

Organising MAS: A Formal Model Based on Organisational Mechanisms

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ABSTRACT

In this paper, we propose a general formal framework for organising multiagent systems whose participants are rational agents. This model is based on the idea of *organisational mechanisms*. These are mechanisms introduced in a multiagent system with the aim of influencing the behaviour of the agents towards more effectiveness with regard to some objectives. We define two kinds of organisational mechanisms: i) *informative mechanisms* which provide additional information to agents, that may persuade agents to behave in a certain way, and ii) *regulative mechanisms* which produce changes in the environment of the agents, that may impose certain behaviours. We also define some properties of these mechanisms which will make it possible to prove certain characteristics of organised multiagent systems. Finally, we present a discussion about how the social concepts proposed by different organisational paradigms can be considered as either informative or regulative organisational mechanisms.

Categories and Subject Descriptors

I.2.11 [Distributed Artificial Intelligence]: Multiagent systems

General Terms

Theory

Keywords

Multiagent Systems, Organisations, Organisational Mechanisms

1. INTRODUCTION

In the last years, the concept of *organisation* has become very important in the field of multiagent systems (MAS). This concept changes the focus in the design of MAS from

an agent-centred approach to an organisation-oriented approach where the problem consists in designing the rules of the game rather than the individual components. Therefore, such proposals are more suited for open MAS where the actual agents that will populate the system are not known at design time and where agents may leave and join the system at any time. Proposals, such as Agent-Group-Role [9], MESSAGE [4], Roadmap [12], Electronic Institutions [8], OMNI [6], MOISE [11] or the models proposed in [5, 3], have been presented in order to organise MAS.

Most of the proposals consider an organisation as an entity that has some concrete purpose or global objective which may or may not be aligned with the individual objectives and preferences of the agents. Then they use a set of organisational concepts, e.g. roles, norms, groups, interactions, etc; to control and modify the dynamics or behaviour of the agents with regard to the global objective of the organisation. In general, such concepts are used to limit the freedom of choice of the agents and, thus, to assure that agents behave in a desired way. In our opinion, this vision of organisation is just one possible vision. In particular, we believe that the concept of organisation is not restricted to the existence of some entity with a global objective or purpose. Organisational structures may also exist (or emerge) as a mean to aid agents in their decision making processes in an uncertain environment. From this point of view, organisational concepts may provide agents with useful additional information that allows them to better estimate the expectations of certain actions.

In this paper, we define a general formal framework for organisations, based on the idea of *organisational mechanisms*, that includes both previously mentioned points of views. We define two different types of organisational mechanisms: *informative* and *regulative*. Informative mechanisms try to organise the system by providing potentially relevant and unknown information to agents. This information can help them to select the best actions related to their individual objectives. Regulative mechanisms are mechanisms which change the environment, either by changing the consequences of actions (i.e., providing rewards or punishments) or by limiting the actions agents can perform in certain states of the system. Thus, regulative mechanisms correspond rather to the focus of most existing proposals for multiagent organisations.

The paper is organised as follows: section 2 presents some notations and necessary definitions. Thereafter, section 3 presents our formal framework for organisations and defines

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the different types of organisational mechanisms. Furthermore, we define some useful properties and characteristics that makes it possible to assess the effectiveness of particular organisational mechanisms. Section 4 provides some discussion and analyses how common organisational concepts can be classified in terms of informative and regulative organisational mechanisms. Finally, section 5 gives some conclusions and provides some ideas for future work.

2. NOTATIONS AND BASIC DEFINITIONS

Our formal framework relies on two basic concepts, *agent* and *multiagent system*. We define these concepts in a rather standard way, similar to the definitions provided by other authors (e.g., [13]). We consider that both concepts are closely related. In particular we consider that agents are always embedded in a multiagent system and this system specifies the environment of the agents.

Definition 1. A multiagent system (MAS) is a tuple $\langle Ag, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi \rangle$ where:

- Ag is a set of agents, $|Ag|$ denotes the number of agents in the system;
- \mathcal{A} is a possibly infinite action space that includes all possible actions that can be performed in the system. \mathcal{A} includes an action a_{skip} ; the action of doing nothing;
- \mathcal{X} is the environmental state space;
- $\Phi : \mathcal{X} \times \mathcal{A}^{|Ag|} \times \mathcal{X} \rightarrow [0..1]$ is the MAS transition probability distribution, describing how the environment evolves as a result of agents' actions;
- $x_0 \in \mathcal{X}$ stands for the initial state of the MAS;
- $\varphi : Ag \times \mathcal{X} \times \mathcal{A} \rightarrow \{0, 1\}$ is the agents' capability function describing the actions agents are able to perform in a given state of the environment. $\varphi(a, x, ac) = 1$ ($\varphi(a, x, ac) = 0$) means that agent a is able (not able) to perform action ac in the state x .

