Self-Organization in Multiagent Systems:

From Agent Interaction to Agent Organization

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Abstract. In this paper we suggest a new sociological concept to the study of (self-) organization in multiagent systems. First, we discuss concepts of (self-) organization typically used in DAI. From a sociological point of view all these concepts are missing the special quality of organizations as self-organizing social entities. Therefore we present a concept of organization based on the habitus-field theory of Pierre Bourdieu. With reference to this theory, organizations are viewed as both "autonomous social fields" and "corporate agents" which are competing with other organizations in the same domain. Finally, we describe the *Framework for Self-Organization and Robustness in Multiagent systems (FORM)* corresponding to these sociological characteristics of organizations. This framework uses delegation as the central concept to define organizational forms and relationships in task assignment multiagent systems.

1   Introduction

Self-organization has been subject of discussions concerning the question of the interrelationship between a system and its environment in various disciplines apart from DAI. During the last decades self-organization has become a interdisciplinary notion. The different theoretical approaches have in common that they call any kind of system self-organizing if it is able to determine its internal structure by itself as the environment changes. The boundaries of a self-organizing system and its structure (i.e. the relation between its elements) are not determined by environmental factors. Rather, these systems generate, change and adapt their internal organization within their own logic in a dynamic process to cope with environmental changes. In consequence, the interrelationship between the internal organization of self-organizing systems and their environment cannot be described in terms of linear causality. As systems are defined to be more than the sum of the relations between their elements, the organization of a system cannot be derived from its single elements either (cf. [10]).

As a result of more recent social theories, the notion of self-organization has become a primitive in sociology when it comes to describe social entities (groups, networks, organizations). Various sociologists pointed out that social order and the emergence of social entities neither can be completely derived from social constraints (norms, rules, resources). Nor can they be entirely derived from the intentions and interactions of single agents as social order may emerge and exist independently from single agent's intentions.

In the field of DAI, there is an enormous body of literature on self-organization using many different interpretations of the term. Nevertheless, Panzarasa and Jennings criticize that the interdisciplinary notion of self-organization mentioned above only has found little attention yet: "Within the MAS literature the concept of self-organising MASs has been partially considered by researchers interested in designing the best match among task, environment, structure and performance. However, these studies still conceive the environment in the usual structural-contingent way of a set of constraints to which the MAS needs to adapt" [11].

In accordance with this critic, we suggest a new sociological concept to the study of self-organization in MAS in this paper as we share the opinion that sociological theory can help overcoming difficulties in modeling MAS. With reference to the habitus-field theory of Pierre Bourdieu we describe organizations as self-organizing social entities ("autonomous fields"). This concept follows a critical discussion of some selected concepts dealing with patterns of self-organization in MAS. We argue that all these concepts are missing the special quality of organizations as self-organizing social entities from a sociological point of view. Then, we introduce a framework for self-organization and robustness in MAS (*FORM*).

We restrict ourselves to MAS that are designed for task-assignment (cf. task-oriented domains [13]). Agents act in their environment in analogy to an electronic market. The market consists of two groups of agents: providers and customers. Customers have tasks that should be performed, possibly they represent human users as avatars. Providers are agents that can perform tasks which are of a certain type, have to be performed within a deadline, and may be composed of subtasks. The tasks can be viewed as environmental factors the providers have to cope with. We will not go into detail about what kinds of tasks are to be performed by the agents but rather concentrate on the effect of organizing groups of providers.

2 Self-Organization in MAS-Organizations

Within DAI-literature a great deal of authors use the term self-organization in combination with MAS-Organizations. With reference to human societies, the term organization is generally used for agent systems that carry out a form of joint action through differentiation and coordination of tasks between members [11]. (Therefore, we do not discuss concepts of self-organization in MAS that only deal with joint cognitive processes in this paper).

The notion of organization has been adopted in DAI, because it has been considered as an advantage that human organizations overcome the cognitive, physical, temporal and institutional limitations of individual agency [5]. Secondly, an organization can be more persistent than a group of interacting agents because of formal structures that regulate membership, procedures, aims of the group and other constraints which are important to organize joint action. This is achieved e.g. by the separation of ends from motivations for paid members in organizations where money acts as motivation. In comparison with interaction systems, organizations do not fall apart as soon as the agents stop to interact. Thirdly, organizations institutionalize anticipated co-ordination. This anticipation could lead to efficient performance of the organization [14]. In summary, formal structures which exist independently from goals, actions and intentions of singular agents, but constrain agents in their actions, can be considered as a major advantage of organizations.

