Optimisation of Multiagent Organsiation for Robustness*

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Abstract. Recent research in distributed artificial intelligence (DAI) has shown that different organizational forms to which agents may organize themselves have beneficial and varying effects on the performance of multiagent systems (MAS) regarding scalability, agent drop-out safety and flexibility. This paper presents a concept to enlarge a spectrum of five organizational forms that has been specified with the aid of sociological research to a search space of organizational forms beyond previous frameworks. The contribution of this work is to search this space for superior forms of organization with the help of genetic algorithms. The theory of sociologist Pierre Bourdieu is used to specify different criteria of robustness to evaluate the performance of the 'new' organizational forms under differing conditions..

1 Introduction

Building robust, highly scalable and well performing multiagent systems (MAS) is one of the major goals for researchers in DAI. Our paper aims at contributing to the improvement of the robustness of task-assignment MAS in market-based scenarios, i.e. MAS in which self-interested agents engage in interaction with other agents to distribute tasks according to costs, competence, maybe even task load. The concept presented in the remainder of this paper is based on previous research on modeling organizations in analogy to human societies in order to increase robustness (cf. [Schillo, M., Fischer, K., Fley, B., Florian, M., Hillebrandt, F., Spresny, D. (In Print). FORM - A Sociologically Founded Framework for Designing Self-Organization of Multiagent Systems. In Proceedings of the International Workshop on Regulated Agent-Based Social Systems. Theories and Applications. Lecture Notes in Computer Science, Berlin et al., Springer.]). We refer to a model that contrasts five organizational forms in contrast to pure market relations, derived by Schillo et al. [Schillo, M., Fischer, K., Fley, B., Florian, M., Hillebrandt, F., Spresny, D. (In Print). FORM - A Sociologically Founded Framework for Designing Self-Organization of

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Multiagent Systems. In Proceedings of the International Workshop on Regulated Agent-Based Social Systems. Theories and Applications. Lecture Notes in Computer Science, Berlin et al., Springer.] from empirical sociological case studies in the field of transportation and logistics and from sociological literature. Each organizational form is defined by eight attributes. Differences between these forms result from the mechanisms used for each attribute (cf. section 2.). In simulation experiments with the implemented model, Knabe [Knabe, T. (2002). Business Organizational Forms in Self-organizing Multiagent Systems. Diplomarbeit, Department of Computer Science, Universität des Saarlandes.] and Schillo et al. [Schillo, M., Spresny, D. (To be published). Organization: The Central Concept for Qualitative and Quantitative Scalability. In Fischer, K., and Florian, M. (eds.) Socionics: Contributions to the Scalability of Complex Social System , Lecture Notes in Artificial Intelligence, Berlin et al., Springer., Schillo, M., Knabe, T., Fischer, K. (to be published): Autonomy Comes at a Price: Performance and Robustness of Multiagent Organizations. In Hillebrandt, F. and Florian, M. (in preparation): Adaption und Lernen in und von Organisationen, Westdeutscher Verlag.] demonstrated that allowing agents to build these organizations using the concept of holonic agents [Fischer, K. (1999). Holonic multiagent systems — theory and applications. In Proceedings of the 9th Portuguese Conference on Progress in Artificial Intelligence (EPIA-99), LNAI Vol. 1695. Springer-Verlag, pp. 34–48] has beneficial effects on the performance and robustness of task-assignment MAS. However, we doubt that these forms are *optimal.* The observed organizational forms have proven to be useful strategies of enterprises in human societies to maintain competitive positions in markets. Nevertheless, not all imaginable organizational structures that can be formed by the recombination of the mechanisms for the eight attributes have been examined. This paper demonstrates an attempt to throw light on these facts by examining feasible organizational structures, i.e. searching the space of all possible combinations of the above mentioned mechanisms with genetic algorithms. Since research on the five already specified organizational forms showed that no 'single best organizational form' for all environments exists, suitable scenarios need to be developed to search the space of possible combinations. Moreover, this requires adequate robustness criteria of MAS first. In accordance with Gasser [Gasser, L. (1991). Social Concepts of Knowledge and Action: DAI Foundations of Open Systems Semantics.], who stresses that MAS are social in character and therefore calls upon DAI research to build on solid sociological foundations, the specification of relevant criteria is informed by sociological theory in this paper. In particular, the habitus-field theory (HFT) of Pierre Bourdieu is used, on which the model of the five organizational forms is already based.