Following the definition presented by Wooldridge in [13] a MAS provides a common environment where agents can act. The model adopts the view that the environment of an agent is everything that surrounds it; i.e. any existing entity including other agents. Implicitly we assume that the system evolves at discrete time steps. In each step, all agents in the system perform one action, that is, the new state of the environment is produced through the joint actions of all agents. We assume that agents can take a "skip" action, which allows for modelling asynchronous behaviours.

The set of actions an agent can perform in a given state of the system (defined by φ) is a subset of \mathcal{A} and will depend on its individual abilities, but also on the restrictions imposed by the environment. For instance, in a traffic scenario, roads and junctions could form part of the environment of an agent. A car represented by an agent has the physical ability to move forward, to move back, to move right and to move left. Given a particular state, the environment can limit the actions an agent can take. For instance in the traffic scenario, a car may not turn right if there is no road going to the right. In the same way, the environment defines the consequences that taking an action may have. From the point of view of an individual agent, the consequences of

doing an action depends not only on the action, but also on the actions of the other agents, the characteristics of the resources embedded in the MAS, and possibly on other external influences. In this regard, it should be noted that our definition allows for existing additional external influences on the environment evolution.

Agents are considered independent, autonomous software components that are able to perceive observations about their environment and, based on these observations, take actions. Formally, we define agents as follows:

Definition 2. An agent is a tuple $\langle \mathcal{S}, \mathcal{O}, g, t, per, s_0 \rangle$ where:

- \mathcal{S} is the set of internal states of the agent;
- \mathcal{O} is the observation space of the agent; i.e., the set of possible observations the agent is able to perceive from the MAS;
- $g : \mathcal{O} \times \mathcal{S} \rightarrow \mathcal{S}$ is the agent's state transition function;
- $t : \mathcal{S} \rightarrow \mathcal{A}$ is the agent's decision function describing the action it will choose given an internal state;
- $per : \mathcal{X} \rightarrow \mathcal{O}$ is a perception function assigning an observation to an environmental state;
- s_0 is the agent's initial internal state.

At each step, agents receive an observation from the environment, change their internal state and take an action, which is finally executed. The internal state of an agent possibly encodes its history of actions and observations, its beliefs about the state of the environment, as well as its own preferences. The internal state evolves by observing its environment. The agent's decision function reflects its behaviour or policy and determines which action it will take in the next step.

A particular type of agents are *rational agents*. Rational agents rule their behaviour based on their preferences about their internal states. These preferences can be represented by means of an utility function. Rational agents select their actions in order to maximise this utility function.

Definition 3. A rational agent is a tuple $\langle \mathcal{S}, \mathcal{O}, g, t, per, s_0, \mathcal{U} \rangle$ where:

- $\mathcal{S}, \mathcal{O}, g, per, s_0$, are defined as in definition 2;
- $\mathcal{U} : \mathcal{S} \rightarrow \mathbb{R}$ is an utility function that assigns a value to each possible internal state of the agent;
- the agent's decision function $t : \mathcal{S} \rightarrow \mathcal{A}$ follows the principle of maximising the expected utility (MEU), that is:

$$\begin{aligned} t(s) &= \operatorname{argmax}_{a \in \mathcal{A}} eu(a, s) \\ &= \operatorname{argmax}_{a \in \mathcal{A}} \sum_{s' \in \mathcal{S}} \mathcal{U}(s') \cdot \overline{P}_s(s'|s, a) \end{aligned}$$

where:

- $eu(a, s)$ is the expected utility of performing the action a in the state s ;
- $\mathcal{U}(s')$ is the utility of the state s' estimated by the agent;
- $\overline{P}_s(s'|s, a)$ is the agents' estimate, at state s , of the probability that state s' will occur when executing action a in state s .

A rational agent’s decision function is based on some preference relation over its available actions given an internal state s . For a rational agent, this preferences relation is an ordering over \mathcal{A} that is defined in terms of some utility function \mathcal{U} and the probabilities $P(s'|s, a)$. Supposing that agents are generally not omniscient, they are unable to calculate $P(s'|s, a)$ and, thus, have to estimate this values. We denote by $\overline{P}_s(s'|s, a)$ the estimation of the probability that state s' will occur when executing action a in state s , given the agent’s current state is s . The estimation may change when new knowledge is available, e.g., the agent is in another internal state.

