Self-Organization and Adjustable Autonomy: Two Sides of the Same Medal?

Michael Schillo
German Research Center for Artificial Intelligence (DFKI)
Stuhlsatzenhausweg 3, 66123 Saarbrücken, Germany.
Email: schillo@virtosphere.de

Abstract

In this paper we explore the relationship between self-organization of multiagent systems and adjustable autonomy in intelligent agents. To discuss multiagent organizations, we introduce the *Framework for self-Organization and Robustness in Multiagent systems (FORM)*. This framework uses delegation as the central concept to define organizational relationships in task-assignment multiagent systems. For this purpose, it distinguishes two types of delegation: task delegation and social delegation. It further defines four different mechanisms to perform these types of delegation. Task delegation, social delegation, and their mechanisms are used as basic building blocks to define a spectrum of seven organizational forms for agent groups. The whole spectrum is defined by qualitatively different relationships that couple agents more or less closely together. Using *FORM*, we show how self-organization, i.e. the deliberate choice of an organizational form in this spectrum, relates to adjustable autonomy.

Introduction

In this paper we restrict ourselves to multiagent systems (MAS) that are designed for task-assignment (cf. task-oriented domains (Rosenschein & Zlotkin 1994)). Agents act in their environment in analogy to a market. The market consists of two groups of agents: providers and customers. Providers are agents that can perform tasks either through their capabilities or, alternatively, due to resources they have access to (database access, production resources for manufacturing domains, etc.). Tasks are of a certain type, include a deadline (latest delivery time), and may be composed of subtasks. Customers have tasks that should be performed, possibly they represent human users as avatars. 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 agents on relationships between agents and the effects on their autonomy. As a result we will not cover issues of adjustable autonomy (cf. (Hexmoor 2000)) in human-computer interaction (as e.g. (Scerri, Pynadath, & Tambe 2001)).

In the next section we will describe some of the organizational theory we are using for our work. Section 3 describes our *Framework for self-Organization and Robustness in Multiagent systems (FORM)* and Section 4 discusses the relationship of self-organization and adjustable autonomy in the light of this framework. Conclusions from this discussion appear in Section 5.

Organizational Theory for Multiagent Systems

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 combining the activities of several agents. To model these combined activities the concept *holonic agent* or *holon* was introduced (Gerber, Siekmann, & Vierke 1999) and has since then found increasing application (e.g. in holonic manufacturing systems (Rabelo, Camarinha-Matos, & Afsarmanesh 1998; Ulieru, Walker, & Brennan 2001)).

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 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 (Schillo, Zinnikus, & Fischer 2001). However, what exactly the ”nuances” or stages on this spectrum can be, remains to be defined. This paper attempts to close this gap.

There is an enormous body of literature on self-organization in many different interpretations of the term. We prefer the interpretation that is also used e.g. by Turner & Jennings (2001), Axtell (2001), So & Durfee (1996) and Ishida, Gasser, & Yokoo (1992), using the term organization to define self-organization. In this sense, self-organization means the process of generating social structure, which is the result of individual choices by a set of agents to engage in interaction in certain organizational patterns. Turner & Jennings (2001) 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. The work of So & Durfee is similar but restricts analysis of tree-like structures to the performance in homogeneous MAS (1996). 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. Other work describes self-organization in terms of agents creating, joining or leaving firms depending on respective utility (Axtell 2001), or several agents that merge into a single agent according to the tasks to be performed (Ishida, Gasser, & Yokoo 1992).

Although organization is a difficult and sometimes ambiguous term, it has been the object of many scientific research, e.g. in sociology, economics and political science. In human societies organizations are created, as an organization can be more powerful than an unorganized set of individuals. An organization can be more persistent, as it regulates membership, aims of the group and procedures. This is achieved for example by the separation of end from motivation for paid members of the organization (e.g. a company), where money acts as motivation. Therefore, these members adapt, for a defined period of their time, the aims of the organization. Also, organizations institutionalize anticipated coordination. This anticipation leads to efficient performance of the organization, but is costly and involves a loss in flexibility, which is profitable to the organization only if it can exploit this anticipation in the given environment. Hence, organization has advantages and disadvantages, depending on its institutions and the environment, which is expressed by Scott in the following three theses (1992):

- There is no on best way to organize. There are no general principles applicable to organizations in *all times and places* (our emphasis).
- Any way of organizing is not equally effective. Organizational structure is not irrelevant to organization performance.
- The best way to organize depends on the nature of the environment to which the organization relates. Organization design decisions depend - are contingent - on environmental conditions.

