# MASQ: towards an integral approach to interaction

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## ABSTRACT

In this paper we describe MASQ (Multi-Agent Systems based on Quadrants), a model that defines four perspectives over an agent-based interaction according to two axes: internal/external and individual/collective. With MASQ, we mainly show how to integrate the essential elements that intervene in the description of the interaction process such as agents, environments, organizations and institutions. We also discuss some methodological aspects of such an approach and show that it is possible to apply it to build practical models.

## Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Multiagent systems*

## General Terms

Theory

## Keywords

MASQ, 4-quadrant approach, institutions, organizations

## 1. INTRODUCTION

Multi-agent systems (MAS) are software systems composed of many agents that interact together to commonly solve a given problem. The main property of the agents that makes them different from other types of software is their autonomy. Agents are considered as active autonomous components with respect to the control of their behavior and to the relationship they have with other components of the system, i.e. the other agents and the environment in which they act. The various studies in the MAS domain showed that the interaction in an agent-based system has multiple facets that are difficult to grasp. The consequence of this is that the basic concepts and principles of MAS have been identified and studied much of the time in isolation from the others and the various perspectives that are adopted are often orthogonal and mutually exclusive (e.g. internal vs. public meaning of the communication, rational vs. reactive internal architectures, agent-based vs. environment-mediated interaction, agent-oriented vs. organization-centered MAS, etc.). However, it seems that if we want to have a deeper understanding and a more complete perspective of the interaction process some efforts should be made to rethink all the basic elements and to integrate as many as possible of them into a unifying framework.

Therefore, in this paper, we describe a general framework and an abstract model of what constitutes a first step towards an integral view of agent-based interaction. The approach we use and that we call MASQ (Multi-Agent Systems based on Quadrants) is based on a 4-quadrant approach and is derived from the AQAL model by Wilber [25], 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 proposes to integrate them in the same conceptual framework.

## 2. AGENT-BASED INTERACTION

Before going into the details of MASQ, we develop first more on the analysis of the main research directions in MAS 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 [10], 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, and the model of the BDI agent coupled with the theory of speech acts seems to be the most appropriate one. However, the vision of interaction as pure rational communication has its limits (e.g. the difficulty to check the conformance between actual communicative acts and their semantics, since no third party observers are allowed). 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 and organization-centered MAS (OCMAS) interaction.

The environment-based interaction research concentrates on the physical distributed aspects of interaction. The environment is considered a first-class abstraction at the same

[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.

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level as the agents, and has its own state and laws of change [23]. 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 [9]. The works here 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 [5, 7, 8]. An organization provides a way of partitioning the whole set of interactions into smaller contexts. From this perspective, an organization is seen as a collection of agents considered together in groups, playing roles or regulated by organizational rules. For instance, in an organizational model such as AGR [7], the agents can interact only inside a group in which they play roles. A role is a general concept to which a MAS architect can associate various semantics (i.e. rights, obligations, norms, powers, patterns of behavior, etc.). An organization is then considered coherently under its functional, structural and deontic aspects (see the family of MOISE models [14]).

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 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 [16] the core layer (kernel) which implements the organizational environment has as basic functionalities to let agents join groups, associate roles to agents and let interact only members of the same group. Another way to represent an organization is to reify it as a socially constructed agent acting at the same level as other agents [2]. 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 in MAS have shown the importance of other social concepts. The works on electronic institutions [17, 6], 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 in economics [18]. 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. Norms are also used to define some deontic states and identify their violation. We think that from this point of view, electronic institutions and organizations converge more and more towards manipulating similar concepts.

Another stream of research that makes use of the term *institution* takes its inspiration from the philosophical work of Searle. According to Searle [21], 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 brute facts from the physical reality to institutional facts. Jones and Sergot [15] 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 [1] 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. More recent works try to clarify the various aspects of the constitutive rules (procedural, declarative, normative) and use them to implement normative agent systems [2, 3] and show their connection to social commitments [12, 11]. Although it is still not clear what is the relationship between institutions and organizations, we can conclude that the tendency in MAS research is to re-consider the structures imposed to interaction (organizations included) from an institutional point of view.