We define the utility function of an agent on the possible internal states. This is slightly different to other approaches, where it is defined on states of the environment. The reason is that we believe that the utility function is somehow *local* to the agent and, thus, has to be defined with respect to what the agent observes from its environment and not with respect to the actual state of affairs. From the agents’ perspective, its utility function will provide the same values for any two *indistinguishable* environmental states – states for which the agent has the same observations and, thus, it is unable to distinguish between them. This definition focuses on the utility function as a means to solve the decision problem from the agents own perspective, rather than as a measure of its performance in solving some given task as seen from the outside. In fact, the utility function defined here, can be used as a measure of an agent’s performance taking into account its perception limitations.

3. ORGANISED MULTIAGENT SYSTEM

The general idea of organising a multiagent system is to provide some mechanisms that influence the behaviour of the agents; usually towards more effectiveness with regard to some objectives. Such mechanisms may either impose certain behaviours or they may persuade agents to behave in a certain way. Formally, we define an organised multiagent system as follows:

Definition 4. An organised multiagent system (OMAS) is a tuple $\langle \mathcal{RA}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{OM} \rangle$ where:

- $\mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi$ are defined as in section 2;
- \mathcal{RA} is a set of rational agents;
- \mathcal{OM} is a non-empty set of organisational mechanisms.

The definition relies on systems with rational agents. The reason is the following. Obviously, any agent (rational or not) will change its behaviour if it is imposed to do so. However, only rational agents, because of their preferences on the states of affairs, are capable of being persuaded to do certain actions and are receptive to incentives and penalties.

As stated before, organisational mechanisms can influence the behaviour of agents towards more effectiveness with regard to some objectives. This can be seen from two different points of view: i) the micro perspective, and ii) the macro perspective.

From the micro perspective (i.e., the perspective of individual agents) an organisational mechanism may help agents to take better decisions regarding their *individual utility* function (\mathcal{U}_{ra_i}).

From the macro perspective (i.e., the perspective of the whole MAS) a system itself may have some *global utility* function (\mathcal{U}_{MAS}) which corresponds to a preference relation on the states of the environment. Such a preference relation may be defined by some authority (e.g., the designer or the manager of the system) or may correspond to some social welfare function. Regarding a global utility function \mathcal{U}_{MAS} , an organisational mechanism may improve the utility of the system by persuading or imposing agents to behave in a determined way.

In relation to these perspectives, we consider that there are two ways to influence the behaviour of agents: i) from a micro perspective; providing them with additional information that may help them in their decision making process, and ii) from a macro perspective; manipulating the environment so as to regulate the possible actions agents can take or the consequences these actions will have. Accordingly, we define two kinds of organisational mechanisms : i) *informative mechanisms*, and ii) *regulative mechanisms*. In the following sections we define both types of mechanisms in more detail.

3.1 Informative Organisational Mechanisms

A rational agent has to evaluate the expected utility of each possible action (or of the actions it is aware of) in order to decide which action to take next. This decision is based on the agent’s own individual knowledge and experience. In real world scenarios, the knowledge of agents about the entire system is usually limited and thus, their decisions are made on more or less accurate estimations. Hence, from the point of view of the agents, any additional information may improve the accurateness of their estimations, and, thus, help them to take “better” decisions. Informative organisational mechanisms may provide such information.

Definition 5. An informative organisational mechanism Γ is a function that given a partial description of an internal state of an agent and taking into account the partial view that the mechanism has of the current environmental state, provides information:

$$\Gamma : \mathcal{S}' \times \mathcal{X}' \rightarrow \mathcal{I}$$

where:

- \mathcal{S}' represents the set of possible partial descriptions of agents’ internal states;
- \mathcal{X}' is the set of partial views of environmental states;
- \mathcal{I} represents an information space.

We have chosen a very general definition of informative organisational mechanisms in order to cover all possible instantiations. The information provided may consist of a set of actions an agent can take but it is possibly not aware of, a recommendation of a particular action which is eventually a “good action” for the agent, or information about the consequences that a given action may have.

All informative organisational mechanisms have in common that their usage is not imposed. Agents are free to use such mechanisms at their own discretion. In fact, when rationality of agents is assumed, agents must use a given informative organisational mechanism if and only if they expect that the usage of the mechanism will be advantageous for them.

The basic algorithm describing how a rational agent selects its next action if there exists an informative organisational mechanisms is given below¹.

Let $ra = \langle \mathcal{S}, \mathcal{O}, g, t, per, s_0, \mathcal{U} \rangle$ be a rational agent embedded within an organised multiagent system. Let x_j be the current environmental state of that system and let Γ be an informative organisational mechanism.