Modeling organizations requires identifying their basic characteristics and transforming them into algorithmic form. The political science literature offers an analytical tool that can act as an interface between the real world of organizations and the world of concrete computer models: the ADICO grammar. ADICO was proposed in 1995 by Crawford and Ostrom to facilitate the analysis of institutions in behavior research and game theory (Crawford & Ostrom 1995). The authors view institutions as "enduring regularities of human action in situations structured by rules, norms, and shared strategies, as well as by the physical world". According to their view, the basic principles characterizing and distinguishing institutions can be expressed in linguistic statements. An important assumption underlying this view is that not only explicit and formal regulations, but also implicit and tacit agreements can be expressed in this form. The ADICO grammar suggests decomposing linguistic statements into the five components *attributes, deontic, aim, conditions,* and *or else*:

(A) Attributes: is a holder for any value of a participant-level variable that distinguishes to whom the institutional statement applies (e.g., 18 years of age, female, college-educated, 1-year experience, or a specific position, such as employee or supervisor).
(D) Deontic: is a holder for the three modal verbs using deontic logic: *permitted*, *obliged*, and *forbidden*.
(I) Aim: is a holder that describes particular actions or outcomes to which the deontic is assigned.
(C) Conditions: is a holder for those variables which define when, where, how, and to what extent an AIM is permitted, obligatory, or forbidden.
(O) Or else: is a holder for those variables which define the sanctions to be imposed for not following a rule.

To illustrate this, Crawford and Ostrom give an example for the transformation of a linguistic rule underlying the cooperative behavior of a group of people to the ADICO grammar:

> *All villagers must not let their animals trample the irrigation channels, or else the villager who owns the livestock will be levied a fine.*

Analysis of this informal description using the ADICO grammar, translates this rule into the following:

(A) Attributes: all villagers
(D) Deontic: forbidden
(I) Aim: animals trample the irrigation channels
(C) Conditions: nil
(O) Or else: the villager who owns the livestock will be levied a fine

We will use this notation in the following description of our framework.

FORM - A Framework for Self-Organization and Robustness in Multiagent Systems

We now present the *Framework for self-Organization and Robustness in Multiagent systems (FORM)*, which is motivated by research in sociology on social order and makes use of the ADICO model briefly described in the previous section. The space restrictions do not allow us to go into details on the topic of robustness, hence let us mention briefly here that we argue that there is a close connection between

robustness and self-organization in certain scenarios. Some details on our concept of robustness can be found in (Schillo *et al.* 2001). In the following we will neglect the topic of robustness and concentrate on the aspect of organization in multiagent systems.

The Matrix of Delegation - A Grammar for MAS Organization

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 decide on a case by case basis whether they delegate a task and to whom.

Recent work on delegation (see (Castelfranchi & Falcone 1998; Falcone & Castelfranchi 2001) for an extensive treatment), has shown that delegation is a complex concept highly relevant in multiagent systems, 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 (functional differentiation and role performance). However, representing groups or teams is also an essential mechanism in complex social interaction, which can again be the result of *social* delegation. In holonic terms, this is the role 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. For example 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. Social delegation is more concerned with the delegate performing a certain role, than with specifying a product. Thus, we belief 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, as they rely on becoming independent from particular individuals through task and social delegation[1].

[1]We are aware of the fact that many aspects that are necessary to describe human organization are left out here. This includes e.g. the concepts necessary for the evolution of organizational networks described by Carley (1999). However, in contrast to Carley we describe the organization of artificial agents, which is not (necessarily) embedded deeply in human networks and requires terms that need to be defined precisely rather than an adequate model of human organizations.

	Task Deleg.	Social Deleg.
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) 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. 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.
(iii) Authority is a well known mechanism, it 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.
(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.

