board when they belong to several groups. Figure 2 represents a classical organization of a program committee for a conference. It can be noted that the "submission group" is composed of authors and of one submission receiver, which happens to be also the program chairman. Members of the program committee may define reviewers groups that they coordinate. It is clear from this diagram that agents may belong to different groups: a committee member may be a reviewing manager of an evaluation group *and* an author submitting a paper.

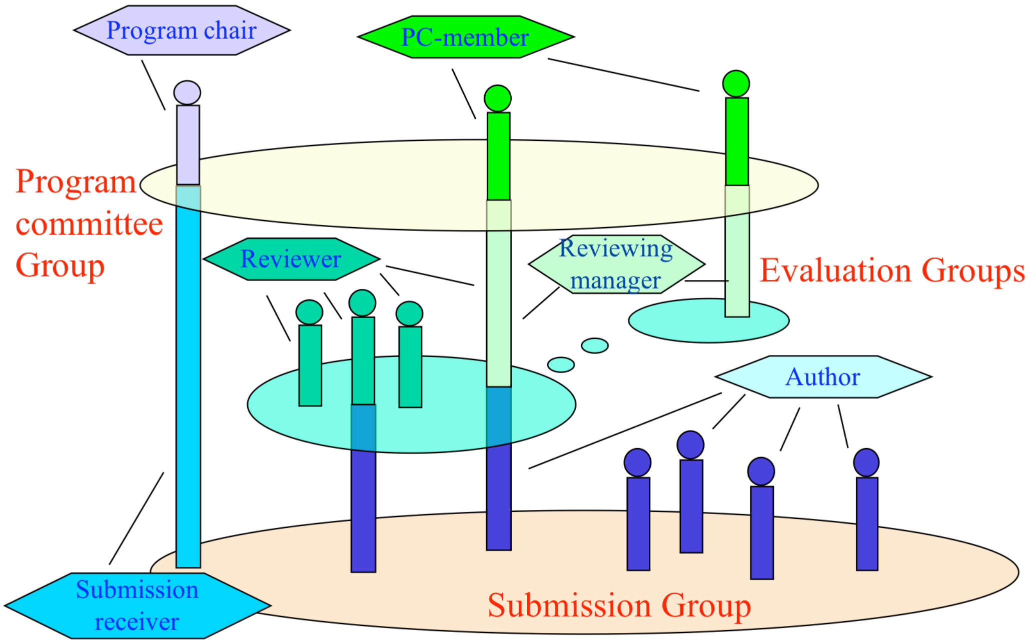

Figure 2. The cheese-board diagram for describing organizations in AGR

However, another very important concept, usually absent from the models described in section 2.1, and more generally in most OCMAS (see for instance the MOISE family of models in (Hübner, Sichman & Boissier, 2007)), is the concept of environment, which is the corner stone of interactions between agents, and more specifically situated agents. Several extensions of AGR have been proposed to integrate environment. For instance, the model proposed in (Odell et al, 2002) consists in directly associating environments to groups, as it is shown on figure 3. However, this extensions did not really solve all questions related to the integration of environments with organizations. Several issues about the relation that exists between an agent and its environment remain unsolved. For instance, the concept of body, i.e. the part of the agent that performs an action in an environment, is not properly analyzed.

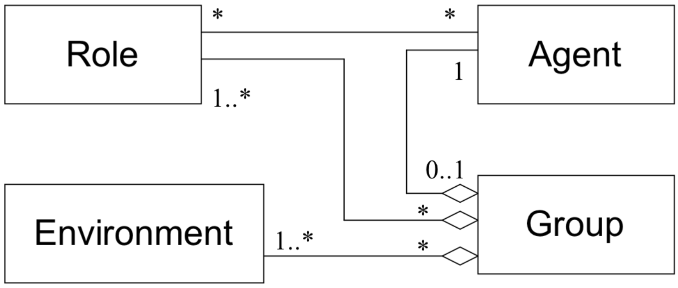

Figure 3. AGR extension with environment proposed by Parunak and Odell

This is why it is important to go further in defining what an agent is. An agent should be thought as having two parts: a mind (or brain) and a body which may be either a "physical body" in an environment, or a "social body" (a role) in an organization. This is what has been proposed in (Ferber, Michel, & Baez, 2005) with the AGRE model, an extension of AGR (E stands for 'Environment'), which integrates the physical and the social aspects of agents (fig. 4). In AGRE, an agent possesses a set of bodies[2]. Social bodies, which may be considered as social interfaces to act in groups, are called *roles*, to be congruent with AGR. Likewise, *physical bodies* are seen as physical interfaces to act in an *area*. More generally *bodies* are social interfaces to act in *spaces*.

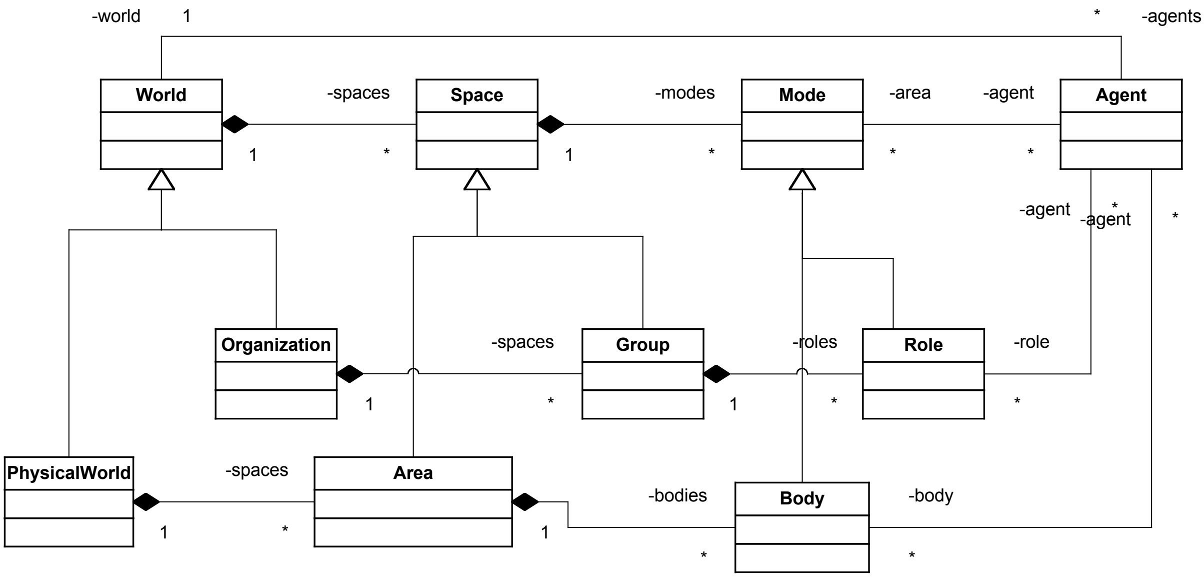

Figure 4. UML diagram of the AGRE model

In AGRE, a *world* proposes the required primitives that are necessary for an agent to enter a space and get its bodies.