Algorithm 1 SelectNextAction

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1:  $o_j \leftarrow per(x_j)$ 
2:  $s_j \leftarrow g(o_j, s_i)$ 
3: if isReasonableToUse( $\Gamma, s_j$ ) then
4:    $\mathcal{I}_j \leftarrow \Gamma(s'_j, -)$ 
5:    $a_j \leftarrow t(< s_j, \mathcal{I}_j >)$ 
6: else
7:    $a_j \leftarrow t(s_j)$ 
8: end if
9: return  $a_j$ 

```

After perceiving the observations of the current environmental state and changing its internal state, the agent decides (*isReasonableToUse*) whether or not it should use the informative organisational mechanism in the current situation. If the agent decides to use the mechanism, it will select its next action by taking into account the information provided by this mechanism. Otherwise, it will select its next action only based on its own experience. In the first case, the agent only provides a partial description of its internal state. The mechanism obtains the partial description of the environmental state through some monitoring module.

Informative organisational mechanisms may improve the performance of individual agents and may have effects on the global performance of an organised multiagent system with respect to a global utility function. In this sense it is possible to define several desirable properties. These properties should be taken into consideration when designing mechanisms and may also serve to prove certain characteristics of organised multiagent systems.

In the sequel we use the following notations. Let $ra_i = \langle \mathcal{S}, \mathcal{O}, g, t, per, s_0, \mathcal{U} \rangle$ be a rational agent. a^{Γ, s_j} and a^{s_j} denote the actions selected by ra_i in the internal state s_j with and without taking into account the information provided by an informative organisational mechanisms Γ , respectively. $\mathcal{U}_{ra_i}(a, s_j)$ denotes the utility of the action a for agent ra_i in the state s_j . When talking about decisions taken at a certain time step t_k , we denote the internal states of the agent at time t_k by s_{t_k} .

Definition 6. An informative organisational mechanism Γ is **useful for an agent ra_i in an internal state s_j** , denoted by Γ_{ra_i, s_j}^* , iff the utility obtained by the agent performing the action a^{Γ, s_j} is greater than the utility obtained by the agent performing the action a^{s_j} . That is:

$$\Gamma_{ra_i, s_j}^* \Leftrightarrow \mathcal{U}_{ra_i}(a^{\Gamma, s_j}, s_j) > \mathcal{U}_{ra_i}(a^{s_j}, s_j)$$

For simplicity, we suppose that the cost associated with the use of the mechanism is implicitly included in the value of $\mathcal{U}_{ra_i}(a^{\Gamma, s_j}, s_j)$.

¹This case is a simplification where there is only one informative organisational mechanism. In case there are more than one mechanisms, the algorithm should be changed accordingly.

A similar definition may be defined considering an agent during a period of time.

Definition 7. Let $T = t_1, t_2, \dots, t_n$ be a time period. An informative organisational mechanism Γ is **strongly useful for an agent ra_i along the time period T** , denoted by $\Gamma_{ra_i, T}^*$, iff the sum of the utilities of the actions selected by ra_i during T is greater if the agent uses the mechanism Γ , than without using it.

$$\Gamma_{ra_i, T}^* \Leftrightarrow \sum_{k=1}^n \mathcal{U}_{ra_i}(a^{\Gamma, s_{t_k}}, s_{t_k}) > \sum_{k=1}^n \mathcal{U}_{ra_i}(a^{s_{t_k}}, s_{t_k})$$

Now, this definition defines strong usefulness, in the sense that it is supposed that an agent *always* uses the informative organisational mechanism. It would be also possible to define a weaker usefulness by taking into account that an agent may be able to select the particular situations in which it will use a given mechanisms (e.g., the implementation of the decision function *isReasonableToUse*).

It is also possible to define properties of informative organisational mechanisms from the point of view of the OMAS, regarding a global utility function defined by some authority.

Definition 8. Let $OMAS = \langle \mathcal{R}\mathcal{A}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{O}\mathcal{M} \rangle$ be an organised multiagent system and let $\mathcal{U}_{OMAS} : \mathcal{X} \rightarrow \mathbb{R}$ be a global utility function of $OMAS$. Let $T = t_1, t_2, \dots, t_n$ be a time period. An informative organisational mechanism Γ is **effective regarding the global utility function \mathcal{U}_{OMAS} during the time period T** , denoted by $\Gamma_{OMAS, T}^+$, iff the sum of the utilities of the environmental states of the $OMAS$ during the period T is greater if $OMAS$ implements Γ than if it would not. That is:

$$\Gamma_{OMAS, T}^+ \Leftrightarrow \begin{cases} OMAS' = \langle \mathcal{R}\mathcal{A}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{O}\mathcal{M} \cup \{\Gamma\} \rangle \wedge \\ OMAS = \langle \mathcal{R}\mathcal{A}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{O}\mathcal{M} \setminus \{\Gamma\} \rangle \wedge \\ \sum_{k=1}^n \mathcal{U}_{OMAS'}(x_{t_k}) > \sum_{k=1}^n \mathcal{U}_{OMAS}(x_{t_k}) \end{cases}$$

Given these definitions, it is also possible to define “more useful” (and “more effective”) informative organisational mechanism.