Therefore, researchers in DAI adapted organizational concepts from social science for the design of MAS in which agents are not explicitly constructed to cooperatively achieve given goals, but act in a self-interested way. For example, Zambonelli et al. suggest to analyze firstly the requirements an organization should meet, then to define which organizational form fits the requirements best. Finally, the designer should constrain the self-interested agents by

creating a formal structure (i.e. create a control regime by designing a role model, specify organizational roles, assign agents to these roles) [21].

However, in comparison with high-level social interaction (coordination, cooperation, negotiation) MAS-organizations designed this way are less flexible due to their formal structure. Therefore the advantages of an organization could turn into disadvantages, if requirements of the organization change because of an unsteady environment. As MAS are more often situated in open and dynamic environments, rigid roles and static organizational structures become a severe problem. MAS need to manage problems like increases and fluctuation of the number of agents, changes of task profiles and drop-outs of agents, etc. [16]. Besides, empirical research on social organizations in human societies informs us that every form of social organization has specific advantages and disadvantages depending on its institutions and the environment. Scott expresses this insight from sociology in the following three theses (in [17]): (1) There is no one best way to organize. There are no general principles applicable to organizations in all times and places. (2) Any way of organizing is not equally effective. Organizational structure is not irrelevant to organization performance. (3) The best way to organize depends on the nature of the environment to which the organization relates. Organization design decisions depend on environmental conditions.

To cope with these problems, researchers in DAI call for self-organizing MAS-organizations: „MASs should be *self-building* (able to determine the most appropriate organizational structure for the system by themselves at run-time) and *adaptive* (able to change this structure as their environment changes)" [19]. Hitherto, various models of self-organizing MAS-organizations have been build. For instance, Turner & Jennings use self-organization for scalability issues in MAS, where organization plays an important role. They improve system performance by the individual agents' ability to determine the most appropriate communication structure for the system by themselves at run-time and to change this structure as their environment changes. This involves a heterogeneous MAS with intermediary agents [19]. The work of So & Durfee is similar but restricts analysis of tree-like structures to the performance in homogeneous MAS [18]. Note that all communication links between the agents are of the same nature and re-organization focuses on the arrangement of communication channels, rather than (re-)defining the nature of each channel. All these interpretations of self-organization have in common that self-organization means the process of generating, adapting and changing organizational structure, which is the result of individual choices by a set of agents to engage in interaction in certain organizational patterns.

From a sociological point of view, we agree with the suggestion that self-organization means the process of generating, adapting and changing organizational structure, but we do not agree with the explanation of this process. To define organizational structure *as the result of individual choices by a set of agents to engage in interaction in certain organizational patterns* is a contradiction from a sociological point of view. Social order and social systems like organizations are emergent phenomena, i.e. the social order that arises from interaction, may not be intended by the interacting agents. However, the definition mentioned implies that organizations are the sum of interactions between single agents and that social order is reduced to links between single agents. Using this definition means that MAS-organizations can not be modeled as self-organizing social systems, which emerge, exist and persist independently from single agents' intentions and goals and react upon the goals and actions of agents at the same time. To exploit the advantages of organizations for MAS, a definition of self-organization in organizations is needed that allows both, (1) the existence of (formal) social structures which are independent from single agents and constrain agents in their actions, (2) the genesis, change, and adaptation of these structures by the actions of agents, even though the resulting structures may not reflect the intentions and goals of single agents.

Based on Bourdieu's „theory of practice", we would like to contribute a sociological model to the formation, stability, and transformation of organizations in the following chapter.

3 Organizational Theory for Multiagent Systems

Although Bourdieu himself did not work on organization theory, we suggest that his concepts of habitus and social field are fruitful starting points to the study of self-organization in MAS-organizations. The theory offers explanations about the emergence, reproduction and change of social order on all levels of social aggregation (groups, organizations, networks, society). Moreover, his theory allows to describe organizations as social fields (cf. [7]).