2 Robustness and Organizational Forms in Multiagent Systems

Within the research on organizational forms to which our paper relates, robustness is considered as graceful degradation of a system's *performance* under *perturbation.* In order to operationalie this definition of robustness, Schillo et al. [Schillo, M., Bürckert, H.J., Fischer, K., Klusch, M. (2001): Towards a Definition of Robustness

for Market-Style Open Multi-Agent Systems. In Proceedings of the Fifth International Conference on Autonomous Agents (AA' 01),pp. 75-76.] specify performance measures for task-assignment MAS: the speed of match-making between agents (number of messages needed), efficient allocation of tasks (rate of unassigned jobs), and the quality of task-fulfillment (rate of failed, but assigned orders). Perturbation typically can be caused by an increase of population size, change of task profile over time or dropouts of agents. From a sociological point of view, these perturbations may diminish the performance of MAS less, if DAI-models account to a greater extent for social structures in which the interactions of self-interested agents are embedded. In this respect, organizations in analogy to human societies are an interesting concept. Organizations are social entities that carry out a form of joint task (e.g. production of goods or services) through differentiation and coordination of tasks between members. The contribution of this metaphor to the robustness of MAS is particularly due to the aspect that they are phenomena on the *meso-level of sociality*.

A fundamental characteristic that distinguishes organizations from *micro level phenomena* (face-to-face interaction, micro social fields, e.g. groups) is that they are associations of agents, which are formally structured. In terms of the HFT, organizations are a specific kind of a social "field" [Bourdieu, P., Wacquant, L. (1992). An Invitation to Reflexive Sociology. Polity Press, Chicago: 94], since interactions in organizations are not only structured by tacitly recognized regularities of practice, unspoken differences in the status positions between agents, and agents' dispositions towards perception, reasoning, and action. They are *additionally* structured by explicit rules, authority and task structures. Since organizations overcome the limitations of individual agency (cf. [Carley, K. M., Gasser, L. (1999). Computational Organization Theory. In Weiss, G. (ed.). Multiagent Systems. A Modern Approach to Distributed Artificial Intelligence. Cambridge MA., London U.K. (MIT Press). pp. 299-330.]), they are likely to be more robust concerning agent drop-outs or the rate of failed tasks.

In comparison to *macro-social phenomena* (macro-social fields, e.g., the economy,, legislation), organizations are associations of agents that show identifiable boundaries towards their environment, so that they can be considered as corporate agents. The resulting effect that an organization can act as a single actor representing a certain number of agents is considered advantageous concerning communication costs when the agent population scales [Schillo, M., Spresny, D. (To be published). Organization: The Central Concept for Qualitative and Quantitative Scalability. In Fischer, K., and Florian, M. (eds.) Socionics: Contributions to the Scalability of Complex Social System , Lecture Notes in Artificial Intelligence, Berlin et al., Springer.]. Not least due to membership limitations, organizations are social fields to which a limited number of agents are affiliated, but generally not the entire population. The restrictions, which the structures of an organization impose upon the member agents, only affect a certain number of agents. Therefore, organizations, even though they constrain agents, still do not oppose the decentralized approach to AI [Gasser, L. (1991). Social Concepts of Knowledge and Action: DAI Foundations of Open Systems Semantics.] by establishing centralized control.

However, not all organizations show the same structure, and differences in structure are not irrelevant to performance. Therefore, Schillo et al. [Schillo, M., Fischer, K., Fley, B., Florian, M., Hillebrandt, F., Spresny, D. (In Print). FORM - A Sociologically Founded Framework for Designing Self-Organization of Multiagent Systems. In Proceedings of the International Workshop on Regulated Agent-Based Social Systems. Theories and Applications. Lecture Notes in Computer Science, Berlin et al., Springer.] used empirical sociological case studies about interorganizational networks based on Bourdieu's HFT to specify four organizational forms (virtual enterprise, alliance, strategic network, and group) in contrast to mere market coordination. Each organizational form as well as market coordination is defined by the different modes and mechanisms which can be used for each of the eight attributes that constitute every governance structure (i.e. market coordination and organizational forms) (see Table 1 and [Schillo, M., Fischer, K., Fley, B., Florian, M., Hillebrandt, F., Spresny, D. (In Print). FORM - A Sociologically Founded Framework for Designing Self-Organization of Multiagent Systems. In Proceedings of the International Workshop on Regulated Agent-Based Social Systems. Theories and Applications. Lecture Notes in Computer Science, Berlin et al., Springer.]).