Definition 9. Let Γ^{*1} and Γ^{*2} be two useful informative organisational mechanism for an agent ra_i in an internal state s_j . Γ^{*1} is **more useful for agent ra_i in state s_j** than Γ^{*2} , denoted by $\Gamma_{ra_i, s_j}^{*1} \times \Gamma_{ra_i, s_j}^{*2}$, iff the utility obtained by the agent performing the action a^{Γ^{*1}, s_j} is greater than the utility obtained by the agent performing the action a^{Γ^{*2}, s_j} . That is:

$$\Gamma_{ra_i, s_j}^{*1} \times \Gamma_{ra_i, s_j}^{*2} \Leftrightarrow \mathcal{U}_{ra_i}(a^{\Gamma^{*1}, s_j}, s_j) > \mathcal{U}_{ra_i}(a^{\Gamma^{*2}, s_j}, s_j)$$

In a similar manner we define informative organisational mechanism that are **more useful for an agent ra_i along a time period T** and **more effective regarding a global utility function \mathcal{U}_{OMAS} of an OMAS during the time period T** .

Although agents can not be obliged to use informative organisational mechanisms Γ , such mechanisms can still be effective with regard to a global utility function \mathcal{U}_{OMAS} of an organised MAS. That is, they can be used to manipulate the behaviour of the system towards some globally desired direction. However, this is only possible if there is a certain alignment between the local utility functions of the agents and the global utility function of the OMAS. In particular, an informative mechanism Γ can not be effective with regard to a global utility function of an organised MAS if it is not useful for at least one agent in at least one state. Supposing

that rational agents are able to determine over time whether or not Γ is useful in a given state, on the long run, no rational agent would use Γ and, hence, this mechanism would not have any effect on the utility of the whole OMAS².

3.2 Regulative Organisational Mechanisms

As regulative organisational mechanisms we consider mechanisms that produce changes in the environment with the aim to improve a system's behaviour from a global, macro level perspective, that is, with respect to some global utility function. Such mechanisms rely on the existence of some entity (e.g., the system designer, a system manager, ...) that defines the preference relation over system states represented through the global utility function, and that has sufficient authority to impose certain changes in the system.

The rationale behind such mechanisms is that rational agents are perceptive to modifications in the environment because such modifications may change the consequences of actions. Thus, rational agents, with the aim to maximise their individual benefit, may adapt their behaviour to such changes.

We consider two types of possible changes in the environment: *i*) introduction of incentives (i.e., changes in the MAS transition probability distribution), and *ii*) of the action spaces of agents (i.e., changes in the agents' capability function). We define regulative organisational mechanisms accordingly:

Definition 10. Let *MAS* be a multiagent system $MAS = \langle Ag, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi \rangle$.

- An incentive mechanism, Υ_{inc} , for *MAS* is a function that given a possibly partial description of an environmental state of *MAS* produces changes in the transition probability distribution of *MAS*

$$\Upsilon_{inc} : \mathcal{X}' \rightarrow [\mathcal{X} \times \mathcal{A}^{|Ag|} \times \mathcal{X} \rightarrow [0..1]]$$

- A coercive mechanism, Υ_{coe} , for *MAS* is a function that given a possibly partial description of an environmental state of *MAS* produces changes in the agents' capability function of *MAS*

$$\Upsilon_{coe} : \mathcal{X}' \rightarrow [Ag \times \mathcal{X} \times \mathcal{A} \rightarrow \{0, 1\}]$$

- A regulative organisational mechanism for *MAS* is either an incentive mechanism or a coercive mechanism for that *MAS*.

\mathcal{X}' represents the set of possible partial descriptions of the environmental states of *MAS*.

Incentive mechanisms may produce changes in the consequences of agents' actions by introducing rewards and penalties. In our formalisation, this is equivalent to changes in the transition probability distribution if we consider that adding rewards or penalties to a given state actually results in another state. Obviously, rewards and penalties may produce variations in the expected utility of an agent's actions and, hence, rational agents would change their decisions accordingly (if they know of such incentives). Note that our

²It is still possible that agents will use Γ , for instance in the case of new agents or because of mechanisms for exploring new, possibly better, actions.

formalisation allows for a probability dependent assignment of rewards and penalties. Thus, these mechanisms cover cases similar to, for instance, putting a radar in a road. In this case, the probability of a car to get fined (and, thus, the probability to change to a state with less money) is higher if the car passes at high velocity than without the radar.

In the case of coercive mechanisms the changes in the system are produced through a modification of the action spaces of agents. This may be obtained by extending or limiting the space of actions either for all agents or for particular agents. New actions may be added or existing actions may be eliminated. For instance, destroying a street or constructing a new street in a city would be such a mechanism. Again, coercive mechanisms may change the behaviour of a MAS with rational agents, since the agents will change their decisions according to such mechanisms.