3.1 Autonomous Fields and Self-Organization

The term field within the theory of Bourdieu is an analytical category. Bourdieu defines a field as an historically developed objective structure, which does not consist of intersubjective links between individuals, but of objective relations between positions. A position is defined by determinations it imposes upon agents, by the present and potential composition of all sorts of capital (economic, cultural, social and symbolic capital), and by its relation to other positions. The structure of capital an agent holds decides about the access to the specific profits that are at stake in the field [4]. These positions must not be conceived as roles. "It becomes activated and active only if the more or less institutionalized position ... finds – like a garment, a tool, a book or a house – someone who sees in it enough of themselves to take it up and make it their own" [3]. Only if the agents are willing and able to act on the positions they have occupied, practice is possible. The term field can not be thought independently from the term habitus and vice versa. The habitus of an agent is defined as a set of dispositions to specific ways of perception, thinking and to perform actions. These dispositions are bounded to the position of the agent within the social structure of a field. They depend on the history of the individual agent in a field and what it experienced in the past. Dispositions may be incorporated or imitated, i.e. learned by observation and acquired by advice. An agent is only capable to take a position because these dispositions acquired in a field enables it to perceive its specific chances and to act according to the objective possibilities available in the social field.

Moreover, Bourdieu assumes that agents take positions, because they are self-interested in a specific way. Their interests depend on their objective position in a field, i.e. their interests are socially shaped. Bourdieu compares a field with a game. Any field follows its own "rules" which are, in contrast to a game, neither explicit norms to be obeyed by individuals nor the product of an intentional act, but *regularities* of practice. Bourdieu assumes that agents act in the field like players in a game. They are taken in by the game, opposing one another and trying to improve their relative positions in the field. Therefore, the distribution of all sorts of capital and the regularities can be object of the agents' attempts to influence the structure of a field in favor of their socially structured interests. According to Bourdieu, we view the agent as the force behind the development, change and reproduction of social structure of any field.

However, fields are not only defined by their structure, their game-like character and their regularities. Any field has its own logic, what makes them autonomous in comparison to other fields. For example, "business is business" (i.e. making profits) is the logic of the economic field. This logic excludes games which are proceeding in another logic. [4]

In summary, fields are self-organizing, emergent social entities. They are emergent social entities because a field is a field of forces, it shows an objective structure of relations between positions. Without these structures of the field agents are unable to act. On the other hand, only if the agents are willing and able to act on the positions they have occupied, practice is

possible (for more details see [15]). They are autonomous as the structures and regularities of a field are getting changed by agents attempting to improve their position within the logic of the field. Fields are self-organizing, not least, because the boundaries of a field are dynamically determined within the field itself. [4].

3.2 Autonomous Fields as Organizations

Our new basic insight is to consider organizations as social fields. In this paragraph, we point out what distinguishes organizations from other social fields like groups of interacting agents or from macro-social fields like the economic or the political field. Argyris and Schön summarized three basic characteristics of organizations which help to adopt the field concept of Bourdieu to organizations: The members of an organization (1) need to conceive measures to carry out decisions in the name of the whole, (2) empower an individual agent to act for the whole, and (3) determine the limits between the whole and the rest of the world [1].

(1) Macro-social-fields fields are sources of practice, but they can not be considered as corporate agents like organizations or micro-social fields. Moreover, organizations are embedded into macro-fields of the society. Corporate agents are competing with other agents in those meta-fields, trying to improve their objective position. As organizations do not have a habitus like individuals, they are lacking the special feel for the game, the practical sense to cope with the constraints of a field. Nevertheless, an organization is not only a corporate agent, but a social field itself in which agents are competing. The members and representatives might aim at achieving a better position for themselves by improving the position of their organization in macro-fields. A basic characteristic of organizations, that distinguishes them from any other kind of social field, are formal structures. These structures regulate aims of the organization, membership, division of labor, competencies of members, distribution of profits. However, it would be a contradiction to the theory of Bourdieu to consider organizations as static and formal apparatuses apparently oriented towards a common function [4]. The social structure of an organization as a field is a cultural as well as a political construction of dominant and dominated agents. Some agents are dominating according to their property and practical use of powerful resources like economic, cultural, social, and symbolic capital. Therefore, the social structures of an organization are formed by relations of power whereby dominant agents like incumbents aim to reproduce their preeminent position over challengers and dominated agents which themselves try to conquer higher positions in the organizational distribution of power and authority. Therefore, formal structures as measures to carry out decisions in the name of the whole, might be i) an object some agents want to change in favor of their interests, ii) a kind of capital or resources some agents use in favor of their interests or iii) constraints to which agents may act in a conform way because it is beneficial to them.