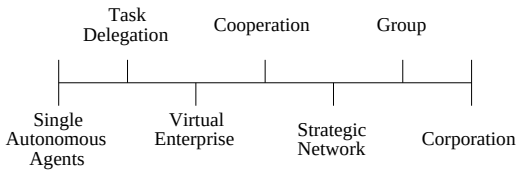

Figure 2: The seven organizational forms arranged on the spectrum according to the intensity of coupling between participating agents.

The Spectrum of Organization

We will now describe seven different organizational forms, in the order of increasing coupling between agents. In our work we used the ADICO model for modeling each of the forms by specifying rules stating what the organization's member agents are allowed to do, what they are obliged to do, and what they must not do. The delegation matrix provides the concepts for describing the interaction between agents in the different organizational forms.

Single, Autonomous Agents This organizational form is not of practical relevance but rather the theoretical starting point, with fully uncoupled agents. All agents that provide services do not interact with each other to accomplish their tasks, the only interaction taking place is between providers and customers.

- Supplier agents must not delegate to other suppliers.

  Attributes: all supplier agents.
  Deontic: forbidden.
  Aim: delegate to other suppliers.

Example (see Figure 3): A set of supplier agents is not performing delegation of any type.

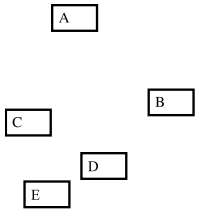

Figure 3: Example with five supplier agents (boxes) with no delegation performed among them.

Task Delegation - Pure Market Here, agents engage in *task delegation* based on *economic exchange*. This means they exchange tasks and some kind of utility (in human society: money). This does not imply that agents build up relationships. Interaction is short-termed, based solely on the economic reasoning of the current interaction and aimed at increasing profit or keeping costs low, respectively. Coupling between agents is defined solely by economic exchange.

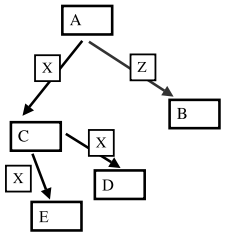

Figure 4: Example of five agents delegating tasks (small boxes on arrows).

- Supplier agents may do task delegation by economic exchange to other supplier agents.

  Attributes: all supplier agents.
  Deontic: permitted.
  Aim: delegate to other suppliers.
  Conditions: economic exchange is the only mechanism used.

Example (see Figure 4): supplier agents are redelegating tasks in a pure market by economic exchange.

Virtual Enterprise The virtual enterprise is a loosely coupled set of participants organizing (possibly very short-termed) to increase the portfolio they are able to offer to customers. It is possibly the stage of initiating tighter coupling between the participants (Kemmner & Gillessen 2000). This organizational form introduces *social delegation*. 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 solve the task by itself, it will then query body agents first for assistance. The mechanisms used here are *economic exchange,* and *gift exchange*. The role of gift exchange here is to be able to strengthen relationships to pave the way for tighter organizational forms.

- All agents in the virtual enterprise may accept tasks from customers.

  Attributes: all agents in the virtual enterprise.
  Deontic: permitted.
  Aim: accept tasks from suppliers.

- All agents may delegate tasks to other suppliers by economic or gift exchange. They then take over the role of the holon head for these tasks.

  Attributes: all agents.
  Deontic: permitted.
  Aim: delegate tasks to other suppliers by economic or gift exchange.
  Conditions: they then take over the role of the holon head for these tasks.

  This implies that the agent that is assigned the role of holon head interacts with its body agents in the same manner as the customer with the supplier agents in the pure market stage. However, agents inside the virtual enterprise are preferred and possibly offered a gift exchange to stabilize the relationship.

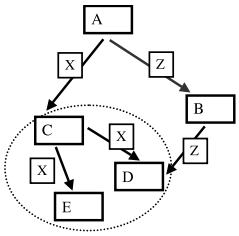

Figure 5: As an example agents C, D, and E form a *virtual enterprise* (dotted circle denotes border of the organizational form.

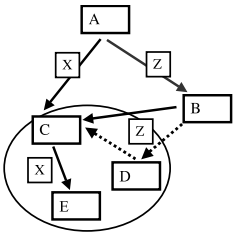

Figure 6: Example of a *cooperation* showing the forwarding of a task from received B by D to D's head C (denoted by dashed arrows).