The transformation of this model of organizational forms into a running MAS requires corresponding methods in DAI. Therefore, we use the concept *holonic agent* as defined by Fischer [Fischer, K. (1999). Holonic multiagent systems — theory and applications. In Proceedings of the 9th Portuguese Conference on Progress in Artificial Intelligence (EPIA-99), LNAI Vol. 1695. Springer-Verlag, pp. 34–48]. A holonic superagent consists of parts called *body agents*, which in turn may be holonic agents themselves. The holonic agent may have capabilities that emerge from the resources of the body agents and it may perform orders 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 acts as a corporative actor since it is represented by a distinguished *head* (agent). To the inside the head organizes the activities of the body agents. Any agent that is part of a holon, contributes to achieve the goals of this superior holon. As proposed by Gerber et al. [Gerber, C., Siekmann, J., Vierke, G. (1999): Flexible autonomy in holonic multiagent systems. In:AAAI Spring Symposium on Agents with Adjustable Autonomy.], agents can give up autonomy to differing degrees during run-time on a spectrum of holonic associations from loose federations in which agents share a common goal for some time to holons in which body agents give up their autonomy completely and merge into a new agent. In this context, the modeled organizational forms represent an advancement of the holonic concept, since they describe 'nuances' or stages of this spectrum. In order to exploit the spectrum completely, the organizational form 'corporation' was added to the model. This form represents the stage in the spectrum of flexible holons when all body agents merge into a new agent.

In the model, only providers are able to form and resolve these organizations. However, with respect to the application scenario (electronic markets), two groups of agents exist: providers and customers. Customers have orders including a deadline that should be performed and may be composed of different types of tasks. Providers are agents that have resources (economic capital) to perform tasks, which are of a

certain type (requiring cultural capital). Another important resource within the HFT is *social capital,* which "is the sum of the resources […] that accrue to an individual or a group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition" [Bourdieu, P., Wacquant, L. (1992). An Invitation to Reflexive Sociology. Polity Press, Chicago: 119]. Providers are not equipped with this kind of capital when initialized. As any kind of capital is "accumulated labor" [Bourdieu, P. (1986). The (three) Forms of Capital, In Richardson, J. G. (ed.) (1986). Handbook of Theory and Research in the Sociology of Education, New York, London: Greenwood Press, pp. 241-258.], agents are capable to accumulate social capital during run-time as a side effect of economic exchange [Knabe, T. (2002). Business Organizational Forms in Self-organizing Multiagent Systems. Diplomarbeit, Department of Computer Science, Universität des Saarlandes.: 82] or by gift-exchange (cf. [Fley, B., Florian, M. (to appear). Trust and the Economy of Symbolic Goods: A Contribution to the Scalability of Open Multi-agent Systems. In Fischer, K., Florian, M. (eds.) (to appear). Socionics: Its Contributions to the Scalability of Complex Social Systems, LNAI. Springer Verlag.]). In the model, the accumulation of social capital is quite important, because firstly message limits for reasons of scalability do not allow agents to communicate with every other agent. Secondly, agents are supposed to be self-interested including the possibility of malicious behavior. Hence, *to be recognized* for prices and quality by providers and customers on the one hand and to *know reliable providers* on the other hand is vital for any agent in order to receive and delegate tasks in the future. Moreover, if costumers demand orders, which are composed of different types of tasks, providers need to cooperate. Hence, providers are able to accept an order and delegate the tasks they cannot complete themselves due to a lack of economic or cultural capital to other agents. They can do this by single-spot (market) transactions or they can decide to found an organization during run-time to supply specific products (composed of several tasks) for longer periods. Besides, they are able to change or resolve the organizational form.