[2] Bodies are called "modes" in AGRE. But because this word was not well understood, we have decided to use the most understandable word "body" in MASQ, which is both an extension and a redefinition of AGRE.

2.3 Limits of the AGR family of models

Approaches such as AGR and AGRE have shown their interest for designing MAS, and build development platforms such as MadKit (2004). While providing an important structuring framework for describing and designing MAS organizations, AGR and AGRE, lack to integrate norms and institutions in a simple and clean way. On the organizational aspect, AGRE has abstracted the concept of groups by introducing spaces, thus providing for a neat abstraction of both physical and social spaces. However, AGRE does not provide an action theory which would take into account concurrent actions. In both AGR and AGRE, it has always been clear that these models are based on OCMAS principles (see above) that do not say anything about mental issues. Still, without contradicting these principles, it is important to be able to take into account agent's mental states into a general framework, in order, not to impose a specific architecture for agents, but to be able to integrate agents with actions and their environment.

We will overcome these limits by proposing a new framework which will extend AGR and its family of models.

3. MASQ as a four-quadrant approach

We propose a new framework for designing OCMAS, called MASQ, which provides a two-dimensional heuristic description of the complex relationships within social systems (Phan & Ferber, 2007; Tranier 2007). This approach, which is loosely based on the work of Wilber (2001), resides on a decomposition along two axes: the *individual vs. collective* perspectives on one side, and the *interior* (i.e. mental states, representations) *vs. exterior* (i.e. behaviour, objects, organizations) perspectives on the other side. These two axes taken together provide for a four-quadrant map where each quadrant must be seen as a perspective by which individuals, situations and social systems may be understood, as it is shown on Figure 5.

The I-I (*Interior-Individual*, upper left) quadrant is about emotions, beliefs, desires, intentions, drives, etc., of an individual, i.e. about its mental states, its subjectivity. The E-I (*Exterior-Individual*, upper right) quadrant describes physical bodies, concrete objects, and also behaviours of individuals. The I-C (*Interior – Collective*, lower left) quadrant is about shared knowledge and beliefs, collective representations, ontologies, social norms, and represents the inter-subjective part of a set of individuals, what could be called their *culture* or the *noosphere*. The E-C (*Exterior-Collective, lower right*) quadrant is about material or formal social structures such as organizations, i.e. collective forms and structures of groups and systems, what could be called the *sociosphere*.

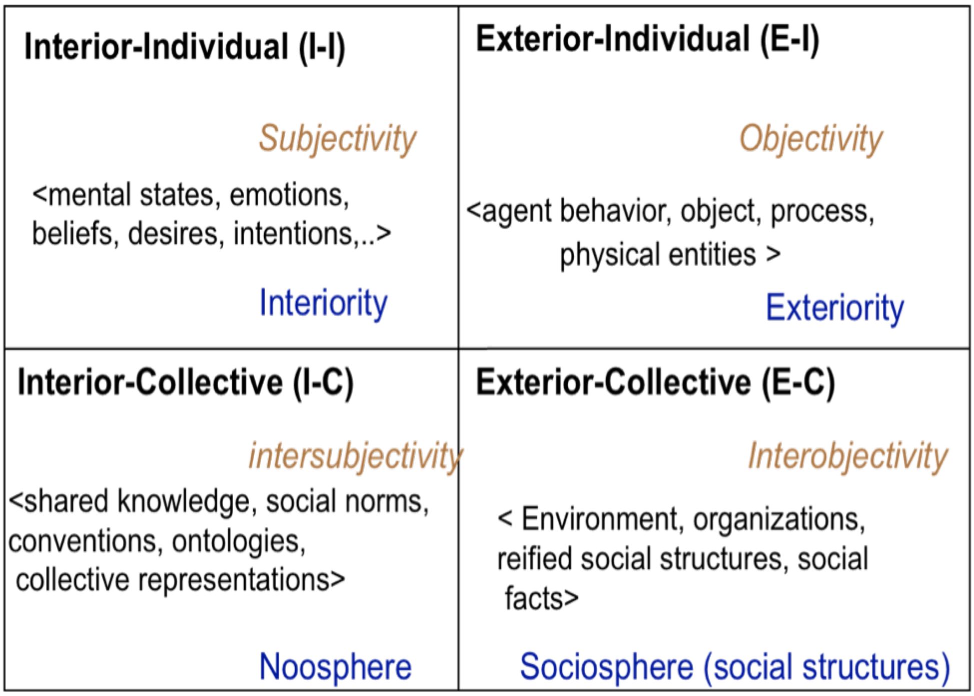

Figure 5. The four-quadrant map

The MASQ meta-model is based on the following assumptions:

a) Separation between mind and body: an agent is assumed to be composed of an interior aspect, its ‘mind’, and an exterior aspect, its ‘bodies’. A mind corresponds to the internal structure of an agent or to its decision-making component. Bodies, either ‘physical’ or ‘social’ are parts of the environment and are connected to minds. This principle is intended to separate the cognitive (e.g. representations, plans, maps, reasoning) and conative (e.g. decisions, goals, intentions, drives) parts of an agent from its environmental part. See a mobile robot for instance: all of its physical parts (chassis, wheels, legs, motors, etc.) and even hardware controls are parts of the physical world, but not its software which resides in the ‘information processing’ domain. This dualistic view allows MAS designers to not mix up what is relevant to the mind of agents, i.e. their representation and decision process, and what refers to their ability to act in a specific domain. Thus, the body of an agent determines the agent’s existence in the environment: it gives the agent the abilities to act and perceive the environment. A body is also the manifestation of an agent in the environment and allows others to perceive it. It is subject to environmental constraints and it forms the basis of the “incarnation” of an agent in an environment because bodies are treated as special kind of objects, i.e. entities that are situated in spaces. Mind and bodies are connected through the influence/reaction principle.

b) The agent integrity principle: the mind of an agent (i.e. its internal structure) is not public and cannot be accessed from outside. Neither the environment nor any other agent can go into the mind of an agent. It is only the behavior displayed in the environment (through its body) that can be used to reason about an agent. This principle allows us to preserve the autonomy and heterogeneity of agents.

c) Actions as reactions to influences: in order to take concurrent actions into account, we use the influence-reaction model (Ferber & Müller, 1996; Helleboogh, Vizzari, Uhrmacher, & Michel, 2007). This principle is based on the idea that an agent cannot directly change the state of the world, but it can only “influence” its dynamics. An agent decides what action to do next, but it is the environment that determines its consequences. For instance, an agent “wants” to mail messages and do the operation to send them, but it is the environment which actually transmits and delivers messages. In the same vein, a robot decides to move but it is the environment (both its body and the external surrounding) that performs the displacement. Thus, the environment reacts to influences produced by agents to determine its dynamics, through a set of "laws", which in the physical world, are the laws of physic and dynamics. Influences represent the transformation of mind elements into physical aspects, and may be seen as a generalization of both the "command" and "sensory" concepts in robotics. (see chapter 14, Formal Specification of Artificial Institutions Specification Using Event Calculus, for another formalism that takes into account parallel and concurrent actions)

This assumption, in connection with the previous one, prohibits any direct interaction between agents, which means that it cannot exist any "telepathy" connection between them. The activity of an agent is made possible only through the environment and through influences and reactions. Consequently, everything that is not provided by the environment is simply not possible for an agent.