Example (see Figure 5): Agents C, D, and E form the holonic structure of a virtual enterprise where C and D both act as heads, as they are both accepting tasks from supplier agents outside the holon. C is also redelegating parts of its task to agents D and E inside the holon.

Cooperation Cooperation as an organizational form is different to the virtual enterprise in that it is manifested by a contract among the participants (Freichel 1992). The representation of the cooperation incurs valuable reputation. Contact to customer agents implies (economic) power. Quitting of one of the agents with many customer contacts may cause loss to the organization, as customers may prefer to interact with the supplier agent they already are acquainted with, no matter in which organization it is in. To decrease the incentive to join the cooperation solely for this purpose and for the stability of the organization, a focal participant, who is, due to his already powerful position, not reliant on this increase in reputation, is elected by *social delegation* through *voting* to represent the cooperation. In the case where this focal participant cannot be determined, rotation according to *voting* to ensure equal chances among the participating agents to ensure equal possibilities to gather reputation. The profit is distributed among the head and all body agents necessary for performing the task by using *economic exchange* and *gift exchange*.

- If a focal agent can be elected, it becomes the head of the cooperation.

  Attributes: the focal agent.
  Deontic: obliged.
  Aim: accept the social delegation by voting.
  Conditions: if a focal agent can be determined by voting.

  This may be prevented, e.g. by each agent voting for itself, or by several agents which are equally powerful, receiving the same number of votes.

- In case no agreement on a single focal participant is possible, a rotation scheme for the assignment of the head role is determined by voting.

  Attributes: all participants.
  Deontic: obliged.
  Aim: participate in the rotation scheme and accept the social delegation through voting.
  Conditions: if no focal agent can be determined by voting.

- After a head agent is identified, body agents must forward messages about incoming tasks to their head(s).

  Attributes: all body agents.
  Deontic: obliged.
  Aim: forward messages about incoming tasks to their head(s).

Example (see Figure 6): Agents C, D, and E form a cooperation. D is no longer allowed to act as a head. D has to forward any incoming tasks to its head C, essentially task delegation will be established only between the single head and the customer. In this case C even keeps the task, but it might also have redelegated it, depending on its own available resources

Strategic Network The strategic network allows for providing reliably an enlarged portfolio. It is more reliable than the previous types of organizations, as by contract the focal participant has to a limited extend power over the actions of other participants (Jarillo 1988). *Authority* is introduced as mechanism for task delegation and agreed upon by contract. The downside for the focal agent is that it is required to guarantee financial support, no matter how many orders can be acquired. In this organizational form anticipated coordination is demonstrated by the body agent's obligation to keep the head agent up-to-date about its available resources, as opposed to the previous types of organization where the head agent needed to request information.

- Body agents must keep heads up-to-date about their available resources.

  Attributes: all body agents.
  Deontic: obliged.
  Aim: keep all heads up-to-date about their resources.

- Body agents must take orders from their heads, if they can allocate enough resources for the task.

  Attributes: all body agents.
  Deontic: obliged.
  Aim: accept delegation of tasks by authority from their head agent.
  Conditions: can allocate enough resources for the task.

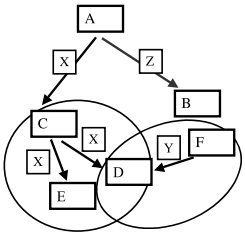

Figure 7: This example shows two *strategic networks* CDE and BDF, demonstrating that agents are permitted to participate in several strategic networks. The arrows inside the strategic network denote authority relationships.

- Head agents must pay body agents financial support.

  Attributes: the head agent.
  Deontic: obliged.
  Aim: pay body agents financial support.

Example (see Figure 7): Agents can participate in several strategic networks, each depicted by a circle around agents. In this case agent D is involved in two networks and receives payment (and tasks) from two heads. In contrast to the previous stages, it does not have the choice to negotiate about tasks as they are delegated by authority.

Group A group (of companies) is different from a strategic network in that it requires that every part is only member of this organization and not involved with any other (Freichel 1992). The relationship enacted by task delegation through *authority* is similar, but the consequence of the single membership restriction ist that the head is informed about all tasks of each body agent. Therefore, messages to keep the head informed are not necessary. Economic exchange is regulated by the constituting contract, gift exchange is not required as the relationship is also defined in the contract.