	Market	Virtual Enterprise	Alliance	Strategic Network	Group	Corporation
TD	EcEx	Ec/ Gift Ex	Ec/ Gift Ex	Authority	Authority	-
SD	EcEx	Ec/ Gift Ex	Voting	Authority	Authority	-
HH	One/ All	All	One	One	One	One
HP	Single Task	Product	Product	Product	Any Task	Any Task
ML	No Limitation	Limitation on Product	Limitation on Product	Limitation on Product	Exclusive	Exclusive
PD	EcEx	Ec/ Gift Ex	Regulation	Regulation	Fixed Income	-
C	Task Accomplishment	Objection	Payment	Period of Cancellation	Period of Cancellation	No Resolution
R	Consensus	One member	One member	One member	Holon Head	-

Table 1. Overview of the different organizational forms in contrast to market coordination. Rows specify the different modes used for each of the eight attributes for each organizational form: TD stands for task delegation. SD (social delegation) indicates the mode of appointing a

holon head, HH indicates number of holon heads. HP stands for holon purpose, ML for membership limitations, and PD for the mode of profit distribution. C (Continuity) determines when and how organizations can be resolved, and R (Resolution) by whom.. Cf. [Schillo, M., Fischer, K., Fley, B., Florian, M., Hillebrandt, F., Spresny, D. (In Print). FORM - A Sociologically Founded Framework for Designing Self-Organization of Multiagent Systems. In Proceedings of the International Workshop on Regulated Agent-Based Social Systems. Theories and Applications. Lecture Notes in Computer Science, Berlin et al., Springer.] for more details.

2.1 Evaluation of Organizational Forms

These organizational forms were evaluated with respect to their contribution to the robustness and performance of MAS in contrast to a mere market scenario. The first experiments conducted by Knabe [Knabe, T. (2002). Business Organizational Forms in Self-organizing Multiagent Systems. Diplomarbeit, Department of Computer Science, Universität des Saarlandes.] focused on the *performance* of the model mainly in *absence of perturbation*. The work concentrates on two performance measures concerning the global behavior of the system (rate of unassigned tasks, number of messages). The simulation runs were configured differently: Firstly, each organizational form was tested separately, in other simulations the organizational forms competed with each other, in a third configuration self-organization was allowed, i.e. agents found, change, and resolve organizational forms during run-time, depending on the orders demanded by providers in previous rounds. The experiments show as major results that for all organizational forms both, the rate of unassigned tasks and the number of messages are significantly lower than for the markets. However, the differences among the single organizational forms are not very large compared to their difference to market coordination. Generally, the more hierarchical an organizational form is due to the use of the mechanism authority, the better results it realizes. Self-organization has primarily beneficial effects on the number of messages needed for task-assignment while the effects on the rate of unassigned orders are insignificant.

Other experiments conducted by Schillo and Spresny [Schillo, M., Spresny, D. (To be published). Organization: The Central Concept for Qualitative and Quantitative Scalability. In Fischer, K., and Florian, M. (eds.) Socionics: Contributions to the Scalability of Complex Social System , Lecture Notes in Artificial Intelligence, Berlin et al., Springer.] focus on the number of messages required under perturbation in simulations where self-organization is contrasted to mere market coordination. The performance is investigated in simulations in which (1) the *agent population increases* while other parameters are kept constant (task profile, ratio between customer orders and providers), and (2) in which both the *task profile is changed* (profile becomes more complex during run-time) and the population is scaled. The major result of those experiments is that the possibility to found organizational forms and to upgrade to more hierarchical forms during run-time leads to a significant smaller increase of messages when the agent population scales and the task profile becomes more complex, additionally.

In [Schillo, M., Knabe, T., Fischer, K. (to be published): Autonomy Comes at a Price: Performance and Robustness of Multiagent Organizations. In Hillebrandt, F. and Florian, M. (in preparation): Adaption und Lernen in und von Organisationen, Westdeutscher Verlag.], perturbation due to *agent drop-outs* is examined while other parameters are kept constant (agent population, task profile). Five percent of the agents drop out after several rounds in a scenario where self-organization is allowed partially. This experiment focuses on performance in terms of failed tasks and shows that organizations realize better results than markets because of their capability to recover tasks. Especially more hierarchical forms are successful in removing tasks from drop-out agents with exception of the most hierarchical organizational form – the corporation.

Further, yet unpublished experiments on robustness examined flexibility as a criteria of robustness when the *task profile varies*. In contrast to [Schillo, M., Spresny, D. (To be published). Organization: The Central Concept for Qualitative and Quantitative Scalability. In Fischer, K., and Florian, M. (eds.) Socionics: Contributions to the Scalability of Complex Social System , Lecture Notes in Artificial Intelligence, Berlin et al., Springer.], not only additional tasks are added that increase the complexity of orders, but the task structure of orders is changed. Flexibility refers to a new performance measure: the price of an order. Since organizational forms cause overhead, costs and therefore the proposed prices rise, if organizations are not well adapted to the task profile with their supply of products. In the experiment, self-organization is allowed. Major results of this experiment are (1) that organizations require lower costs to satisfy an order *without perturbation* in contrast to markets. (2) Under perturbation, the costs of all organizational forms exceed market level initially, but drop under market level after a few rounds. (3) The less hierarchical an organizational form is the faster it adapts to a changing task profile and prices drop.

