Autonomous Agents in Multiagent Organizations

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Abstract: Autonomous agents are constantly gaining relevance in economic applications. Autonomy as a characteristic of agents enables flexible behavior in cases of unforeseeable conditions. Multiagent systems research has analyzed various dimensions of autonomous behavior. However, the application of agents in an organizational context requires the actors to apply externally given rules that restrict agent autonomy. While multiagent systems aim at maximum flexibility, economical applications in organizations require stable structures. Multiagent organizations in terms of structured and stable multiagent systems are necessary to successfully link autonomous agents with organizations. Modelling autonomous agents in multiagent organizations requires to include the organizational structure and the operational processes, but also needs to consider the constitutive processes that enable the creation, adaption and dissolution of multiagent organizations. We survey extant literature from distributed artificial intelligence and management science and propose models for organizational structure and procedure of multiagent organizations. The models address new aspects for including autonomous agents in organizations that result from the linkage between both perspectives.

1 INTRODUCTION

Agent autonomy is a widely discussed field of research that continuously gained relevance in the last decade (Vernon, 2014). Especially the emergence of autonomous cars has contributed to spread the term "autonomous" both in scientific literature and in everyday life (Gerla et al., 2014). However, the definition of autonomy remains unclear and, thus, creates difficulties to integrate autonomous agents in organizations. In the economically orientated context of organizations, a trade-off between flexibility and stability is necessary to ensure processes that are mainly stable but may be adapted due to modified circumstances (Brenner, 2003).

The problem of connecting autonomously working machines with organizational concepts has already been addressed by Grochla (1966). Already in 1966, he analyzed whether machines might get intelligent enough that the complexity of their work may be classified on a similar level as the work of humans. Since then, this thesis has been controversially discussed in management science. Technical systems continuously gain a higher level of autonomy and multiagent literature assumes agents to be autonomous. Autonomy, which mainly results from learning capabilities, enables agents to consider unpredictable environmental effects. Built-in incorrect or incomplete knowledge might be compensated by learning capabilities, which contributes to agents' decisions that are mainly independent from the work of the developer (Russel and Norvig, 2009).

Multiagent systems research assumes autonomous agents to cooperate when necessary and therefore participate in multiagent systems (MAS). Thus, MAS are created to follow a single task and diminish as soon as the task is solved, creating maximum flexibility. However, the integration of agents and MAS in organizations requires reliable structures. We use the term multiagent (MA)-organization to describe a collaboration of autonomous agents that is

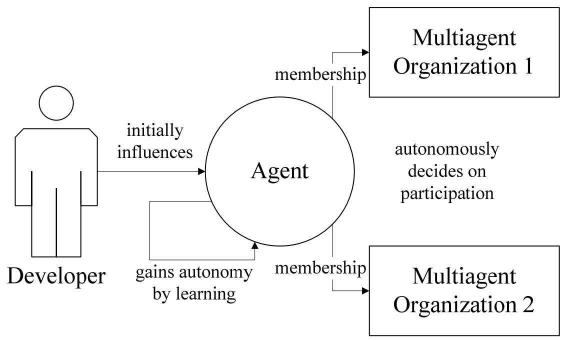

Figure 1: Autonomy and participation in multiagent organizations.

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structured similar to organizations, creating stability and means for economical applications.

Figure 1 illustrates the interconnections between the initial influence of the developer, the learning capabilities of the agent and its autonomous decision on participation in MA-organizations. However, the figure reveals an additional aspect: As autonomous agents may participate in multiple MA-organizations, goal conflicts between them may occur and need to be resolved by the agent. Autonomy is also present in other domains and on another level: Processes in hospitals are performed highly autonomous by the involved departments. The central hospital process management has only limited influence on the process steps within the departments. The concept of fractal processes helps to analyze and explain the interdependencies arising with autonomous departments. We address this problem by modelling the interdependencies between different organizational departments and fractal business processes that involve autonomous agents. This paper is based on previous work (Premm and Kirn, 2015, Widmer et al., 2016) and its aim is twofold: First, we survey literature from distributed artificial intelligence (DAI) and organizational theory to underline the importance of agent autonomy in organizations. Second, we present models for organizational structure and procedure to analyze dependencies between them.