Integration of a), b) and c) allows for a simple definition of an agent through its mind/body decomposition: a mind is a process, independent of the environment, but in interaction with it through its bodies. It has its own life cycle, and it maintains a permanent asynchronous communication with the environment. The communication is made under the form of an exchange of influences (issued by the mind) and sense data (issued by the environment). The result of the deliberation phase determines the operations that will generate influences on the environment. Figure 6 shows this distinction between mind and body in an influence-reaction model.

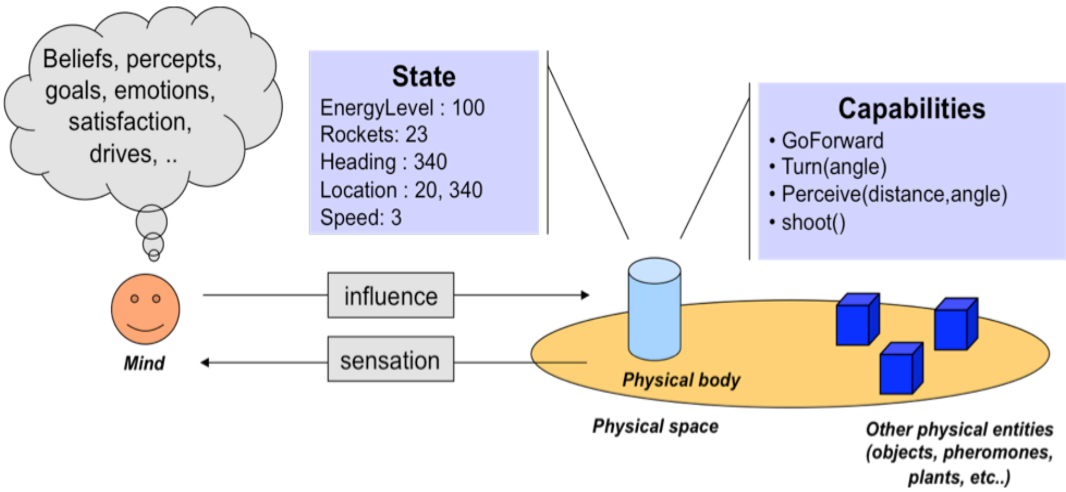

Figure 6. Separation between "mind" and "body".

d) Groups and physical spaces. Groups (i.e. social spaces) and physical spaces are seen as different varieties of 'spaces', in which agents (i.e. minds) may have bodies. Thus, agents may possess social bodies as well as physical bodies. Social bodies are the active parts of roles. It is then possible to generalize and extend the AGR and AGRE models (Ferber, Gutknecht, & Michel, 2004; Ferber, Michel, & Baez, 2005) by mapping groups and roles into social spaces.

e) Brute environment vs. culture. This principle stems from Searle's work on the construction of social reality (Searle, 1995). It provides a clear distinction between what constitutes a brute reality, i.e. its objective part of what happens in a world, and the collective knowledge and subjective values that can be made by a society of agents to describe and interpret that "objective" world. We use the term *culture* to denote this collective and subjective realm which is situated in the I-C quadrant. A culture is made of collective subjective elements such as social norms, social commitments, ontologies or more generally common knowledge. Following Searle, institutions are produced by "count as" functions of the form X count as Y in C, where Y are elements of cultures and X are elements of both cultural and brute spaces. Thus, cultures may be seen as interpretive domains giving values to sensations, i.e. brute perceptions.

Different interpretations of the brute reality may exist at the same time for an agent. They depend on the various societies that an agent accepts to belong to. A society of agents can influence the agents in their decisions, particularly in terms of social pressure, but it has no direct impact on the brute reality. The interpretation of the brute reality does not impose any physical constraint on an agent. As we will see below, these concepts are all linked together. An agent makes decisions with its mind and acts in the brute space through its body where it will be possible to enter into interaction with various other objects. Then the interpretation of the brute space interaction will be used as support for the construction of the culture in which the agent is immersed.

4 Description of MASQ

Given the above principles we can now describe in more details the main elements on which the MASQ model is based. The meta-model MASQ is built on five basic concepts, (mind, object, bodies, brute space and cultures), a set of relations among these primitive concepts and a set of laws that describe the dynamics of the system.

4.1. Mind

A mind is a dynamical system characterized by:

1. an internal state,
2. a mechanism of state change that determines how the state evolves over time, given the sensation information the mind receives. It should be noted that the execution of a mind is not synchronized with that of the environment. Therefore, in one loop the input on the agent side can be composed by a (possibly empty) set of senses data issued by the environment at different times. This mechanism can be modeled by a state transition function.
3. an influence production mechanism that determines the influences produced by the mind according to its internal state. This mechanism can be modeled by a production function.

The last two points are grouped under the term *internal dynamics*. The internal state of an agent corresponds to the individual internal reality, in the sense of four quadrants, and its internal dynamics expresses the agent's cognitive abilities, i.e. how its internal state can evolve.

The mind definition we propose is intentionally left very generic. It allows someone to integrate various agent models and let co-exist heterogeneous agents in the same system. The only requirement that we impose on this definition is that the mind should be able to receive sense data from its environment and issue influences back on it.

Objects

In MASQ, the concept of object is used to describe individual entities that compose the environment. Unlike minds, objects are neither proactive, nor autonomous. Their evolution is entirely determined by the laws of the environment and the different activities that occur in it. Objects are considered as passive entities because the environment controls completely their evolution. However, they are not inert because they can have their own activities such as rolling for a ball or changing periodically of color for a traffic light. An object is characterized by a dynamic state, which describes at a given instant t both the state of the object (state variables) and its activity (dynamic variables).

In a "natural" environment (e.g. the movement of a ball moving in the "real" world) the evolution of an object can be determined if one has sufficient knowledge of the laws of physics. In the case of a virtual environment, the laws that govern its evolution should be described explicitly. Thus, we introduce the concept of instantaneous evolution law (or *internal activity*) that allows one to describe the dynamic state of an object in isolation. An instantaneous evolution law is a function Φ that associates two dynamic states δ and δ', where Δ_O the set of all possible dynamic states of the object *o*:

$$\Phi : \Delta_O \rightarrow \Delta_O : \delta \rightarrow \delta' = \Phi(\delta)$$

Obviously, objects are not isolated. The future state of an object depends also on the activities of other objects. For example, an arrow may encounter an obstacle during its flight, which stops its movement. Thus, the evolution of an object cannot be determined by considering only the object itself. We will see later that it is the role of the environment to completely compute the evolution of the objects that compose it[3].

When describing objects we make use of the concept of object type, so that an object is always the instance of a certain object type. An object type contains the description of the set of dynamic or state variables and the instantaneous evolution law. For each variable we provide also the corresponding domain that gives the set of all possible dynamic states for the objects of that type.