To summarize, the experiments show that the organizational forms have several advantages in comparison to classical decentralized market coordination in terms of performance and robustness from the perspective of the global system. However, it depends on the situation in the system and the kind of perturbation which organizational form performs best. No ‘best organizational form’ for all scenarios exists.

2.2 Strategic Adaptation in Economic Fields

The observed organizational forms have been derived from empirical sociological case studies. However, these forms are abstractions from the reality in human societies, which is far more complex. Those reductions of complexity have been necessary in order to identify the typical characteristics that have proved to contribute to the maintenance and improvement of competitive positions in markets in human societies among an undetermined variety of organizational forms. We have seen, that the previous described organizational forms are defined by eight attitudes. The unique behavior of each organizational form evolves from the different mechanisms the organizations use to fulfill their specific attributes. For generalization, we can say that an organizational form is defined by eight attributes, specifying the behavior and the

structure of the organization, where each attribute is again defined by a set of possible mechanisms (Table 2). The presented basic organizational forms illustrates instances of the set of educable organizational forms. However, with respect to MAS, it is unclear whether these basic organizational forms are optimal in terms of robustness and performance, because not all imaginable organizational structures that can be formed by the recombination of the values (Table 2) for the eight attributes have been examined yet. The combination of all mechanisms of each attribute generates more than 19000 possible distinct organization forms, which should all be evaluated, in order to find optimal organizations in terms of robustness and performance.

From a sociological perspective, the use of genetic algorithms as a heuristic at design-time is a fruitful contribution to overcome this inherent limitations of empirical social research, although evolutionary algorithms do not represent a sociological appropriate description of the process, how organizations adapt their structure to turbulent environments during run-time. Nevertheless, from the perspective of the HFT, it is reasonable to add criteria of robustness to the already defined ones when searching the space of possible combinations of the mechanisms for the eight attributes. This means to pay attention to supplementary performance measures, to enlarge the spectrum of perturbation categories and to develop corresponding experiential environments (scenarios).

TD	EcEx	Ec/ Gift Ex	Authority		
SD	EcEx	Ec/ Gift Ex	Voting	Authority	
HH	One/ All	All	One		
HP	Single Task	Product	Any Task		
ML	No Limitation	Limitation on Product	Exclusive		
PD	EcEx	Ec/ Gift Ex	Regulation	Fixed Income	
C	Task Accomplishment	Objection	Payment	Period of Cancellation	No Resolution
R	Consensus	One member	Holon Head		

Table 2. The eight attributes of each organization and the set of possible mechanisms to fulfill the specific attribute.

Performance measures: In the HFT, agents are considered to try to improve their status and power positions in a social field (e.g., a market) in a self-interested way by accumulating different sorts of capital (economic, cultural, and social capital). This has an impact on robustness criteria regarding two aspects: (1) Knabe already pointed out that "self-interested agents who give up more of their autonomy do so only if the payoff is likely to be higher" [Knabe, T. (2002). Business Organizational Forms in Self-organizing Multiagent Systems. Diplomarbeit, Department of Computer Science, Universität des Saarlandes.: 76]. Since robustness of MAS is only achieved, if agents abandon parts of their autonomy, the global performance of the system depends on local performance in terms of *the interests of selfish agents*. (2) However, it is not enough only to pay attention to the economic interests of agents. According to the part

of the HFT on the different sorts of capital, 'payoff' not necessarily has to be a kind of economic capital, but can be a sort of social or cultural capital [Bourdieu, P. (1986). The (three) Forms of Capital, In Richardson, J. G. (ed.) (1986). Handbook of Theory and Research in the Sociology of Education, New York, London: Greenwood Press, pp. 241-258.].