The remainder is organized as follows. In section 2, we discuss the state of the art. Section 3 presents a modelling approach for MA-organizations. Section 4 discusses the linkage between organizational structure and procedure. Section 5 concludes.

2 STATE OF THE ART

This section surveys extant literature from DAI and organizational literature, with a focus on agent autonomy, basic problems of DAI and the fractal company approach introduced by Warnecke (1993).

2.1 Agent Autonomy

Autonomy has been attributed to software agents widely in DAI literature. A definition, often quoted, defines autonomous agents as agents that *"have control both over their internal state and over their own behavior"* (Jennings, 2000). However, this definition lacks a specification, when an agents has control over its internal state or its own behavior, including its own reconfigurability (Dennis et al., 2014): Software agents still have a developer who has large influence on its behavior and, thus, also over its internal state. Therefore, 4 levels of autonomy can be distinguished in the context of DAI (Müller-Hengstenberg and Kirn, 2016): (i) *Autonomy of the developer*: Besides the agents, the developer also a certain kind of autonomy in developing the agent. This includes choosing the software architecture and programming language. (ii) *Autonomy by design* is part of the product respectively agent definition and insures that the agent is protected against external influence. (iii) *Technical autonomy* addresses the feasibility of intelligent and autonomous behavior with respect to sensors and actuators as well as available resources, e.g. energy, time, storage. (iv) *Autonomy of MAS* describes the ability of MAS to develop and maintain problem solving capabilities partially independently from the participating software agents. Here, we stick to the level of technical autonomy, i.e. the technical feasibility of autonomous actions, and thus will first analyze the term autonomy that is broadly used in literature.

In current technical development the term autonomous car is widely used to describe cars that are capable of driving to a specified destination without interaction of a human driver. But are these "autonomous" cars really autonomous? The goals of the car are partly given by the developer, e.g. restrictions, rules, and partly given by human users, e.g. destination, maybe even restrictions on the possible route. Thus, the car has no control over its own goals as they are externally given and consequently only partly over its internal state. So, we might rather term it a "fully automated" car as it is only automated in the sense of following directions. However, we might also think of an autonomous taxi that may act on behalf of a goal function, e.g. earn money, and may decide on its own with whom it is willing to make a contract. This taxi would be classified as "more autonomous" than a purely automated car.

Autonomy in general includes the ability to temporarily give control away, e.g. an autonomous or fully automated car may decide to join a group of other cars to optimize travelling characteristics: Safety distance may be reduced to decrease air resistance and space occupied on the road. These participation decisions are directly connected to organizational structuring as each participant brings along new competences and responsibilities for new tasks (Widmer et al., 2016). Although, these organizational structures do not include humans, maximum flexibility – as provided by MAS – would not be expedient: Other cars of the group need to rely on foreseeable behavior of each participant. These MA-organizations, however, inherently limit the autonomy of the participating agents as organizational rules limit their scope of action (Schillo and Fischer, 2004). Besides these self-controlled restrictions by participation decisions, agents also face continuously restrictions by authorities: Not only do autonomous or automated cars need to follow traffic rules, but these restrictions may be even increased in the case of a police car or ambulance in action passing their way. Consequently, autonomy is never a characteristic that can be ultimately applied. Instead, autonomy is in general restricted in some way and is always a relation concept (Castelfranchi, 1995).

Agent autonomy is inevitably linked to the responsibility for actions. As an autonomous agent needs the freedom to act autonomously, the question arises whether the agent is able to be responsible for its actions. However, we have to distinguish between two types of responsibilities: (i) the implementation responsibility for actions that lead to a successful solution of the task and (ii) the juristic responsibility that offers the possibility for contractual partners to claim contractual performances (Widmer et al., 2016). While autonomous agents may take the first type of responsibility, they cannot be a contractual partner and cannot be responsible in a legal sense.