| **Interior-Individual (I-I)** | **Exterior-Individual (E-I)** |
|---|---|
| Subjectivity<br><mental states, emotions, beliefs, desires, intentions,..><br>Interiority | Objectivity<br><agent behavior, object, process, physical entities ><br>Exteriority |
| **Interior-Collective (I-C)** | **Exterior-Collective (E-C)** |
| intersubjectivity<br><shared knowledge, social norms, conventions, ontologies, collective representations><br>Noosphere | Interobjectivity<br>< Environment, organizations, reified social structures, social facts><br>Sociosphere (social structures) |

**Figure 1: The 4-quadrant map**

However, the works on institutions seem to ignore the importance of environment and of actions in environments [24], apart from communications [11]. Reciprocally, 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. We think especially to an integrated model that would consider in a loop how from internal activities local to agents that act into a shared environment it is possible to emerge a more complex structure at both physical and institutional levels that will influence back the internal activities of the agents.

## 3. MASQ: A 4-QUADRANT APPROACH

MASQ is a new framework for designing MAS that provides a two-dimensional description of the complex relationships existing in such systems. This approach, which is inspired from the work of Wilber [25], resides on a decomposition along two axes: the individual vs. collective perspectives on the one side, and the interior (i.e. mental states, representations) vs. exterior (i.e. behavior, objects, organizations) perspectives on the other side. These two axes taken together provide for a 4-quadrant map where each quadrant must be considered as a perspective by which individuals, situations and social systems may be understood as it is shown on Figure 1. The I-I (Interior-Individual, upper left) quadrant is about emotions, beliefs, desires, intentions, drives of an individual. It describes an internal subjective reality that is defined in terms of mental states. The E-I (Exterior-Individual, upper right) quadrant describes physical bodies, concrete objects, and their behavior. The reality defined at this level is given by the external properties of an individual. The E-C (Exterior-Collective, lower right) quadrant is about material and formal social structures such as collections, groups, organizations, and systems. The reality defined at this level is what could be called the *socio-sphere*. 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. The reality defined at this level is what could be called the *noosphere*.

In addition to the 4-quadrant decomposition of the analysis and design of agent-based interaction, the MASQ metamodel is based on several basic concepts which we justify as it follows.

## 3.1 Mind vs. Body

The internal/external axis suggests to consider that an agent is composed from a *mind* and many *bodies*. A mind corresponds to the internal structure of an agent or to the decision-making component. Bodies, either *physical* or *social* are parts of the environment and are connected to minds. For instance, in the case of a mobile robot, we usually dissociate its physical hardware elements (wheels, legs, motors, sensors, etc.) from the software control units. A body is also the manifestation of an agent in the environment and allows others to perceive it. It is considered as an active object in the physical environment and is subject to environmental rules and constraints.

## 3.2 Agent integrity principle

The mind of an agent is not public, that is, it cannot be accessed from the 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.

## 3.3 Actions as reactions to influences

Mind and bodies are connected through the influence/reaction principle [9, 13]. This principle is based on the idea that an agent cannot directly change the state of the world, but only *influence* its dynamics. An agent decides what action to do next and then the environment determines its consequences. For instance, when an agent *intends* to mail a message and consequently to do the operation to send it, it is the environment which actually transmits and delivers the message. In the example of a robot, it is the robot who decides to move, but it is the environment (through its body and other objects) who performs the movement. Thus, the environment reacts to influences produced by agents to determine its dynamics, through a set of "laws", which in case of the physical world are the laws of physics and dynamics. Consequently, everything that is not provided by the environment is simply not possible for an agent.

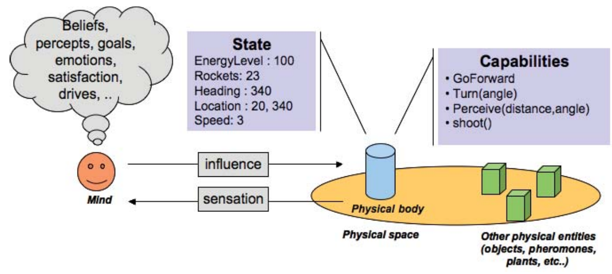


**Figure 2: Mind-Body**

To summarize (see Figure 2), a mind is a process, independent of the environment, but in interaction with it through its bodies. It has its own life cycle and the result of the deliberation phase determines the operations that will generate the influences (through asynchronous communication) on the environment. The link between the I-I and E-I quadrants is therefore made under the form of an exchange of influences (issued by the mind) and sense data (issued by the environment).