With respect to MAS, the work of Knabe [Knabe, T. (2002). Business Organizational Forms in Self-organizing Multiagent Systems. Diplomarbeit, Department of Computer Science, Universität des Saarlandes.] supports this argument. He already investigated the performance of organizational forms from the perspective of the self-interest of agents, i.e. the income of the different organizational forms and the profit realized per provider agent. He assumes that more hierarchical organizations may acquire more orders due to a lower rate of unassigned orders and hence, realize a higher income and are more attractive for agents. One surprising result of his simulations is that more hierarchical forms do not realize higher income than more cooperative and flexible forms. From a sociological perspective this is not surprising, since agents in the model build up preferences about favorite partners for task delegation. These preferences represent a kind of social capital. In the implemented model of Knabe, income depends on the number of orders an agent receives, since prices are fixed at different levels. Hence, enough social capital may compensate for the advantages of a lower rate of failed tasks. Another important result is that in scenarios where single agents are present, members of organizations with no exclusive membership (see Table 1) often act as single agents and hence lower the income of their organization. This allows the presumption that the pursuit of self-interest may lower the effects of self-organization and organizational forms on the global performance of the system, since it is little attractive to give up autonomy and join an organization with a low income. Therefore, the accumulation of the different sorts of capital should be considered as a prerequisite and a performance measure with respect to robustness.

Forms of perturbation: Bourdieu uses the term 'strategies" ([Bourdieu, P. (1990). In Other Words. Essays Towards a Reflexive Sociology, Stanford/ Cal., University Press, Cambridge/UK, Polity Press.], 59) with respect to the process of the agents' struggles for positions, i.e. the accumulation of capital. With respect to enterprises (corporate agents) in the economic field, the choice of an organizational form by several agents can be considered as a strategy to accumulate different sorts of capital to improve status positions (cf. [Dederichs, A. M., Florian, M. (2002). Felder, Organisationen und Akteure – eine organisationssoziologische Skizze. In Ebrecht, J., Hillebrandt, F. (eds.). Bourdieus Theorie der Praxis. Erklärungskraft – Anwendung – Perspektiven. Wiesbaden. Westdeutscher Verlag,]). These strategies not necessarily need to be oriented towards the accumulation of economic capital, even though the agents in our model act within the economic field where the accumulation of economic capital is highly recognized. For example, certain organizational forms may have the effect that they enable the agents to accumulate social capital in particular. This may pay out economically for longer periods. However, in the HFT strategies are not intentionally planned projects under perfect information about possibilities and environmental circumstances that allow the choice between an unlimited number of

alternatives with unbounded rationality. Strategies are objective courses of action, which can be analyzed statistically as 'the aggregate product of individual actions guided by the same constraints" ([Bourdieu, P. (1990). In Other Words. Essays Towards a Reflexive Sociology, Stanford/ Cal., University Press, Cambridge/UK, Polity Press.], 64). According to Bourdieu, these constraints are (1) the logic, the regularities, and rules of a field, (2) the agent's current position, defined by its resources, i.e., the volume and structure of accredited capital it possesses, (3) the structure of forces in a social field, i.e. other agents' possessions of the different sorts of capital, and (4) the agent's mental and bodily capabilities to take part in the 'game' of the field, i.e. its practical sense for the 'game'.

With respect to the search for optimal combinations of the mechanisms for the eight attributes regarding the interests of selfish agents, the HFT suggests firstly that it depends on the *agents' positions* (their possession of economic, cultural, or social capital) whether a strategy (organizational form) is successful. Secondly, the local performance of an organizational form depends on *the objective structure of the relations between the social positions occupied by the agents* that act in the economic field (the entire system). Therefore, variations of the structure of the agent population due to inhomogenous equipment of the different sorts of capital may serve as interesting perturbation scenarios to which agents need to adapt using different strategies.