MA-organizations primarily aim at structuring the decisions of autonomous agents in a long-term manner (Hübner et al., 2010). In contrast to MAS that dissolve after the problem is solved, MA-organizations have a long-term goal. Thus, the members of a MA-organization have to restrict their own freedom to act and give up some of their autonomy. On the other side the MA-organization needs to address the still existing autonomy of the agents by creating motivation to work towards the global goal. However, the MA-organization is not able to prevent agents from withdrawing from the organization, in case their own goals run contrary to those of the MA-organization. These problems are largely analyzed in organizational theory (Pfeffer and Salancik, 1978), however, the involvement of autonomous software agents in organizations and the creation of MA-organizations is unattended in literature.

2.2 Basic Problems of DAI

Bond and Gasser define basic problems of DAI and distinguish five basic questions that DAI needs to address (Bond and Gasser, 1988). Agent autonomy has major influence on these basic problem, but is often neglected in literature. The influence of agent autonomy on each of the five basic problems of DAI is analyzed in the following paragraphs:

Problem Description and Solving. The first basic problem of DAI is about *"how to formulate, describe, decompose, and allocate problems and synthesize results"* (Bond and Gasser, 1988). However, problem description is usually performed on a global basis, neglecting the fact that agents act autonomously and might use their own models. Especially in an organizational context, intelligent agents need to align their own models, including problem descriptions, with those of the MA-organization. On the other side, due to single agents' autonomy, Ma-organizations have only restricted influence on internal models of their members.

Communication. In general, interaction and communication between agents needs communication languages or protocols. In a MA-organization, communication languages and protocols are usually defined by the MA-organization itself and may intend strict rules. The purpose of strict rules are foreseeable behavior of the involved actors. However, the autonomy of each agent may hinder communication by disregarding communication rules or the sequence of a protocol, e.g. the initiation of an interaction. Analogously to other rules, motivation, e.g. by incentives or sanctions, is necessary to ensure agents following given rules.

Local Decisions. Autonomous agents are inevitably associated with local decisions and the effects of local decisions form the basis for decentralized control. In an MA-organization, decisions of each member need to be aligned with the goals of the MA-organization. However, the participating agents will act on behalf of their own goals in the first place. Thus, the regulations for their membership need to include incentive mechanisms that ensure local decisions in the MA-organization's interest.

Coordination. Coordination in MAS is often characterized and influenced by approaches from management science especially organizational theory. Subsumed under the term coordination, this basic question includes *"how to enable individual agents to represent and reason about the actions, plans, and knowledge of other agents in order to coordinate with them"* (Bond and Gasser, 1988). This includes the information exchange of autonomous agents, which is especially relevant in an organizational context and is directly connected to the local decisions of each agent: Without the willingness to share information the MA-organization might not profit from additional knowledge generation, e.g. by combining knowledge, or might suffer from inconsistencies in distributed knowledge bases.

Consistency. Consistency, e.g. of distributed knowledge, in a group of agents depends on the local decisions of single agents. Comparing MAS with agents in an organizational context, the problem of inconsistencies between the knowledge bases of different agents even gains importance. As agents in MA-organizations will work on a long-term basis, inconsistencies might have severe impact on organizational outcome. Influencing the coordination mechanism and encouraging agents to resolve inconsistencies in their knowledge base or conflicting intensions is key to organizational performance.

The basic problems of DAI form a basis to discuss agent autonomy in an organizational context. Addressing corresponding questions helps to understand the impact of deploying agents in organizations and, hence, leads to an improvement of organizational performance. While MAS evolve to solve a problem and dissolve after a solution is found, MA-organizations need to address the basic problems of DAI from a long-term perspective.