Note that by limiting the agents' action space we mean a "hard" coercion, because the system is changed in such a way that agents are not able to perform the eliminated actions.

Regulative mechanisms may be implemented at design time as fixed mechanisms for the whole life cycle of a MAS (as it is done in many approaches on multiagent organisations). They may also be introduced when necessary and may even adapt their functioning to each particular situation of the system.

In contrast to informative organisational mechanisms, agents can not decide to "use" regulative mechanisms. They are just confronted with the new state of affairs. From their point of view, it makes no difference whether changes in the environment have been produced because of some regulative mechanisms, because of random events, or because of the activities of other agents. Rational agents just have to take into account such changes when they decide their next actions.

As for informative mechanisms, we can define the effectiveness of regulative mechanisms with respect to some global utility function.

Definition 11. Let $OMAS = \langle \mathcal{RA}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{OM} \rangle$ be an organised multiagent system and let $\mathcal{U}_{OMAS} : \mathcal{X} \rightarrow \mathbb{R}$ be a global utility function of *OMAS*. Let $T = t_1, t_2, \dots, t_n$ be a time period. A regulative organisational mechanism Υ is **effective regarding the global utility function \mathcal{U}_{OMAS} during the time period T** , denoted by $\Upsilon_{\mathcal{U}_{OMAS}, T}^+$, iff the sum of the utilities of the environmental states of the *OMAS* during the period T is greater if *OMAS* implements Υ than if it would not. That is:

$$\Upsilon_{\mathcal{U}_{OMAS}, T}^+ \Leftrightarrow \begin{cases} OMAS' = \langle \mathcal{RA}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{OM} \cup \{\Upsilon\} \rangle \wedge \\ OMAS = \langle \mathcal{RA}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{OM} \setminus \{\Upsilon\} \rangle \wedge \\ \sum_{k=1}^n \mathcal{U}_{OMAS'}(x_{t_k}) > \sum_{k=1}^n \mathcal{U}_{OMAS}(x_{t_k}) \end{cases}$$

Definition 12. Let Υ^{+1} and Υ^{+2} be two effective regulative organisational mechanism w.r.t. a global utility function \mathcal{U}_{OMAS} of an organised MAS (*OMAS*) during the time period $T = t_1, t_2, \dots, t_n$. Υ^{+1} is **more effective w.r.t. the global utility function \mathcal{U}_{OMAS} during the time period T** than Υ^{+2} , denoted by $\Upsilon_{\mathcal{U}_{OMAS}, T}^{+1} \propto \Upsilon_{\mathcal{U}_{OMAS}, T}^{+2}$, iff

$$\begin{aligned} OMAS_1 &= \langle \mathcal{RA}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{OM} \cup \{\Upsilon^{+1}\} \rangle \wedge \\ OMAS_2 &= \langle \mathcal{RA}, \mathcal{A}, \mathcal{X}, \Phi, x_0, \varphi, \mathcal{OM} \cup \{\Upsilon^{+2}\} \rangle \wedge \\ \sum_{k=1}^n \mathcal{U}_{OMAS_1}(x_{t_k}) &> \sum_{k=1}^n \mathcal{U}_{OMAS_2}(x_{t_k}) \end{aligned}$$

Informative and regulative organisational mechanisms may be related. Whereas, regulative mechanisms just manipulate the environment of the agents, they do not inform the

agents about the new situations. In many cases it will be reasonable to make agents aware of changes produced in their environments. That is, regulative mechanisms may be complemented by informative mechanisms that give agents information about the (new) dynamics of the system.

4. DISCUSSION

Both, informative and regulative organisational mechanisms, may be effective with regard to some global utility function of a MAS. That is, they may produce changes in the dynamic behaviour of a system which leads the system towards preferred states.

Regarding informative mechanisms, they may provide a means to influence the behaviour of agents even in environments where other, regulative mechanisms can not be implemented (e.g., because of the lack of sufficient authority). However, as agents are free to use the services that such mechanisms provide, and assuming that agents are rational, this is only possible if the mechanisms are also useful for the agents. That means that informative mechanisms can only be effective w.r.t. a global utility function if there is a certain alignment between the individual utility functions of the agents and the global utility function of the system. An example for an effective informative mechanism is the reputation system used by eBay. In this system both, the individual agents (at least most of them) and the global system benefit from the provision of information about sellers.

Considering regulative organisational mechanisms, they can only be effective if the changes they introduce in the environment influence in some way the decisions of the agents (e.g. constructing a new road that no one will use is useless).