Agents: embodiment of minds into objects

Some objects have the distinction of being connected to a mind, and in such a case we speak of *bodies*. A body plays the role of mediator between the mind and the environment. A body allows the mind to act on its environment, perceive it and be perceived by other minds. A body is also the manifestation of an agent in its environment; it allows its very existence in it.

We stated previously that a mind could only influence and perceive the environment. We can now specify that a mind can do this only because it has a body into that environment. We note *HoldBody* the relationship between a body and a mind. It should be noted that a mind may have several bodies and a body is associated to a unique mind. To describe how a mind can intervene on the evolution of a dynamic state of its body we use the notions of influence and reaction. A reaction law indicates how a set of influences may modify the dynamic state of a body. A reaction law of an object type *T* is a function :

$$RLaw : \Delta_T \times 2^\Gamma \rightarrow \Delta_T$$
$$(\delta, \{\gamma_1, \gamma_2, \ldots, \gamma_i\}) \rightarrow \delta'$$

where γ_1 are influences produced by a connected mind. A reaction law is always linked to a type of object T. It is a function that computes the new dynamic state of a body from its current dynamic state and the influences that it receives from its mind. For a given dynamic state and a set of influences, a law of reaction can return the initial dynamic state, which means that the influences issued by the mind will not necessarily produce a transformation of its body. A mind can potentially send all kinds of influences to its body, but only certain types of influences will have a real effect on it. We will then call these influences valid. Since bodies are not synchronized with their minds, issuing an influence by a mind does not lead to an immediate transformation of body's dynamic state. Influences are simply queued for later computation. It is the environment that manages the dynamics of its objects and determines the timing of the reaction of a body according to the body type reaction law and queued influences.

[3] This idea is very often applied in the physical engines that are used in video games for simulating the laws of physics and animate bouncing objects.

The concept of body that we define in MASQ is very general. This usually suggests a physical nature, as it is the case in the example of a mobile robot. But this concept should be seen only as any means to perceive and act in an environment, whatever its nature. The notion of body introduced here is identical with the concept of *mode* presented in (Báez-Barranco, Stratulat & Ferber, 2007) and the concept of agent-in-role as in (Pacheco, Carmo 2003).

In MASQ, the relationship between body and mind is dynamic. As we already mentioned previously, a mind could have multiple bodies, and over time it can acquire new bodies or lose bodies it currently possesses. Therefore, the material capabilities available to an agent on the environment are not frozen: they can change depending on the bodies that are taken or released by the mind. We will give more details on this later in the next section.

4.2. Brute space

We introduce the concept of brute space to describe the environment. The environment represents for a MAS the brute reality that corresponds to the quadrants E-I and E-C. It maintains a state of affairs that is objective, independent of agents' points of view. From a conceptual point of view, the environment is composed of objects and has as main role to manage how these objects interact. A brute space is composed of objects (where some of these objects are bodies), and forms a boundary between its objects and the rest of the environment. Objects are dynamically interconnected inside a brute space. Motions (i.e. how objects can move in a space) and communications (i.e. how information can be exchanged between objects) are examples of such connections. An object cannot belong to several brute spaces.

Physical Spaces vs. Social Spaces

The nature of brute spaces can be very diverse, but two categories of brute spaces are usually distinguished: physical spaces and social spaces.

A physical space is used to model a portion of the physical world (e.g. a football field). It may be equipped with a particular topology that allows someone to locate objects and to establish topological relations between objects (e.g. distance, collision and contact detection). Reaction laws implement the dynamics of the physical space (gravity, mass, dynamics forces, etc.).

A social space is used to model specific and deterministic social structures of interaction. For instance, message transfer and routing is accomplished in a space where agents are located through their email address. To send and receive messages an agent must possess a communicative body (e.g. in an email system, an address and a queuing mechanism for storing incoming and outgoing messages) situated in a communicative environment (e.g. an infrastructure for message delivery). These communicative capabilities are associated to specific rights (what kind of communications the agent is allowed to perform) which refer to its status (e.g. administrators often have more rights than simple users). A good way to understand what is a social space is to see it as an abstraction of most community related web systems, such as forums, wiki, meeting systems, etc. In those systems, each participant has a pseudonym, related to a status, which gives the participants their specific capabilities for acting in this space. The pseudonym, with all the capabilities associated to it, may be seen as a social body, and the web system as an interaction space. Like in physical spaces, it is also possible to define a topology for social spaces (Zambonelli, Jennings & Wooldridge, 2003). For example, an organization that uses the roles of master and slave defines a hierarchical topology. Note that the concept of group from AGR is absorbed in MASQ as a social space and the concept of role as a social body.

We have shown that from an abstract point of view, social and physical spaces may be seen as two forms of the same concept of space. A brute space, whether physical or social, contains bodies that are able to perceive and act, and its dynamics is described by reaction laws.

Therefore, we have reused the diagrams of AGR that represent groups and roles to represent spaces and bodies, as it is shown on figure 8. Note that, for drawing simplicity, we have merged the quadrants E-I (Exterior-Individual) and E-C (Exterior-Collective) in just one zone called E (Exterior). But bodies belong to E-I and spaces to E-C.

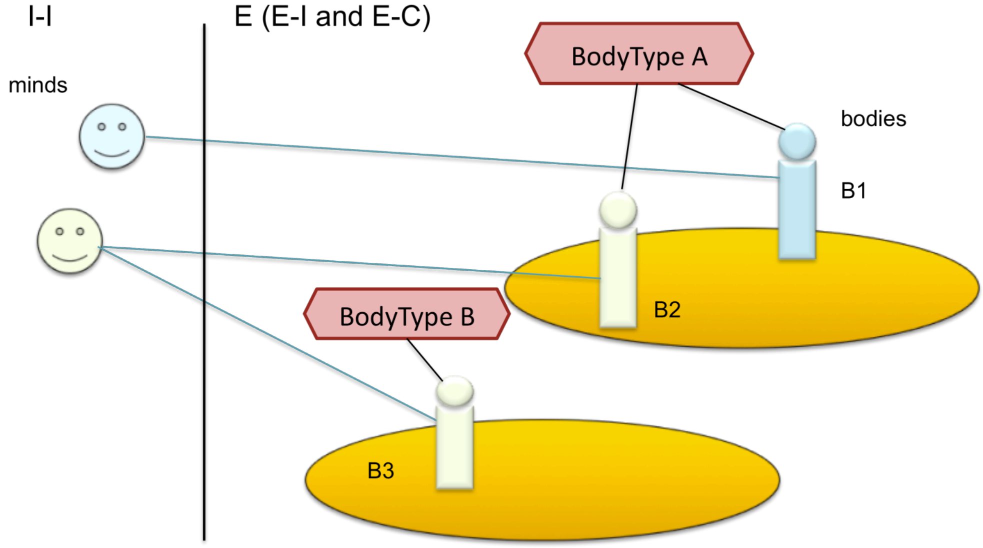

Figure 7. Diagrams of brute spaces, whether physical or social and the HoldBody *function between minds and bodies. Thus minds may be seen as being embodied in brute space through their bodies.*

Relation to minds

Minds are connected to objects by the relationship *HoldBody* and objects are linked to brute spaces by the relationship *BelongTo*. Therefore we can transitively define the relationship between minds and brute spaces by introducing the concept of incarnation or embodiment: a mind is embodied in a body, which is situated in a brute space (fig. 7).