## 3.4 Brute spaces: physical and social

The E-C quadrant corresponds to the place where the physical and social interactions happen, called also the brute reality or the brute space. Together with the E-I, both quadrants are used to represent the environment. For practical reasons, in order to tackle the complexity of the interactions, the brute reality can be partitioned further in *spaces*. Inside a space, agents are represented through bodies.

A space can be of one of two types: *physical* or *social*. Thus, agents may possess more specialized bodies, physical as well as social. We therefore try to generalize the concepts of group/organization (e.g. as in AGR [7]) and agent-in-role [19] to which now correspond those of social space and social body respectively.

## 3.5 Brute spaces vs. cultures

The distinction between I-C and E-C quadrants gives us a better understanding of how Searle's work on the construction of social reality [21] applies to MAS. It provides a clear separation between what constitutes the brute reality, i.e. the objective part of what happens in a world, and the collective knowledge and subjective values that can be made by a collection of agents to describe and interpret the objective part. We propose to 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 interpretations. Following Searle, the institutional or cultural reality is produced by applying *count-as* operators of the form "$X$ counts as $Y$ in context $C$", where $Y$ are facts in a cultural space and X are facts in a brute space. Thus, cultures may be seen as interpretive domains giving values to sensations or brute perceptions. The reason for which we use the term culture instead of institution is that we are further interested in dynamical aspects of an institution such as its evolution and propagation, which in social sciences are categorized as cultural.

Different interpretations of the brute reality may exist at

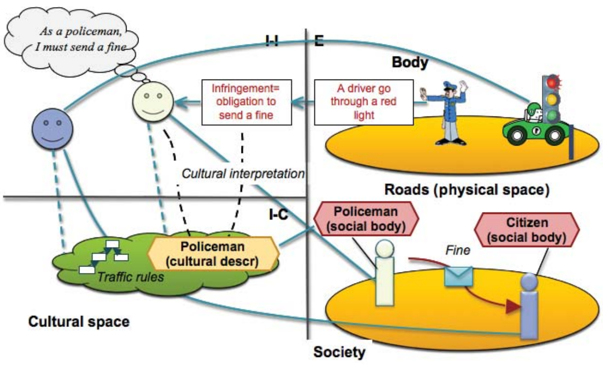


**Figure 3: Scenario in MASQ**

the same time for an agent. They depend on the various cultures that an agent accepts to belong to. A society of agents can influence the agents in their decisions, particularly in terms of cultural 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.

The main scenario in a 4-quadrant approach is that of an agent that makes decisions with its mind and acts in a brute/social space through its body where it will be possible to enter into interaction with other various objects. Then the interpretation of the brute/social interaction that it perceives will be used as support for the construction of the cultural/institutional reality according to the culture in which the agent is immersed.

# 4. MASQ: THE MODEL

Given the above justifications we can now describe in detail the main elements composing MASQ. The meta-model MASQ is built on (i) five basic elements: minds, objects, bodies, brute spaces and cultures; (ii) a set of relations between basic elements; (iii) a set of laws that describe its dynamics.

## 4.1 Minds

A mind is a dynamical system characterized by a) an internal state, b) a mechanism of state change, given the sensation information the mind receives, among other things[2], c) an influence production mechanism that determines the influences produced by the mind according to its internal state[3]. The last two elements are grouped under the term internal dynamics. The internal state of an agent corresponds to the I-I quadrant, 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 coexist 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.

[2]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 sense data issued by the environment at different times. This mechanism can be modeled by a state transition function.

[3]This mechanism can be modeled by a production function.

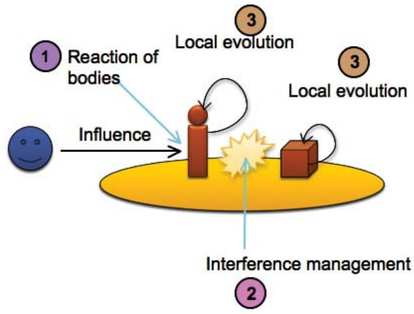


**Figure 4: Brute space life cycle**

## 4.2 Objects

We use objects 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 events that occur in it. Objects are considered as passive entities because the environment controls completely their evolution. However, when modeling objects in MASQ we can adopt an object-oriented approach and associate behavior to objects for instance to specify own activities such as rolling in the case of a ball, or changing periodically of color for a traffic light. An object is therefore 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). Each object is of an object type $T$ that is used to contain the description of the structure and the behavior of similar objects.