The presented model is intended to be a common framework for organisational paradigms in multiagent systems. Many authors have proposed the use of social concepts: roles, norms, interactions, and so on to regulate or organise the activities of agents in a MAS [9, 4, 12, 8, 6, 11, 5, 3]. According to the different approaches, the use of such social concepts can be considered as either informative or regulative organisational mechanisms as we propose in this paper. When comparing several approaches of organisation-oriented methodologies, they can be classified into two groups [1]: on the one hand, methodologies which design the system by means of roles, groups, and relationships (e.g., [9, 4, 12]). On the other hand, proposals that focus on social norms, defining control policies to establish and reinforce them and designing an organisational structure (e.g., [8, 6, 11, 5, 3]). The concept of role appears in these kind of methodologies as a main piece. They are mechanisms which restrict the set of possible actions that an agent can perform. From our point of view, such schemes can be classified as regulative organisational mechanism (in particular coercive mechanisms), since role assignments limit the action spaces of agents. But the usage of roles can also be considered from another perspective. Knowing the assignment of roles to agents, an agent also knows what actions another agent can take and what actions it is likely to take (in the case of obligations assigned to roles). From this perspective, the assignment of roles to agents represents an informative organisational mechanism as it provides additional information to the agents in the system. A similar view is also the one used in [10] and [2], where role taxonomies are used to reflect the capabilities of agents rather than to establish permissions and obligations. In these cases, the organisa-

tional concepts used provide information to agents about the expectations of future actions and, hence, can be seen as informative mechanisms.

Another important social concept used in multiagent organisation approaches is the norm. In a classical view, a normative system indicates to agents what actions are permitted and/or prohibited in a certain situation. Now, if such a system establishes prohibitions and permissions and is coupled with a mechanism that imposes these restrictions in a way that no agent is able to violate them then the normative system is a pure coercive mechanism. On the other hand, if a normative system defines permitted and prohibited actions as a basis of penalties if agents violate the norms, then the mechanism turns into an incentive mechanism. Indeed, from the point of view of an agent in this case it is actually irrelevant that a given action is prohibited. The only relevant information for a rational agent consists of the possible consequences an action will have (e.g. the penalty). From the point of view of an agent, there is no difference between an action that has negative consequences “by nature” or due to some normative system. The agent will make its decision by analysing the utility of all possible actions. From our perspective, this type of normative system represents a regulative mechanism, in particular an incentive mechanisms, which may be coupled with an informative mechanism. Whereas the incentive mechanism is the part that actually imposes the fines/rewards, the informative mechanism provides the agents with information about (possible) consequences of their actions (e.g., providing the norms).

Many existing models for multiagent organisations that focus on norms can be classified as coercive mechanisms. In Electronic Institutions [8] for example, norms are imposed through governors in a way that agents are not able to violate them. In fact, in this case, from the point of view of the agent, it does not even have to know the norms. Rather it is the mechanism that imposes the norms (e.g., the governors) that has to know the norms because it has to reason about what actions are permitted (prohibited) in order to impose these restrictions.

Another examples of coercive mechanisms are the policies (assignment, behavioural and reorganisation policies) proposed by DeLoach et al. [5]. In particular, assignment and behavioural policies can be seen as coercive mechanisms as they define constraints on possible assignments (Agent x Role x Goal), that is, they define the possible actions agents can take. Regarding reorganisation policies, they can be considered as *adaptive* coercive mechanisms in the sense that they specify future Agent x Role x Goal assignments based on observations of the current state of the system.

Boella et al. [3] propose an organisation model that distinguishes among two types of norms: regulative and constitutive norms. In relation to our work, regulative norms are regulative mechanisms. In particular, they can be seen as coercive mechanism – if they are imposed in a way that agents can not violate the norms – or as incentive mechanisms – if norm violation is possible and implies some type of penalties. In this case again, the publication of the norms, that is the publication the consequences of certain actions, can be seen as an informative mechanism. Regarding constitutive norms, they can be seen as coercive mechanisms because they manipulate the action space of agents.

Finally, several other methods that are usually not di-

rectly considered as organisational approaches, but have certain organisation effects on multiagent systems can be represented through the proposed framework. This is the case, for instance, with different reputation mechanisms, which are essentially informative mechanisms among groups of agents. A similar case are systems with self-organising features like swarm-intelligence [7]. Also in these cases, information exchange among individuals (informative organisational mechanisms) produces behavioural patterns.