A mind can have several bodies in different brute spaces. Note also that a mind can have many bodies in the same brute space, although in many cases a unique body per space is the common scenario. A brute space is also used to limit the scope of the perception and the possible actions for a mind in the brute reality. In addition, we recall that the perception remains local; a body does not perceive an entire brute space. This property is called the principle of locality of perception.

Brute interaction

A brute space defines the context of interaction for the objects that compose it. Each object taken individually has an internal activity that is expressed at any moment by its dynamic state. The various activities that are carried out within a brute space may interfere with each other as, for example, when two moving objects come into collision. The conditions under which an interference may occur and its corresponding effects are described at the level of brute spaces.

As in (Helleboogh, Vizzari, Uhrmacher & Michel, 2007) interferences can result in a transformation of activities of the corresponding objects. For example, when two objects come into collision, their speed and direction of movement can change. Such a transformation in activities is expressed in MASQ by a change in the objects' dynamic state using the influence/reaction model (fig. 8).

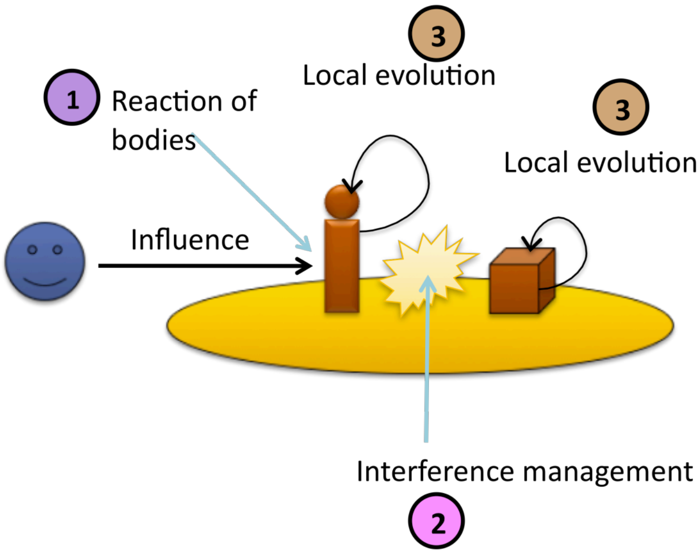

Figure 8. Evolution of brute spaces results of a cycling process of 1) reaction of bodies to mind's influences, 2) interference management, 3) local evolution of objects.

4.3. Cultures

Cultures[4] have been introduced to capture the perspective of the I-C quadrant, i.e. intersubjectivity. A *culture* represents the subjective elements that are shared by a group of minds, i.e. collective interpretations, social norms, ontologies, common or shared knowledge, Schank's scripts, etc.

The main interest of cultures is to provide a context that allows agents to reach a common understanding. From the perspective of an agent, culture is used to interpret communications, understand events and anticipate the behavior of other agents. Conversely, from the perspective of a society, a culture is a tool that helps the society to control the behavior of its members while preserving their integrity and heterogeneity. Thus, a culture induces a form of social pressure to obtain better coordination between the members of a society while reducing and/or solving possible conflicts.

In MASQ, a mind can have access to shared knowledge by being embedded in one or more cultures. To express the relationship between a mind and a culture we say that a mind *m* is *immersed* in at least a culture *CS*. A mind may be immersed in several cultures. Coherence of a mind between several cultures is left to the mind's developer.

For a culture, here are three important types of common knowledge:

1. **Shared knowledge and ontologies**: information expressed in the form of concepts and relations between concepts that gives a culture its conceptual basis.
2. **Shared patterns of behaviors** that are displayed by all individuals of the same culture in similar situations, i.e. his or her role in a specific context. These patterns of behavior may be represented as deontic elements (obligation, interdiction, authorization), shared plans, protocols, Schank's scripts, etc.
3. **Collective interpretation**: interpretations of phenomena occurring in brute spaces that are not specific to a single mind but are collectively accepted in a culture.

An important issue of cultures is the notion of interpretation of brute space events. A body in a brute space acquires information through its sense, and gets a sensation which is a kind of

[4] In MASQ, we distinguish between the objective aspect of society, and we call it social, and its intersubjective (or interior) aspect and we call it cultural. Thus 'social' has here a different meaning than in the work of Searle. Thus most of the use of "social reality" in Searle should be translated here as "cultural reality". For instance a father-son relation is social, because it is a fact, but what is associated to it in a specific culture is called "cultural" and here "social" refers to aggregates and relations that belong to the brute space.

brute percept. This has to be transformed into a percept, i.e. a representation of something through the cultural filter. For instance, an electric plug may be seen by a robot as a kind of food resource for its own purpose. But in a different context, the same plug may be considered as a way to power devices. We say that the same plug may have different *interpretations* depending on its culture, which constitutes a context of interpretation. A collective interpretation of a brute event in a culture *cs* is a function which maps a sensation to a percept:

$Interpret_{CS}$: *Sensation* → *InterpretedPercept*

where *InterpretedPercept* (or *percept* for short) are descriptions represented with the ontology of the culture *cs*. This means, that an interpretation function takes a sensation and delivers a percept described in terms of the cultural ontology. For instance: a car driver which sees a red light interprets it as a road signal which means that she has to stop, as shown on figure 9, due to the interpretation function defined in her "driver's culture".

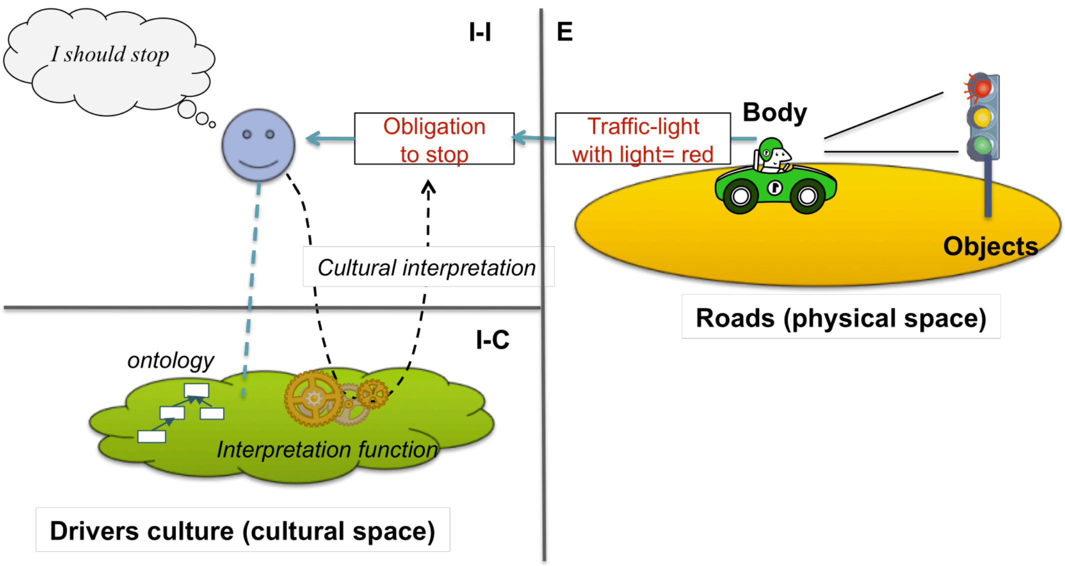

Figure 9. A driver interpretation of a red light as an obligation to stop through the interpretation function of his or her culture.