2.3 Fractal Company

Enterprise modelling is constantly advancing by including additional aspects of the real world. A topic that has been addressed lately is the view on enterprises as fractal companies (Witte, 2001; Sandkuhl and Kirikova, 2011). Ever-changing competition on globalized markets and the corresponding complexity of decisions reveals new challenges for the involved actors. Decentralization is one key for enterprises to address these challenges and involves decisions about organizational structures: Which degree of autonomy is appropriate for which hierarchical level? Which resources and responsibilities do the members need for decentralized decision (e.g. Warnecke, 1993, Tapscott and Caston, 1993)? Organizations are forced to substitute strict hierarchical structures with decentralized patterns of coordination. Conversely, organizational subunits that already show autonomous characteristics, increase their degree of freedom and thus their level of autonomy. To address the emerging challenges, Warnecke (1993) introduces the term *organizational fractals* that are characterized by the following four major criteria: (i) *Self-similarity* are the structural characteristics of organizations and modalities of generating added value enabling resource sharing between different organizational fractals. (ii) *Self-organization and self-optimization* represents a decentralized approach addressing the strategic, the tactical as well as the operational level of autonomous local decisions for solving tasks that have previously unknown conditions. (iii) *Goal-orientation* enables continuous measurement of each organizational fractal's performance, controlling their autonomous behavior, e.g. by motivation. (iv) *Dynamic* adaptation to unforeseeable changes of the environment are enabled by autonomous behavior.

Organizational fractals in the sense of Warnecke (1993) have a high degree of local autonomy, self-control, and self-organization skills. The paradigm has been transferred to multiagent literature under the term holonic multiagent systems (Fischer et al., 2003). Like autonomous agents in organizations, organizational fractals aim to maximize their local utility (e.g. in terms of workload or profit). Local decisions as one basic problem of DAI is also relevant in terms of organizational fractals: They autonomously decide whether to cooperate with other organizational fractals. There are no means to force organizational fractals to act in a specific way. Although a direct influence is not possible, one way to manage the behavior of organizational fractals or groups of collaborating fractals is motivation. Addressing goal-orientation, the individual goal-systems of organizational fractals needs to be aligned to a globally consistent objective system by incentives as well as sanctions (Warnecke, 1993). As human members are usually only bounded rational, establishing consistent goal hierarchies in organizations is nearly impossible (March and Simon, 1958). Consequently, parallel existing goals within an organization are lacking consistency and, thus, knowledge about internal objectives and dependencies between them remains incomplete or even false. In this context, consistency as one of the basic problem of DAI is directly affected by the autonomy of the organizational members and their internal decision mechanisms. This inconstancies only address organization internal goals. However, goal conflicts also emerge on a higher level, as objectives between the organization and its customers or other cooperating or competitive organizations may differ.

3 MODEL

Modelling MA-organizations has to involve software agents as well as human agents and, thus, needs to link the perspectives of information systems with those of economics: First, constitutive processes are necessary to analyze the evolvement, adaption and dissolution of MA-organizations. Second, the organizational structure has to be mapped to the model as organizations are usually divided into departments with local decision competences, referenced as organizational fractals. Third, organizational procedures involve multiple of these organizational fractals working together in multiple ways.

3.1 Constitutive Processes

The constitution of a MA-organization is necessary to distinguish it from MAS that do not show long-term stability. Therefore, the constitutional processes help to scale up from sole non-binding interaction to organizational structures with the corresponding active processes (Cooren and Fairhurst, 2009).

Constitutive processes include the constitution, adaption and dissolution of a MA-organization. The processes that constitute organizations have already been analyzed for their transferability to MA-organizations: Kirn and Gasser (1998) provide a life-cycle framework based on the Vienna Development Method with three types of constitutive processes:

Constitution. The constitution of MA-organizations requires agents willing to found and participate in a new MA-organization. The constitution includes the creation of organizational structures and processes (see section 3.2 and 3.3). Hence, constituting a new organization is dependent on the local decision of several agents and is usually performed if all participants expect to have a positive return.

Adaption. While the initial constitution is designed for a long-term period, changing environmental circumstances and evolving goal definitions may occur, but may also be initiated by a subset of the organizational members. It includes the reorganization of the organizational structure and procedures as well as the admittance of new members or the exclusion of existing ones.