- Body agents must perform tasks when ordered by their head to do so.

  Attributes: all body agents.
  Deontic: obliged.
  Aim: perform task ordered by their head agent.

- Agents must not be body agent of more than one head agent.

  Attributes: all agents.
  Deontic: Forbidden.
  Aim: be body agent of more than one head agent.

Example (see Figure 8): Body agents are assigned tasks by authority but must decide for one group membership. Agent D, which was part of two strategic networks now can only be part of one group.

Corporation Merging of the agents with the loss of separation between the agents finally is the end of the spectrum: all agents provide their knowledge and resources for the creation of a single new agent. The merging of agents has been treated in technical terms for production systems for example by Ishida, Gasser, & Yokoo (1992).

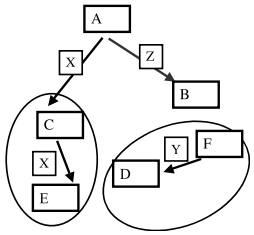

Figure 8: Example of agents C and E, D and F forming two *groups*. Sets of group agents must be exclusive.

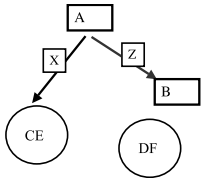

Figure 9: Example for *corporation*: body agents C and D, E and F have merged into two new agents.

- There are no institutions, as individual agents are not present any more.

Example (see Figure 9): Body agents C and D, E and F have merged into two new agents.

Before we go into the discussion on the relationship to adjustable autonomy, e would like to add some more comments to this overview. Although this discussion gives the impression that the spectrum is the process of several agents merging, through different stages, into one agent, it is a process that depends on the current situation of all participating agents. Each individual agents will choose, depending on the situation in the MAS, whether it is in their interest to proceed with the process. 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 stage of the organization here builds on earlier stages, and introduces new restrictions. Therefore, we can speak of a total ordering of the organizational forms and hence, a *spectrum* of organizational forms.

Self-Organization and Autonomy

Here, we cannot go into the reasons for an agent to choose one organizational form for itself rather than another. For our context here it is important to note that a) each organizational form has its advantages and disadvantages and that b) our agents are self-interested and choose what is beneficial to them according to expected profits (depending on the environment) and the specification of the organization.

By modeling organization and the involved relationships in a computationally accessible way, our agents are enabled

to engage in these different kinds of organizations by choice and to reason about which organizational form with which set of agents is most profitable to them. In this context most important: all types of organization also involve qualitatively different dependencies.

Autonomy of agents is a phenomenon with qualitatively different aspects (Castelfranchi 2000): an agent can be autonomous (independent) or dependent on others concerning information, the interpretation of information, planning, its motivations and goals, resources, and authority ("being allowed to do X", deontic autonomy) and these dependencies directly relate to losses of autonomy (e.g. loss of goal autonomy, resource autonomy etc.). We agree with Falcone & Castelfranchi that "studying how to adjust the level of autonomy and how to arrive to a dynamic level of control, it is necessary [to have] an explicit theory of delegation (and trust), which specifies different dimensions and levels of delegation, and relates the latter to the notion and the levels of autonomy" (2001). When stepping through the spectrum of organizational forms as described in Section 3.2., not only did the agents intensify their level of organization, increase the delegational ties to other participants in the organization, but they also lost autonomy step by step.

From single autonomous agents to pure market: Although this increases the number of options to the agents, it actually increases the dependency. Delegating a task involves trust in that the delegate will actually perform this task, which may be based on trust on the institution of task delegation by economic exchange (which in human societies involves a contract which is enforced by jurisdiction). The delegating agent depends on the delegate to perform the task, it is now beyond his power to control execution of the task. We interpret this dependency as a loss in autonomy (cf. (Castelfranchi 2000)).

From pure market to virtual enterprise: This transition introduces two novelties. Firstly, the agents now engage in social delegation and introduce holonic structures. This involves in designating a head agent which is in charge of coordinating the holon's behavior and communication for a (possibly single) given task. Secondly, the mechanism of gift giving is introduced in this stage, increasing the importance trust in other agents.