Cultures contain also plans, protocols and scripts, i.e. patterns of behavior that one is supposed to apply in a specific circumstance with a specific role. Let us suppose that our driver of the previous example does not stop and goes through the traffic light, and let us suppose that a policeman watches the scene. Because he plays the role of the policeman, he interprets the behavior of the driver as an infringement and then as the obligation to send a fine to the driver. But sending a fine is associated to both the rights *and* the effective power to send it, the latter being possible in MASQ through a social body. Thus, the policeman has the capability to send a mail containing a fine (fig. 10). Then the driver, when receiving the fine will interpret it, with regard to her culture, as an obligation to pay, etc.

We can see that there is still a possibility of "free will" for the policeman. The obligation to send a fine is determined by its role in a culture, but he may circumvent it. This is due to the fact that the culture produces deontic elements such as obligations and interdictions, but does not execute minds. Thus the decision process is still an autonomous quality of agents in MASQ.

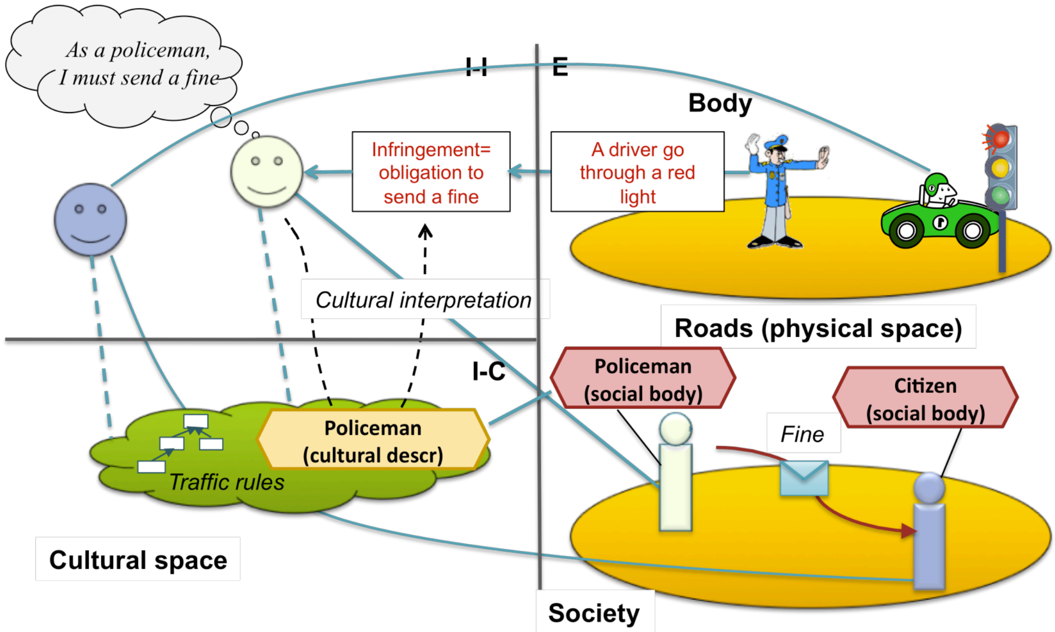

Figure 10. A policeman sends a message to the drivers that should stop to a signal.

MASQ captures the main ideas behind the concept of institution as in (Searle 1995) where institutions are defined as a set of constitutive rules and regulative rules. According to Searle, an institution can be used to build a social reality from the brute reality and/or other social realities. *Constitutive* rules can give a meaning to a brute fact or a fact from another social reality. They are of the form "X $\Rightarrow_C$ Y" which is read "X count as Y in the context C" and they put a brute fact X in relation with an institutional fact.

For instance the "driving culture" which contains the traffic rules is an institution built from rules of the form:

$$going\text{-}through\text{-}red\text{-}light(driver) \Rightarrow_{driving} infringement(driver)$$

R*egulative* rules give a characterization of the institutional facts showing "how things should be". The distinction between these two types of rules is essential. The constitutive rules are used to create a social reality, whereas the regulative rules regulate the activities in an already existent social reality.

A regulative rule is an expression that associates a deontic description to an institutional fact. Since we do not think of a specific representation for regulative rules, our proposal is intentionally very generic. One can see rules, as it is often done, as formulas of the form : $\beta \Rightarrow OPI\alpha$ where $OPI\alpha$ is a deontic characterization (*OPI* – obligation, permission or interdiction) of a property or action α, and β is a conditional boolean expression. But our goal is not to explicitly describe how rules should be expressed, but merely to show how normative aspects may be linked to other aspects of MAS. In practice someone will obviously need to be very explicit on the details of the integration of such a deontic formalism, that is application dependent.

Roles, groups and organizations in MASQ

We have seen that MASQ integrates the environmental, social and cultural perspectives. One may ask how groups, roles and organizations are now handled in this meta-model.

We have shown that AGR groups are now represented as social spaces, i.e. as special kinds of brute spaces, more akin to message passing and status position. However, we propose that descriptions of groups and roles be situated in cultures as shared knowledge. Thus, minds can access this information if they are immersed in the corresponding culture.

In MASQ, groups and roles have now two aspects: a brute and a cultural one. Since a group corresponds to a space, a group is formed at the cultural level from a brute aggregation of agents, according to some constitutive rules. A social group could be seen like in AGR as a collection of social bodies subject to some brute (physical or social) causal laws.

As for roles, as it has been shown previously in the MAS literature (see for instance Odell et al. 2003), they may have several meanings. In MASQ the cultural aspect is related to the normative behavioral repertoire of an agent, and the social and physical aspects concern the powers and abilities that an agent acquires in a space when playing a role. A role in MASQ contains also the link between these aspects by indicating how social bodies are related to collective representations at the cultural level (e.g. through constitutive laws).

4.4. How to represent institutions?

The work of Searle (Searle, 1995) is fundamental in our approach because it allows someone to understand how an institutional reality can be constructed from the brute reality by using institutions. However, Searle has not fully addressed the relationship between individuals and the institutional reality, that is, how people become aware of the facts that are institutionally established. This becomes more obvious if we condition that the knowledge that an agent may have of an institutional reality is directly dependent on its perception of the brute reality. In practice, an agent has only a partial representation of the environment in which it operates and hence it can not have a complete representation of the institutional reality even that it has full knowledge about the constitutive rules. Therefore, we believe that the institutional rules, both constitutive and regulative, should be considered and handled as common knowledge, but their application or the interpretation of the brute reality is something that happens at individual internal level (mind).