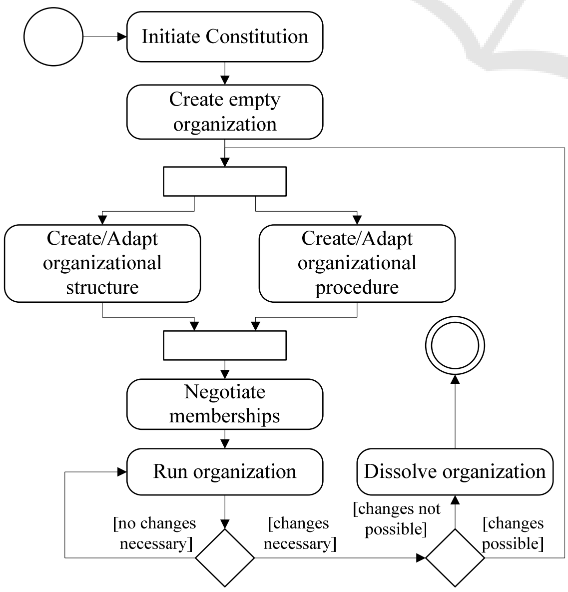

Figure 2: Constitutive process of multiagent organizations.

Dissolution. If running the organization is not beneficial for the remaining members anymore, dissolution processes are necessary. These processes have to determine how the (non-)physical resources are spread between the current set of members.

Constitutive processes aim at creating, maintaining and if necessary dissolving the organizational structure and procedure. Figure 2 shows the constitutive processes for MA-organizations in an UML activity diagram. The presented models are preconditions for describing and applying the constitutive processes creating and running a MA-organization.

3.2 Organizational Structure

As the agent's autonomy forms the basis for its local decisions, the organizational structure also influences the negotiations between the organization and potential members. Term definitions for a common language between both negotiators are necessary to prevent inconsistency in alter stages. Therefore, we adapt terms from literature of organizational theory.

The smallest autonomously acting organizational unit is the *position*, which is in general constituted independently of instantiations. The position and the occupying agent are linked, while the unidirectional cardinality is set to a maximum of 1. Thus, a position can only be occupied by a single agent. However, an agent may occupy multiple positions, possibly in multiple organizations. A position is linked to one or more tasks and thus to the corresponding competences and responsibilities: (i) A *task* is the target performance linked to the position. Reaching the target performance is one goal of the agent occupying the position. Handling tasks requires the agent in charge to provide a set of capabilities and access to resources. (ii) *Competences* denote the right to act in a certain way in organizational literature (Hill et al., 1994) and are the formal basis for position-specific influence on the work of agents. (iii) The obligation to act in a certain way (especially with respect to an assigned task) is denoted *responsibility*. The responsibility has an executive (performing an action) and a legal dimension (bear the legal consequences).

Assigning a task to a position and consequently to an agent implies expectations of other members for task fulfillment. These expectations in MA-organizations are called *roles*. Three types of roles can be found in an organizational context (Hill et al., 1994): (i) *Task-specific roles* specifying expectations in relation to a task. (ii) *Position-specific roles* as expectations related to the position that is occupied by a member/agent. (iii) *Individual-specific roles* are expectations that are founded in individual behavior or certain characteristics of a member, e.g. former behavior of a member that is expected for future actions. Figure 3 gives an overview on the main UML classes for modelling hierarchical structures.

The link between a member of a MA-organization and a position is the main representation of organizational membership. The position itself is linked to several tasks, competences and the corresponding responsibilities to use the competencies to solve the tasks. The member provides a set of capabilities and resources that are useful for the MA-organization. “Usefulness” in the context of organizational membership is represented by matching capabilities used for solving specific tasks. Thus, tasks are linked to capabilities and resources that the agent provides and that are required for solving the task. The class *role* is divided into three major subclasses representing expectations with respect to a specific subject: (i) Individual-specific roles linked to members, (ii) position-specific roles linked to positions and (iii) task-specific roles linked to tasks.