The change in the dynamic state of an object in isolation is described through instantaneous evolution laws (or internal activity). An evolution law is a function $\phi$ that associates two dynamic states $\delta$ and $\delta'$, where $\Delta_o$ is the set of all possible dynamic states of the object $o$.

$$\phi : \Delta_o \to \Delta_o$$
$$\delta \to \delta' = \phi(\delta)$$

Note that a mind may have several bodies and a body is associated to a unique mind. We use $HoldBody$ to define the link between a body and a mind. We also use reaction laws to describe the evolution of a dynamic state of body as reactions to the influences sent by its mind. A reaction law $RLaw$ of an object type $T$ is a function:

$$RLaw : \Delta_T \times 2^{\Gamma} \to \Delta_T$$
$$(\delta, \{\gamma_1, \gamma_2, ..., \gamma_i\}) \to \gamma'$$

where $\gamma_i$ are influences produced by a connected mind. A mind can potentially send all kinds of influences back to its body, but only certain types of influences will have a real effect on it. The life cycle of a body as an object in an environment is managed at the brute space level.

Although the concept of body usually suggests a physical nature, as it is the case for a mobile robot, it should be seen as a means to perceive and act in an environment, whatever its nature.

## 4.3 Brute spaces

We introduced the concept of brute space to partition the interactions from the E-C quadrant. A brute space maintains a state of affairs that is objective, independent of agents' opinions. From a conceptual point of view a brute space is composed of objects. An object cannot belong to several brute spaces at the same time. 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. The role of the brute space is to manage the interaction between the objects and the boundaries/interfaces to other spaces or quadrants of the system.

#### 4.3.1 Brute interaction

In a brute space, 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 however 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 therefore at the level of brute spaces through interference laws as in [13]. The effects are in general transformation of activities of objects or of properties of the brute space. For example, when two objects come into collision, their speed and direction of movement can change. The life cycle of a brute space is represented in Figure 4.

#### 4.3.2 Physical Spaces vs. Social Spaces

Two categories of brute spaces are usually distinguished: physical and social. 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 define 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. an e-mail address and a message box) which is situated in the infrastructure for message delivery. The communicative capabilities are associated to specific rights (what kinds of communications the agent is allowed to perform) which refer to its role (e.g. administrators often have more rights than simple users). Other examples of social spaces are most of community related web systems, such as forums, wiki, meeting systems, etc. In such systems, each participant has a pseudonym, related to a role, which gives the participant specific capabilities for acting in the system. The pseudonym, with all the capabilities associated to it, may be seen as a social body, and the web system as an interaction social space. Like in physical spaces, it is also possible to define a topology for social spaces [26]. For example, an organization that uses the roles of master and slave defines a hierarchical topology.

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. Note that in figure 3, for drawing simplicity, we have merged the quadrants E-I and E-C in just one zone called E (Exterior). But bodies still belong to E-I and spaces to E-C.

#### 4.3.3 Relation to minds

Minds are connected to objects by $HoldBody$ relationship and objects are linked to brute spaces by $BelongTo$ relationship. 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. A brute space is then used to limit the scope of the perception and the possible actions of 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.

### 4.4 Cultures

The main interest of using cultures is to provide a context that allows agents to reach a common understanding. From the perspective of an agent, a 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 or solving possible conflicts.

A culture is defined through three important types of common knowledge:

**Shared knowledge and ontologies** which represent information expressed in the form of concepts and relations between concepts.

**Shared patterns of behaviors** that are displayed by all individuals of the same culture in similar situations, i.e. roles. These patterns of behavior may be represented as regulative rules, shared plans, protocols, Schank's scripts, etc.

**Constitutive rules** which represent rules of interpretation of phenomena occurring in brute spaces that are not specific to a single mind but are collectively accepted in a culture.

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 $C$. A mind may be immersed in several cultures. Coherence at mind level between several cultures is left to the mind's architect.

The mechanism of constructing the cultural space (or institutional reality) functions as it follows. A body in a brute space acquires through its sensors some new information which is sent to the mind as a sensation, a kind of brute percept corresponding to the brute fact. Then a mind, depending in which culture is immersed, can use the appropriate constitutive rules to interpret the brute percept and build the cultural or institutional facts. The institutional facts are described then within the culture's ontology.