By representing an institution as a set of institutional rules leads to similar problems as when representing common knowledge. Therefore, in our proposal we make a distinction between two kinds of constitutive rules, formal and informal. Intuitively, a *formal* rule is similar to a written law such as the civil code, code of conduct in an organization, etc. It has a representation in the brute world. An *informal* rule corresponds to a shared knowledge or custom, accepted by the members of a culture, but that is not described in a formal way, for instance how to greet each.

In MASQ a formal rule is an institutional rule that is reified in a brute space. It means that the rule will be expressed in a certain language and will be encapsulated in a particular object. All the formal rules can be accessed by minds through the mechanism of bodies and percepts. Instead, the informal rules since they have no counterpart in brute spaces, they have an existence only in cultures. To be aware of informal rules, a mind must belong to the culture that they establish. For a mind ignorant of a specific culture, a learning process is required to incorporate the rules of this culture. This learning can be achieved in various ways: by imitating others, observing and generalizing the behavior of others, being informed of the practice by members of this culture, or in terms of rewards and penalties received.

The acquisition process is hence different for formal rules and informal rules. In the case of formal rules it is sufficient to consult the "official records" whereas in the case of informal rules it is necessary to discover or adopt them through interaction.

Whether the rules are formal or informal, it is necessary that a mind internalize them in order to be able to have a representation of an institutional reality. The process of internalization is the adoption of institutional rules as beliefs. By considering the institutional constraint operator $D_s\alpha$, introduced by Jones & Sergot (1996) to describe that α is an institutional fact, a constitutive rule of the form $X \Rightarrow_s Y$ could be internalized by an agent i within a belief of the form $B_i(X \Rightarrow D_s Y)$.

In our proposal, there is no explicit representation of an institutional reality that is external to minds. Instead, every mind can have its own representation according to the internalized rules and its perception of the brute space.

As a consequence, every mind may have a partial and inaccurate representation of an institutional reality, which is the price to pay to preserve the principle of locality of perception. In addition, the construction of a representation of the institutional context is made by the minds themselves, and because minds cannot be controlled from the outside, it is possible that some do not simply create any such representations.

4.5. Culture vs. brute space

In MASQ, the distinction between a culture and a brute space is essential. A brute space allows the realization of an action while a culture allows the interpretation of a collective activity. In the environment, that is, brute spaces, things are as they are. The environment provides no judgment on the elements it contains. The culture, through cultures, gives a meaning to the phenomena occurring in the environment.

The rules that govern a brute space and correspondingly a culture are of very different natures. Rules in a brute space determine its evolution, what an agent can do and what consequences of its actions are. These rules are given to agents. Rules in a culture are descriptive in nature and they have no direct impact on the brute reality. They have no impact on the capabilities of an agent in a brute space. For instance, considering an action as “good” or “bad” is performed at the cultural level and does not alter the ability for an agent to execute it, nor does it change its consequences in the environment, i.e. in brute spaces.

However, while a culture does not affect directly the brute reality, it influences agents’ minds in their decisions, which may lead them to behave differently, and ultimately change the brute reality indirectly.

5 Example: Warbot, a virtual war of robots

We will illustrate the MASQ model through Warbot[5], a computer program in which two teams of virtual robots fight in order to destroy their opponent. This game has been created to help MAS students to understand concepts of coordination, cooperation, conflicts, local behavior, communications, beliefs, organizations, etc. and it is part of the MadKit platform (2008). A player has to describe the “minds” of its robots and to develop his coordination tactics for the whole team to behave collectively. The player disposes of several categories of robots: rocket launchers, explorers and bases. The number of each is not fixed, but the two teams have the same number of robots in each category. The main difference between Real Time Strategy games and Warbot, is that the player does not play while the game is in progress. Figure 11 shows a snapshot of Warbot in progress.

Warbot has been created with most of the MASQ principles (mind-body distinction, influence-reaction, and organizations with AGR), and it is therefore a good platform to test ideas and implementation of MASQ concepts.

[5] www.warbot.fr

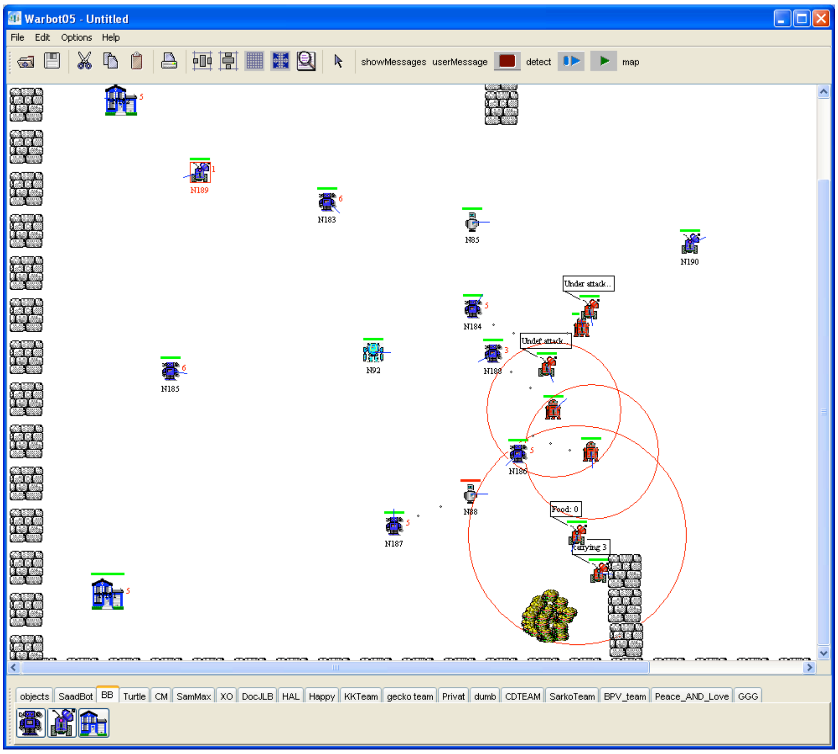

*Figure 11. A snapshot **of Warbot in progress***

Figure 12 shows a representation of Warbot using the MASQ approach in the four-quadrant map. In terms of MASQ, there are two kinds of spaces: a physical space, the *arena*, where physical bodies may move, perceive their environment and send rockets, and social spaces. Two social spaces, inheriting from the default MadKit group, represent the teams. By default, all agents possess a *member body*, which inherits from the default role of MadKit (and AGR). This *member body* allows agents to send messages to each other, to know who is the member of a group and to broadcast messages.

There are other groups that correspond to tactical coordination units (e.g. assailants, defenders, etc.). Reaction rules and local evolution of objects are parts of the MadKit (for the groups) and of Warbot (for the arena and the robots bodies).