3 The Genetic Algorithm Approach

A genetic algorithm describes a search heuristic, which restricts the search space by scanning a subspace of a given problem in each 'evolutionary' step. The algorithm maps a so-called chromosome to each individual where the attributes of the individual are encoded. In our implementation, characteristics prescribing behavior (the modes and mechanisms specified in Table 2) are mapped to each agent on a set of genes in the initialization phase, which together represent the chromosome. Inside the chromosome, the first gene describes the mechanism used for task delegation. We implemented three possible mechanisms (see Table 2, first row): economic exchange, economic exchange combined with gift exchange or authority. One of these three mechanisms is assigned to the first gene of each chromosome. The remaining seven genes are assigned the same way. The possible mechanisms for the specific gene can be seen in Table 2. Each chromosome stands for one possible organizational form which is defined by these eight genes. After a defined number of rounds in which the agents solve tasks, the best adapted chromosomes of the agent population with respect to certain performance measures are *selected* and *recombined.* Afterwards, the genetic information of the new created chromosomes are altered (selected genes are *mutated*). The new chromosome population is then assigned to the agent population in the next evolutionary step. This evolution process continues until a predefined aborting criterion is reached. The result in this search process is a set of chromosomes, i.e. organizational structures described by the mechanisms used, which perform and adapt best in a given environment in terms of performance. A genetic algorithm describes a powerful mechanism to handle huge search spaces. Theoretically, the search space of

our program consists of 19,440 different chromosomes, if each mechanism of a specific gene is combined with all other defined mechanisms of the remaining seven genes (see Table 2). All of the mentioned gene combinations could be implemented and we are interested in examining all possible combinations, although some of these combinations do not seem to be efficient.

3.1 Selection

As described, in the selection phase, some members (the fittest individuals with respect to some performance criteria) are selected to reproduce new individuals of the new generation or population, respectively.

3.2 Recombination (Crossover)

The recombination method describes the main method for producing offspring by combining parts of the two parent chromosomes. We have implemented two mechanisms for crossover in order to be more flexible, if one of the following mechanisms turns out to be insufficient.

3.2.1 Single Point Crossover

Single point crossover is the simplest form of crossover, in which an arbitrary point in the chromosome is picked. All the information from the parent A is copied from the start of the chromosome to the crossover point, then all information from the parent B is copied from the crossover point to the end of the chromosome (Figure 1). The second child is build analogously.

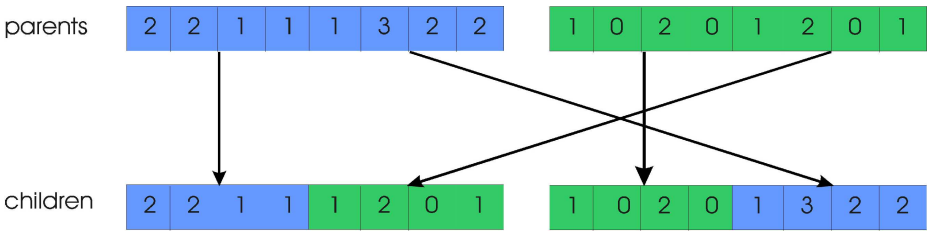

Figure 1. Single Point Crossover. The crossover point in this example is between the 4th and 5th gene. The numbers inside the gene represent the specific mechanism used, the "2" in the first gene of parent 1 describes that this organization uses ' authorityfor task delegation. The recombination process is expressed by the colors of the chromosome parts of each child.

3.2.2 Uniform Crossover

Normally, the crossover point is fixed to a low constant value, as seen in the method of the single point crossover. However, there are indications that situations exist, in which a higher number of crossover points are beneficial. In the uniform crossover, more than two crossover points are randomly chosen, on the average L/2 crossover

points for chromosomes with L genes. The process of building new children is similar to single point crossover with more than one crossover point.

3.3 Mutation

Mutation in nature describes the source of genetic variation, this means that the genetic information is chemically changed, which causes new genes to be created. The mutation process is asexual and very rare.

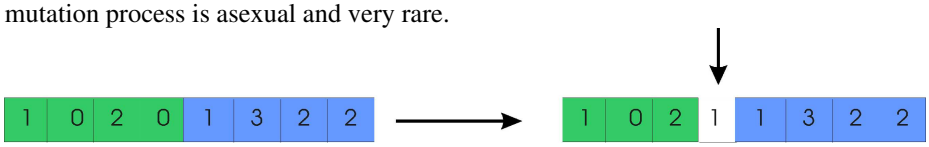

Figure 2. Mutation alters the gene information of selected children. In this example the gene value of the gene holon purpose is changed form ' single task' to ' product' .

The mutation operator in a genetic algorithm randomly alters the structure, the mechanism of genes of a new individual built out of crossover. The purpose of mutation is to introduce new features into a population. Mutation randomly selects a member of the child population. If a member is selected a random mutation point, the gene in a chromosome which will be changed, is randomly chosen and the gene value reassigned. For instance, the second child in Figure 1 is selected for mutation. Assume the mutation operator selects the gene responsible for the holon purpose as mutation point (see Figure 2). The mutation operator will now replace the mechanism ' single task' by another mechanism specifying the holon purpose, e.g. ' product' (see figure 2).