Similarly to institutions [21], *constitutive rules* can give a meaning to a brute fact or a fact from another cultural reality. They are of the form $X \Rightarrow_S Y$ which is read "$X$ counts as $Y$" and they put some brute facts $X$ in relation with an institutional fact $Y$. For instance, a car driver which sees a red light interprets it as a road signal which means that she has to stop, and going through red light is considered as an infringement, as shown on Figure 3. The constitutive rules for this case are: $redLight \Rightarrow_{road} stop$ and $goThroughRedLight(driver) \Rightarrow_{road} infringement(driver)$.

A *regulative rule* is an expression that associates a deontic description to an institutional fact of the form : $\beta \rightarrow OPI\alpha$ where $OPI\alpha$ is a deontic characterization ($OPI$ stands for obligation, permission or interdiction) of a property or action $\alpha$, and $\beta$ is a conditional boolean expression.

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 the driver from the previous example does not stop and goes through the traffic light, and let us suppose that a policeman watches the scene. The policeman can now interpret the behavior of the driver as an infringement and that it has the obligation to send a fine to the driver. But sending a fine supposes both the rights and the effective capabilities (or power) to send it, the latter being possible in MASQ through the status accepted commonly by the agents immersed in the culture. Thus, the policeman has the capability to send a mail containing a fine. Then the driver, when receiving the fine, interprets it, with regard to her culture, as an obligation to pay, etc. Note that in this scenario it is always possible to preserve the free will of the minds. For a policeman the obligation to send a fine or for a driver the obligation to pay the fine are determined by the roles they play in the culture. But both agents may circumvent them. 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 at the agent level remains autonomous.

Representing institutions as sets of institutional rules leads to similar problems as when representing common knowledge. Therefore, 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 a brute space, expressed in a certain language and encapsulated in a particular object. 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 and hence can be accessed by minds through the mechanism of bodies and percepts. Instead, the informal rules, since they have no counterpart in brute spaces, 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[4].

[4]This is a simplified and naive view of how to relate I-I to I-C, which needs more thought to become effective. Reflecting social structures on the agents' minds is still a complex (philosophical) debate. See for instance [22, 4].

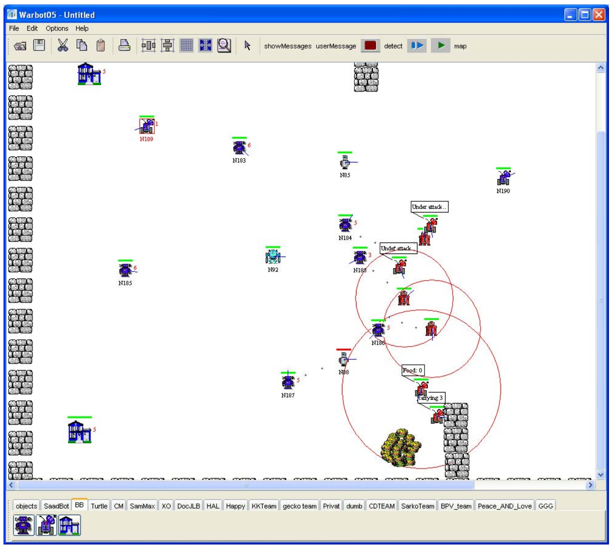

**Figure 5: A snapshot of Warbot**

## 4.5 How to represent the cultural reality?

Whether the rules are formal or informal, it is necessary for a mind to 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 and Sergot [15] to describe that $\alpha$ 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 $B_i(X \rightarrow D_sY)$.

In our proposal, there is no explicit representation of the cultural 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. This is the price to pay to preserve the principle of locality of perception. Much more, it is possible that some minds do not simply create any such representations.

# 5. EXAMPLE: WARBOT

We illustrate the use of MASQ by modeling Warbot, a computer game in which two teams of virtual robots fight in order to destroy their opponent. Warbot has been created to help MAS students to understand concepts of coordination, cooperation, conflicts, local behavior, communications, beliefs, organizations, etc. and is part of the MadKit platform [16]. A player has to describe the "minds" of the robots and develop the coordination tactics inside a team. There are several categories of robots: rocket launchers, explorers and bases. The number of each is not fixed, but at the beginning both 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 5 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