(2) Although Bourdieu himself did not work on organization theory, he worked out a concept of (social) delegation, which is fruitful for organization analysis, too. Bourdieu suggests, that it is necessary for the formation of a group or an organization to delegate a representative, which is empowered to speak for the organization and makes the organization visible to the social environment. However, the fact that another agent speaks for the represented agents may incur commitments in the future, that are not under control to the represented agents. Officially the task of the delegate is to represent the interests of the organization and the members, nevertheless, due to the position it has in the organization the delegate has his own interests that may deviate from those of the organization. (cf. [2])

(3) According to Bourdieu, the "question of the limits of a field is a very difficult one" [4]. The same can be stated for organizations. Within earlier organization theory, there had been an analytical separation of markets and hierarchies. Since the 1970s organizational networks

became an important organizational form. Therefore, the determination of limits between formal organizations and market relations between organization became difficult [7]. Bourdieu remarks that the "limits of a field are situated at the point where the effects of the field cease" [4]. Hence, we suggest to define networks as well as organizational fields, if they are "hybrid" organizations (cf. [7]). These hybrids may not be completely economically and legally integrated, they may be partially integrated by contracts and share a specific interest (e.g. a jointly fabricated product), which results effects of a field. The boundaries of these hybrids are at that point, where the effect of the field declines (e.g. a member of a network produces other products on his own as well and offers them for sale on the market).

4 FORM - A Framework for Self-Organization and Robustness in MAS

Now we present the *Framework for self-Organization and Robustness in Multiagent systems (FORM)*, which is motivated by the argument that there is a close connection between robustness in terms of scalability and self-organization in certain scenarios (for details see [16]). In the following we will only concentrate on the aspect of self-organization in MAS. FORM was inspired by sociological research on the genesis of social forms of organization (network building) and social structure in the field of transportation and logistics.

4.1 The Matrix of Delegation – A Grammar for MAS Organization

The first of two forms of delegation is the delegation of *tasks*. Delegating tasks to other agents is not new to MAS research, research on task-oriented domains has for a long time been involved in how to distribute the right task to the right agent. But the models of delegation were restricted to two kinds of settings: settings where agents are benevolent, i.e. they are all designed to share common goals, or settings where agents simulate authority relationships (as in distributed problem solving). Neither of these apply in (semi-) open MAS. Here, delegation and the choice of the delegate is the result of a reasoning process. This means that agents generally decide on a case by case basis whether they delegate a task and to whom. Recent work on delegation (see [6] and [8] for an extensive treatment) has shown that delegation is a complex concept highly relevant in MAS, especially in semi-open systems. The mechanism of delegation makes it possible to pass on tasks (e.g. creating a plan for a certain goal, extracting information) to other individuals and furthermore, allows specialization of these individuals for certain tasks.

Now we come to the second mode of delegation, *social* delegation. Representing groups or teams is also an essential mechanism in situations, which are dealing with social processes of organization, coordination and structuring. At this point we refer to the concept of holons, which was developed for the task-management in MAS. In many application domains of MAS, tasks can be decomposed into particular subtasks performed by several agents and often a domain allows hierarchical decomposing of tasks. This means that analyzing a domain may show that a task requires to combine the activities of several agents. To model these combined activities the concept *holonic agent* or *holon* was introduced [9] and since then has found increasing application (e.g. in holonic manufacturing systems [12], [20]). A holonic agent consists of parts called *body agents*, which in turn may be holonic agents themselves. Any holonic agent is part of a whole and contributes to achieve the goals of this superior whole. The holonic agent may have capabilities that emerge from the composition of body agents and it may have actions at its disposal that none of its body agents could perform for alone. The body agents can give up parts of their autonomy to the holon. To the outside, a holon is represented by a distinguished *head (agent)* which moderates the activities of the body agents