5. CONCLUSIONS

In this paper we have presented a formalisation of multiagent organisations that aims to be a general framework for organisational paradigms. The framework defines an organised multiagent systems by means of two types of organisational mechanisms: *informative* and *regulative* mechanisms.

Informative mechanisms influence the behaviour of agents by providing potentially new information which the agents can use to improve their decisions. Informative mechanisms do not rely on some global utility function, they can not be imposed and agents can use them at their own discretion. In this sense, an informative mechanisms is a “soft enforcement” mechanisms.

On the other hand, regulative organisational mechanisms produce changes in the environment of the agents that may affect their decisions. Regulative organisational mechanisms rely on some global utility function and on some entity that has sufficient authority to impose environmental changes. We differentiate two types of regulative mechanisms: *i*) incentive mechanisms - that change the consequences of certain actions in the system -, and *ii*) coercive mechanisms - that restrict or increase the action space of agents. Regulative mechanisms reflect the approach used in most organisation based methodologies in multiagent system.

We have defined some properties of informative and regulative mechanisms which may be used to demonstrate certain desirable properties of multiagent organisations. In particular, these properties may help to determine under which constraints an informative mechanisms may be an effective instrument to direct the behaviour of a system at a global level. This will be especially of interest in domains where informative mechanisms are the only possible way to influence the behaviour of agents, that is, where regulative mechanisms can not be implemented (e.g., peer-to-peer and other similar systems).

In our future work we will try to analyse more deeply under which circumstances informative organisational mechanisms may be effective with respect to some global utility function of an OMAS. Furthermore, we plan to specify more detailed organisational mechanisms for particular scenarios by imposing certain restrictions on different parameters of a system. Our long term goal is to create a set of organisational mechanisms - appropriate for different kinds of MAS - that can be used in multiagent system design.

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7. REFERENCES

- [1] E. Argente, V. Julián, and V. Botti. Multi-agent system development based on organizations. *Electronic Notes in Theoretical Computer Science*, 150(3):55–71, 2006.
- [2] H. Billhardt, R. Hermoso, S. Ossowski, and R. Centeno. Trust-based service provider selection in open environments. In *Proceedings of the 2007 ACM Symposium on Applied Computing (SAC)*, pages 1375–1380, 2007.
- [3] G. Boella, J. Hulstijn, and L. van der Torre. Virtual organizations as normative multiagent systems. In *HICSS '05: Proceedings of the Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS'05) - Track 7*, page 192.3, Washington, DC, USA, 2005. IEEE Computer Society.
- [4] G. Caire, W. Coulier, F. J. Garijo, J. Gomez, J. Pavon, F. Leal, P. Chainho, P. E. Kearney, J. Stark, R. Evans, and P. Massonet. Agent oriented analysis using message/UML. In *AOSE*, pages 119–135, 2001.
- [5] S. A. Deloach, W. H. Oyenon, and E. T. Matson. A capabilities-based model for adaptive organizations. *Autonomous Agents and Multi-Agent Systems*, 16(1):13–56, 2008.
- [6] V. Dignum, J. Vázquez-Salceda, and F. Dignum. Omni: Introducing social structure, norms and ontologies into agent organizations. In R. H. Bordini, M. Dastani, J. Dix, and A. E. Fallah-Seghrouchni, editors, *PROMAS*, volume 3346 of *Lecture Notes in Computer Science*, pages 181–198. Springer, 2004.
- [7] A. P. Engelbrecht. *Fundamentals of Computational Swarm Intelligence*. John Wiley & Sons, 2006.
- [8] M. Esteva, J. A. Rodríguez-Aguilar, C. Sierra, P. Garcia, and J. L. Arcos. On the formal specifications of electronic institutions. In *Agent Mediated Electronic Commerce, The European AgentLink Perspective.*, pages 126–147, London, UK, 2001. Springer-Verlag.
- [9] J. Ferber, O. Gutknecht, and F. Michel. From agents to organizations: An organizational view of multi-agent systems. pages 443–459. 2004.
- [10] R. Hermoso, R. Centeno, H. Billhardt, and S. Ossowski. Extending virtual organizations to improve trust mechanisms. In *Proceedings of 7th International Conference on Autonomous Agents and Multiagent Systems AAMAS 2008, Estoril, Portugal, May 12-16, 2008*, 2008.
- [11] J. F. Hübner, J. S. ao Sichman, and O. Boissier. A model for the structural, functional, and deontic specification of organizations in multiagent systems. In G. Bittencourt and G. L. Ramalho, editors, *Proceedings of the 16th Brazilian Symposium on Artificial Intelligence (SBIA'02)*, LNAI 2507, pages 118–128, Porto de Galinhas, PE, Brazil, 2002. Springer.
- [12] T. Juan, A. Pearce, and L. Sterling. Roadmap: Extending the gaia methodology for complex open systems, 2002.
- [13] M. Wooldridge. *Introduction to MultiAgent Systems*. John Wiley & Sons, June 2002.