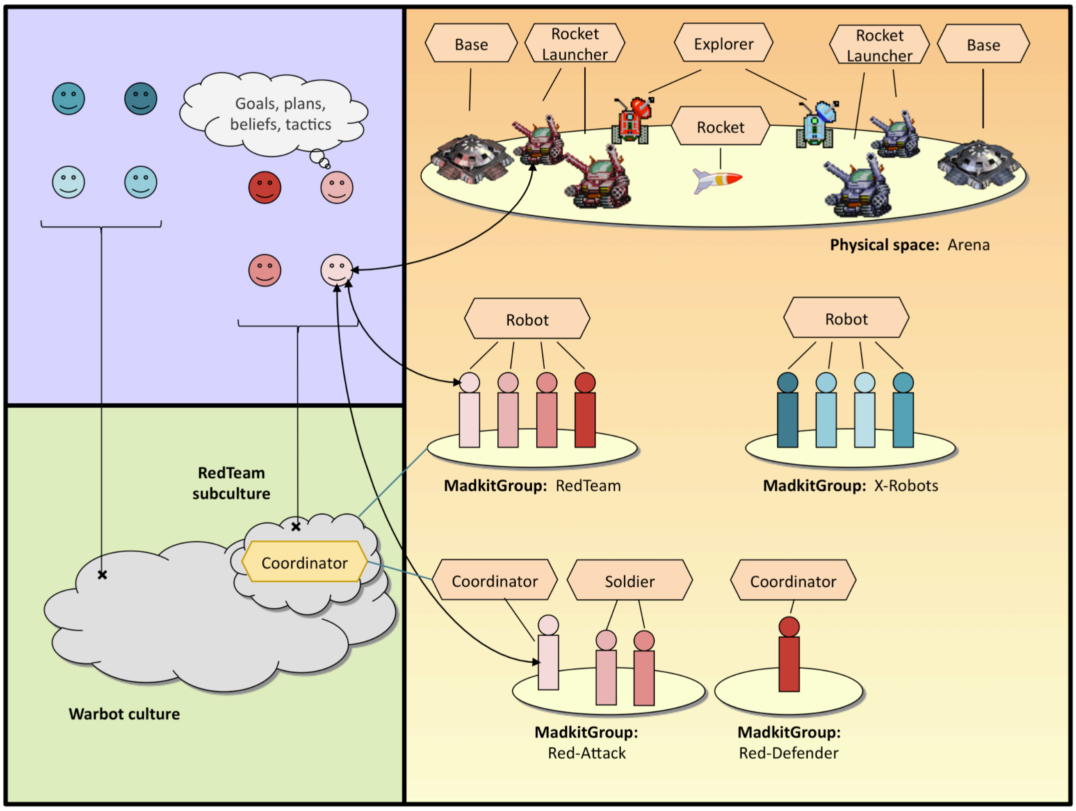

Figure 12. The Warbot example described within the MASQ approach

Robots can perceive objects in the environment: they receive sensory data (brute percepts) through the sensors of their bodies, and these sensations will be interpreted relative to their culture.

For instance, a mind connected to an explorer body *b* will perceive the environment through a combination of sensation and interpretation:

```
Set<Percept> p = WarbotCulture.interpret(b.getSenseData())
```

will return a set of percepts as they are interpreted in the `WarbotCulture` (the default culture in which all robots are immersed).

Specific cultures, such as team subcultures, may easily be represented in MASQ as cultures which contain new concepts, new rules and add new interpretations. For instance, a RedTeam may define a notion of danger, which could be expressed with the following pseudo-code:

```
when a rocket-launcher with team = other
     and with distance(Base) < security-distance
then the team-is-in-danger
```

If the `team-in-danger` concept is considered as a cultural element for the RedTeam, all members of the group may use this item as if it was a simple percept. It is part of their culture, part of the way they reason. Thus, they know that they may send messages using this item because it has some meaning for all members of the team.

6 Discussions and Conclusions

We have briefly presented a new meta-model, called MASQ, which is able to take into account both actions in an environment and cultures (norms, institutions) in an integrated way. We have shown that it is possible to represent several aspects of OCMAS systems in this framework.

Actually, MASQ may be used in different ways. It can be used as an operational framework, and the next MadKit platform will use MASQ as its core. But it can also be used as a methodological tool to take into account the various perspectives of OCMAS.

In the case of natural systems the role of physical and institutional reality is rather clear, if we suppose that there is such thing as an objective reality, but when modeling artificial systems it is necessary to determine precisely what is in the brute reality and what forms the cultural reality. For example, to set up a voting system, humans must establish an institution so that raising a hand may count for a vote. But, in an artificial system, we can choose to use the environment and its brute spaces to give the agents the capability to vote. It is not necessary to represent minds in such systems.

The choice to model a certain aspect of the system at the brute level or at the cultural level depends on the properties we want to obtain for that system. By using brute spaces we have more control on how things happen, e.g. to promote security issues or guarantee a certain result. Problems that are modeled with such approaches have fixed solutions that may be "hardwired". The way to solve them is mostly implemented within evolution and interference laws at the brute level. Thus, brute spaces are rather used to model well-defined causal interaction such as physical interaction (e.g. a rolling ball) and social organized interaction (e.g. playing a role in an organization with fixed protocols).

The choice to model a system at the cultural level gives a new alternative that promotes the adaptability, by promoting culture and agents' autonomy in detriment of causal determinism. Agents have many possibilities to act and to adapt their behavior to world events, and the way to control them may be given in terms of institutional laws, both constitutive and regulative. However, in a cultural approach it is nearly impossible to guarantee that a satisfactory solution will finally be obtained.

A mix of brute and cultural approaches should be used diligently. For instance, in the case of agents that exchange goods on the Internet, trust in others is important. We may let trust be built only at the cultural level, but it is clear that we can improve its construction by using protocols of interaction described at the brute level (keep trace of exchanged messages, force agents to identify themselves, make payments through third-party organisms, etc.). One of our future efforts will be to propose a methodology based on MASQ that will help a designer to decide how to model a system in terms of culture and brute spaces.

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KEY TERMS

AGR (stands for Agent-Group-Role) a generic model of multi-agent organizations which does not impose any constraints on the architecture of agents. AGR conforms to the OCMAS principles.

AGRE (stands for Agent-Group-Role-Environment) adds the concept of environment to AGR.

Body: the interface between a mind and a brute space. Social bodies, i.e. bodies which are situated in organizational spaces, are called 'roles'.

Brute spaces are the environmental domains in which action takes place and where objects (and bodies) are objectively situated.

Culture: In MAS, we use the term "culture" to denote the subjective elements that are shared by a group of minds, i.e. collective interpretations, social norms, ontologies, common or shared knowledge, etc.

Influence-Reaction: a model of action which allows for concurrent activities.

MASQ (Multi-Agent Systems based on Quadrants), an approach in which multi-agent systems are seen from four perspectives: the subjective and personal perspective of minds, the objective and personal perspective of behaviors, the objective and collective perspective of environments and their structuring in terms of objective organizations, the subjective and collective perspective of culture.

Mind: the reasoning, decision-making and cognitive part of an agent. Minds are associated to bodies in order to act in brute spaces.

OCMAS (Organization Centered Multi-Agent Systems): a set of principles to design multi-agent systems based on organizations. In OCMAS, organizations neither describe how tasks are carried out, nor impose any constraints on the cognitive aspects of agents.