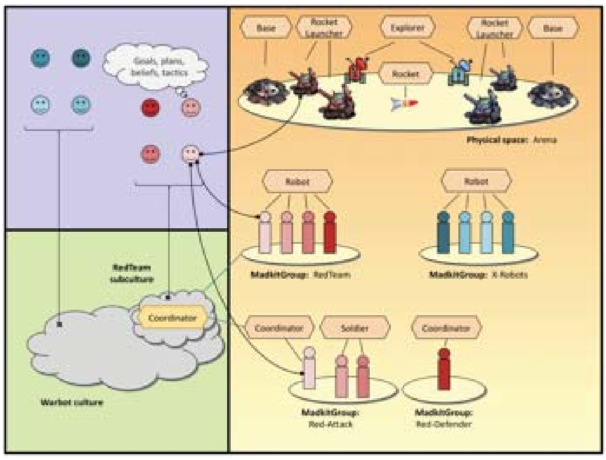


**Figure 6: MASQ model of Warbot**

test ideas and implementation of MASQ concepts.

Figure 6 shows a 4-quadrant map of Warbot. In terms of MASQ, there are three spaces: a physical space, the arena, where physical bodies may move, perceive their environment and send rockets, and two social spaces that represent the teams. Both social spaces inherit from the default MadKit group. Inside a space, by default, all agents possess a member body, which inherits from the default role of MadKit (and AGR). The member body allows agents to send messages to each other and to know who is the member of a group. Other groups can be formed to correspond to tactical coordination units (e.g. assailants, defenders, etc.). Reaction rules and local evolution of objects are developed using parts of MadKit (group management) and of Warbot extension (to represent the arena and the robot bodies).

Each group has its own culture space containing interpretations (sensory to perception rules), norms, and concepts that may be used by agents to decide what they should do next. The perception process of robots is as follows: they receive sensory data on of objects in the environment 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:

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

will return a set of percepts as they are interpreted in the WarbotCulture (the default culture in which all robots are immersed) from sense data that depends from the robot's body. 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, for a team `?t` we may define a notion of danger, which could be expressed with the following pseudo-code:

```
when rocket-launcher(?r)  and
     team(?r, ?t2) and ?t2 != ?t and
     distance(?r, Base) < security-distance
then team-in-danger(?t)
```

If the `team-in-danger` concept is considered as a cultural element for `?t`, all members of the group may use this item as if it were 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. Norms are also represented as rules that specify what is forbidden or obligatory in a culture. For instance, the following rule specifies that messages between members of different groups are forbidden:

```
when messageSentFromTo(?a, ?b) and
     team(?a, ?t1) and team(?b, ?t2) and
     ?t1 != ?t2
then rule-violation(?t1, no-message-outside-team)
```

Thus, when an agent `?a` from team `?t1` sends a message to a member of team `?t2`, it is the whole team `?t1` which is considered as violating the rule.

## 6. DISCUSSIONS AND CONCLUSIONS

In this paper we presented MASQ, a new meta-model able to equally handle in an integrated way various basic elements that compose the interaction process such as agents, environments, organizations and institutions. MASQ may be used in different ways. It can be used as an operational framework, and we hope it would have some impact to the current MAS architectures since it introduces some new generalizations. The graphical representation of the 4 quadrants is quite intuitive and very explicit in terms of the architectural layers that would compose a 4-quadrant based system.

MASQ can also be used as a methodological tool to take into account the various perspectives of mediated-interaction. 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 put in the brute reality and what in 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 without going through the complications of the reasoning with constitutive rules. 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 cultures and brute spaces. We suppose that a mix of brute and cultural approaches should be used equally. 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.).

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 socially 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 the detriment of the 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, since in a cultural approach the result of interaction depends on the agents' capacity to apply or interpret the institutional laws autonomously, it becomes difficult to guarantee a satisfactory result from an external point of view (e.g. that of an architect).

Finally, we think that MASQ can be a useful map to guide the understanding of the agent-based interaction process with many respects. In our case, adopting a 4-quadrant approach has been proved crucial to realize that organizations should be finally represented as any other physical or material system ruled by causal laws and therefore be placed in the E-C quadrant. The same is true for institutions each time we make them formal or want to reify or "implement" the institutional reality, since we go from I-C to E-C. We can argue now that even organizations are in fact institutions, which in social sciences is a well accepted idea [20], and much more, that in MAS they should be treated as reified institutions. We also think that by using the more general concepts of social body and social space it would be possible to indicate the relationship that exists between the works on organizations and those of "electronic institutions" in order to unify them.

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