4 Conclusions and Future Work

In this paper, a concept that uses genetic algorithms as a search heuristic to advance the investigation of organizational forms in order to build robust MAS has been presented. This concept has been inspired by the habitus-field theory of sociologist Pierre Bourdieu. At present a testbed is implemented in order to conduct experiments with the genetic algorithm. Later on, we will specify different scenarios with respect to the theory of the sociologist Pierre Bourdieu. These scenarios will relate to robustness criteria as defined above. The results of these experiments can give information about how to build robust MAS that are capable to manage agent drop-outs, a changing task profile, inequalities in agents' resources and scaling of agent population. Moreover, the performance of previously established organizational forms in contrast to the new organizational forms found by the genetic algorithms approach will be evaluated.

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References

4. Bourdieu, P. (1990). In Other Words. Essays Towards a Reflexive Sociology, Stanford/ Cal., University Press, Cambridge/UK, Polity Press.
5. Bourdieu, P. (1986). The (three) Forms of Capital, In Richardson, J. G. (ed.) (1986). Handbook of Theory and Research in the Sociology of Education, New York, London: Greenwood Press, pp. 241-258.
6. Bourdieu, P., Wacquant, L. (1992). An Invitation to Reflexive Sociology. Polity Press, Chicago.
7. Carley, K. M., Gasser, L. (1999). Computational Organization Theory. In Weiss, G. (ed.). Multiagent Systems. A Modern Approach to Distributed Artificial Intelligence. Cambridge MA., London U.K. (MIT Press). pp. 299-330.
8. Dederichs, A. M., Florian, M. (2002). Felder, Organisationen und Akteure – eine organisationssoziologische Skizze. In Ebrecht, J., Hillebrandt, F. (eds.). Bourdieus Theorie der Praxis. Erklärungskraft – Anwendung – Perspektiven. Wiesbaden. Westdeutscher Verlag,
9. Fischer, K. (1999). Holonic multiagent systems — theory and applications. In Proceedings of the 9th Portuguese Conference on Progress in Artificial Intelligence (EPIA-99), LNAI Vol. 1695. Springer-Verlag, pp. 34–48
10. Fley, B., Florian, M. (to appear). Trust and the Economy of Symbolic Goods: A Contribution to the Scalability of Open Multi-agent Systems. In Fischer, K., Florian, M. (eds.) (to appear). Socionics: Its Contributions to the Scalability of Complex Social Systems, LNAI. Springer Verlag.
11. Gasser, L. (1991). Social Concepts of Knowledge and Action: DAI Foundations of Open Systems Semantics.
12. Gerber, C., Siekmann, J., Vierke, G. (1999): Flexible autonomy in holonic multiagent systems. In:AAAI Spring Symposium on Agents with Adjustable Autonomy.
13. Knabe, T. (2002). Business Organizational Forms in Self-organizing Multiagent Systems. Diplomarbeit, Department of Computer Science, Universität des Saarlandes.
14. Schillo, M., Spresny, D. (To be published). Organization: The Central Concept for Qualitative and Quantitative Scalability. In Fischer, K., and Florian, M. (eds.) Socionics: Contributions to the Scalability of Complex Social System , Lecture Notes in Artificial Intelligence, Berlin et al., Springer.
15. Schillo, M., Bürckert, H.J., Fischer, K., Klusch, M. (2001): Towards a Definition of Robustness for Market-Style Open Multi-Agent Systems. In Proceedings of the Fifth International Conference on Autonomous Agents (AA' 01), pp. 75-76.
16. Schillo, M., Fischer, K., Fley, B., Florian, M., Hillebrandt, F., Spresny, D. (In Print). FORM - A Sociologically Founded Framework for Designing Self-Organization of Multiagent Systems. In Proceedings of the International Workshop on Regulated Agent-Based Social Systems. Theories and Applications. Lecture Notes in Computer Science, Berlin et al., Springer.
17. Schillo, M., Knabe, T., Fischer, K. (to be published): Autonomy Comes at a Price: Performance and Robustness of Multiagent Organizations. In Hillebrandt, F. and Florian, M. (in preparation): Adaption und Lernen in und von Organisationen, Westdeutscher Verlag.