and represents the holon to the outside. In general, three types of association are possible for a holon. Firstly, body agents can build a loose federation sharing a common goal for some time before separating to regulate their own objectives. Secondly, body agents can give up their autonomy and merge into a new agent. Thirdly, any nuance on the spectrum between the first and second scenario is possible, considering that agents can give up autonomy on certain aspects, while retaining it for others. In this case of flexible holons, the responsibility for certain tasks and the degree of autonomy that is given up is subject to negotiation between the agents participating in the holon, not a matter of pre-definition by the designer.

In holonic terms, social delegation is a task of the head, which, in addition, can also be distributed according to a set of tasks to different agents. Just like fat trees (multiple bypasses to critical communication channels) in massive parallel computing, the distribution of the task of communicating to the outside is able to resolve bottlenecks. This makes social delegation a principle action in the context of flexible holons and provides the basic functionality for self-organization and decentralized control. The task of social delegation (representation) is in many respects different from the tasks mentioned previously. It involves a long-termed dependency between delegated agent and represented agent, and the fact that another agent speaks for the represented agent may incur commitments in the future, that are not under control to the represented agent. Implicitly, an authority structure is constituted by social delegation. Therefore social delegation refers to trust and power, whereas task delegation is mainly based on economic principles. Thus, we believe it is justified to differentiate two types of delegation: task delegation, which is the delegation of (autistic, non-social) goals to be achieved and social delegation, which does not consist of creating a solution or a product but in representing a group or organization. Both types of delegation are essential for organizations because of two reasons: Firstly, they rely on becoming independent from particular individuals. Secondly, they make it possible to describe and explain the phenomena of our interests at a level of social practice, in particular the organization, structuration and power relations in the field of organization.

	Task Delegation	Social Delegation
Economic Exchange		
Gift Exchange		
Authority		
Voting		

Figure 1: The delegation matrix showing two modes of delegation and four mechanisms for performing each mode.

Theoretically, every combination of mode and mechanism is possible in multiagent organization. Given the two types of delegation, it remains to explain how the action of delegation is performed. We observe four distinct mechanisms for delegation (see Figure 1):

(i) *Economic exchange* is a standard mode in markets: the delegate is being paid for doing the delegated task or representation. In economic exchange, a good or task is exchanged for money, while the involved parties assume that the value of both is of appropriate similarity (market price).

(ii) *Authority* as a well known mechanism represents the method of organization used in distributed problem solving. It implies a non-cyclic set of power relationships between agents, along which delegation is performed by order.

(iii) *Gift exchange*, as a sociological term, denotes the mutually deliberate deviation from the economic exchange in a market situation. The motivation for the gift exchange is the

expectation of either reciprocation or refusal of reciprocation. Both are indications to the involved parties about the state of their relationship in the organizational field regarded, precisely the distribution of power and resources. This kind of exchange entails risk, trust, and the possibility of conflicts (continually no reciprocation) and the need for an explicit management of relationships in the agent. The aim of this mechanism is to accumulate strength in a relationship that may pay-off in the future.

(iv) Another well-known mechanism is *voting*, whereby a group of equals determines one of them to be the delegate by some voting mechanism (majority, two thirds, etc.). As a distinguishing property we observe that this is the only mechanism that performs a "many to one" delegation, while all other mechanism are used between a delegating agent and a delegate. Description of the mandate (permissions and obligations) and the particular circumstances of the voting mechanism (registering of candidates, quorum) are integral parts of the operational description of this mechanism and must be accessible to all participants.

As is suggested by Figure 1, these four mechanisms work for both types of operation: for example, economic exchange can be used for social delegation as well as for task delegation. Possibly this set of mechanisms is not complete, however, many mechanisms occurring in human organizations that seem not be covered here, are combinations of the described mechanisms.

4.2 The Spectrum of Organization

Modeling organizational fields requires identifying organizational schemes first (i.e. specifying for different organizational forms the mechanisms generally used for task delegation and social delegation as well as membership limitations, strategies, profit distribution and the number of possible representatives). In the following we describe three[1] organizational forms we derived from empirical case studies about the emergence of organizations composed of formerly autonomous companies in the field of transportation and logistics. The case studies were based on our sociological concept and the matrix of delegation. Note that in our current model single agents represent companies, not individuals.