From virtual enterprise to cooperation: Being a representative for the organization is no longer allowed. The constitutional contract for cooperation requires that at any time, only one agent is head of the organization. With this contract agents give up the autonomy to represent themselves, which they still had in the virtual enterprise. In terms of autonomy this is a drastic pruning of the abilities an agent has and increases its dependency on others.

From cooperation to strategic network: Here the crucial addition to the organizational structure is the mechanism of authority. In return to a guaranteed regular payment, body agents agree to accept orders by authority of the head agents. In addition to the reduction of autonomy by previous transitions, this reduces the planning autonomy of the agent.

From strategic network to group: While in both types of organization, body agents are obliged to accept the orders of their head agents, the group body agents are no longer permitted to have several head agents. So while the strategic network body agent can choose any number of head agents to maximize the profit of assigned tasks, the group body agent trades the higher stability of the group for the autonomy of choosing other organizational contexts.

From group to corporation: This finalizes the process of losing autonomy. Agents give up task execution, knowledge and stop existing as individual entities, autonomy is turned over to the newly created agent.

Hence, agents can adjust their autonomy by choosing different organizational forms. In this sense, the adjusting of autonomy and the self-organizaion of the population of agents is the same process. It is interesting to note here that although the recursive structuring of holonic MAS allows in principle the delegates of whole organizations to be participants in other organizations, it is precisely the issue of autonomy that imposes restrictions on self-organization in the sense of *FORM*. Subholons are forbidden to be organized by an organizational form further left on the spectrum described by *FORM* than the organizational form of the superholon. Otherwise body agents with autonomy of a higher degree would be introduced to an organizational form that requires more restrictions on the subagents' autonomy. If however, the subholon is of the same organizational form or further to the right on the spectrum, it does not affect the institutions described here whether a body agent is representing a whole organization or just itself.

We believe that our work on self-organization corresponds well to the work of Falcone & Castelfranchi (2001), as we believe we can describe *FORM* also in their terminology. In addition to their work, we introduced different mechanisms, i.e. different types of delegation with long-term consequences. This becomes apparent e.g. if we look at the reasons they state for an agent to reduce its autonomy: the agent *will consider the received delegation (for example providing sub-help and doing less than delegated) and its level of autonomy in order to reduce it by either asking for the specification of the plan (task) or for the introduction of additional control ("example: "give me instructions, orders; monitor, help, or substitute me")*. This reduction of autonomy is concerned with increasing the involvement of the *delegating* agent in performing the task. However, in the work presented here, we have shown that in choosing an organizational form this reduction of autonomy is manifested (and hence can be used by other agents to reason about agents' behavior) and is valid beyond the actions involved in performing a single task: engaging in group causes loss of planning autonomy, and a merger results in loss of information autonomy by the individual agent. Also, the different mechanisms have different implications to autonomy: economic exchange is almost neutral, it only involes the loss auf autonomy incurred by delegation itself, whereas gift exchange accepts a short-term decrease in utility, with the trust in future reciprocity, which depends solely on the good will of the interaction partner. Authority obviously reduces autonomy tremendously, while voting is a very foreseeable and limited invokation of reduction of autonomy.

Conclusions

We laid out the *Framework for self-Organization and Robustness in Multiagent systems (FORM)* based on differentiation of types and modes of delegation, which acts as a grammar for describing organization. By using Crawford and Ostrom's ADICO model we were able to more specifically describe a spectrum of types of organizations agents can engage in. Just as Castelfranchi argued that autonomy relates directly to dependence theory, we showed that for task-assignment, market style MAS adjustable autonomy relates directly to deliberate configuration of types of organization, and hence self-organization. By assuming advantages and disadvantages for every organizational form and using self-interested agents we further gave the motivation for agents to use adjustable autonomy. We believe that we also gave an in-depth description on how adjustable autonomy can be implemented in MAS.

In our ongoing work we implement the *Testbed for Organisation in Multiagent systems (TOM)* which instantiates *FORM* in a concrete FIPA-compliant multiagent simulation environment to conduct experiments for exploring the benefits of this framework in terms of performance and robustness of MAS. Part of this work is to pin down the exact criteria for agents to prefer a organizational form over any other in a given environment.

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