(1) Virtual Enterprise The virtual enterprise is a loosely coupled set of companies organizing themselves (possibly short-termed) to merge their core competences in order to produce a specific product not in the portfolio of any single agent. The single companies stay widely autonomous, as they are not economically or legally integrated and there is no integrative management. The model of this organizational form introduces longer termed *social delegation* that is specific to a single type of composed task. However, agents are still loosely coupled, every agent in the virtual enterprise holon can accept tasks from outside the holon and act for this task as the head agent. If it cannot carry out the task by itself, it will then query other agents of the holon first for assistance. The mechanisms used here are *economic exchange* and *gift exchange*. The role of gift exchange here is to strengthen relationships to pave the way for a trusty atmosphere and maybe a tighter organizational integration (e.g. shared economic resources).

(2) Cooperation Cooperation as an organizational form is different to the virtual enterprise in that it is manifested by a contract among the participants. This contract creates a formal structure regulating the conditions of a long-term relationship under a collective control and management. The representation of the cooperation incurs valuable reputation. Contact to customer agents implies (economic) power and is advantaged by a large social network of relations. Quitting of one of the agents with many customer contacts may cause loss of social

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[1] We have modeled five organizational forms, but we present only three here. For more details see [14].

capital to the organization, as customers may prefer to interact with the supplier agent they already are acquainted with, no matter to which organization it belongs. To decrease the incentive to join the cooperation and for the stability of the organization, a focal participant who is not reliant on this increase in reputation due to his already powerful position, is elected by *social delegation* through *voting* to represent the cooperation. The profit is distributed among the head and all body agents necessary for performing the task by using *economic exchange* and *gift exchange*. However on creation of the cooperation agents agree on a ratio (which is in our case fixed by the designer) that describes how the profit is split between the head agent and the body agents that are involved in performing the task.

(3) Group A group of companies is different from a strategic network in that it requires that every compnay is only member of this organization and not involved with any other. Compared with the other organizational forms some fundamental differences are worth mentioning: One refers to the possibility of leaving the cooperation. In a group of companies a single company can not decide to exit autonomously, because it is dependent on the holding company and bound by contract. A group of organizations is equipped with an uniform management and powerful control mechanisms. The relationship enacted by task delegation through *authority* is similar to that of the strategic network, but the consequence of the single membership restriction is that the head is informed about all tasks of each body agent. Economic exchange is regulated by the constituting contract, gift exchange is not required as the relationship is also defined in the contract. The downside for the head agent is that it is required to guarantee financial support, no matter how many orders can be acquired. The head agent pays each body agent variable costs plus a fixed income per time unit.

We cannot specify the whole spectrum of conditions, which are decisive to the building of the presented organizational forms. In our modeling approach each individual agents will choose, depending on the situation in the MAS, whether it is in their interest to proceed with joining an organization. As each organizational form has advantages and disadvantages, it may well be, that a transition is not beneficial in the light of the current market situation. It is also worth noting that each form of the organization introduces new restrictions.

5 Conclusions

In this paper we presented a general and interdisciplinary definition of self-organization. In order to achieve self-organization of MAS-organizations we described FORM. This framework was inspired by theoretical sociological research on organizations using the habitus-field-theory of Pierre Bourdieu and by empirical sociological research on organizational forms within the domain of transportation and logistics. In contrast to previous work on using organization as a metaphor to increase MAS performance, we extended *FORM* beyond the modeling of communication or authority topologies by using two more mechanisms for delegation (the gift exchange built on trust, and the voting mechanism for coordination among equals) and more attributes of organization (most notably membership limitations and mechanism for social delegation). As result, *FORM* overcomes the duality whether to model self-organization of interaction systems or to model static MAS-organizations. In contrast to the increased complexity of the organizational model, it is not static and allows membership in multiple organizations (unless explicitly forbidden) for an organizational structure that dynamically adapts to the current task profile in the environment. Therefore, *FORM* allows to model self-organization of MAS-organizations.

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