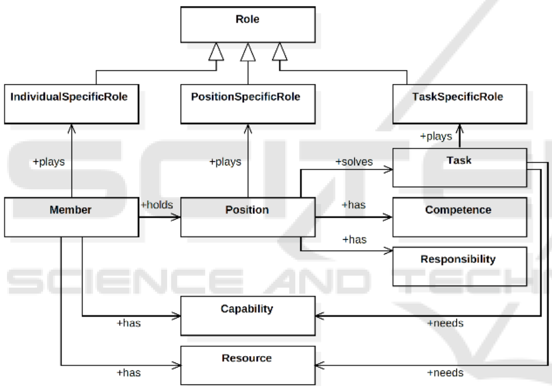

Figure 3: UML class definition of organizational structure.

3.3 Organizational Procedure

Besides organizational fractals in the sense of autonomous departments, network-wide business processes consist of flexibly coordinated process fractals autonomously making local decisions. These process fractals may involve actors from multiple departments. Two dependent organizational problems evolve in the context of process fractals: (i) the intra-organizational structure of each process fractal and (ii) the overall inter-fractal procedure that isn’t under control of a single fractal. Process fractals, thus, have to coordinate their actions for an appropriate global output. Table 1 presents a meta-model for modelling supply chains consisting of autonomous process fractals. The logistics term transshipment describes the actions connecting different logistics process steps and, thus, allows the output of one fractal to be used as an input for the next one.

While the participation of an agent in an organization is due to its autonomy dependent on its willingness to participate, the presented meta-model takes a look at higher level organizational procedures. The process fractals within an organization usually also have a certain degree of freedom in their actions: In general, they cannot decide on the participation at a certain process itself, but the fractals are able to decide on their internal processes. The organizational management has only limited influence on the internal processes and thus has to motivate the fractals to behave in a manner beneficial for the organization. The meta-model visualizes this aspect, which is especially important for agents in organizations, as they are usually able to handle considerably more parallel tasks in different organizational processes than their human co-workers.

Table 1: Meta-model of organizational procedure.

Label	Symbol	Description
Process Fractal		Self-contained and self-organized series of activities that involves actors and is available via interfaces
Actor		Autonomous organizational entity in a process fractal that has the competency to make individual decisions within a given scope
Interface		Coupling point of a process fractal that allows for incoming or outgoing products/services from or to another process fractal
Interaction Path		Bidirectional communication link between two actors of a fractal
Transshipment		Transition of a product/service from one process fractal to another one

4 LINKAGE OF STRUCTURE AND PROCEDURE

The preceding sections presented two types of fractals that occur in enterprises: (i) Organizational fractals that may be embodied in departments or teams, hence, hierarchical structures and (ii) process fractals that have to solve specific logistic tasks as interdependent steps of an overall enterprise output. Organizational structures and organizational procedures are interconnected in various ways. In general, there are numerous processes in enterprises that involve multiple departments. Thus, one cannot assume that the process fractals follow the same pattern as the organizational structure. Consequently, organizational structure and procedure have to be linked for a holistic view on the enterprise. Figure 4 shows the linkage of structure and procedure via an identifier of the acting position. The example involves a care robot that supports processes in a hospital. Due to their ethical high responsibility for their patients, physicians and their corresponding organizational fractal are usually characterized by highly autonomous decisions. Thus, hospital management face the problem of efficient overall processes involving multiple process fractals. As agents might be included in more the one fractal, but lack legal responsibilities and need mechanically readable problem descriptions, the linkage between organizational structure and procedure needs to consider these circumstances. However, the problems stated in the context of hospitals may be also transferred to other domains, e.g. autonomous production islands in a manufacturing enterprise.

When autonomous agents are involved in organizations, other factors have to be considered: Autonomous agents usually act in behalf some natural or juristic person. Hence, somebody is responsible for the agent's action and has to stand in for contracts that have been signed. In the example of autonomous cars, this leaves the question open who is responsible in case of an accident: The owner, the manufacturer or the driver – who actually didn't drive. The same question arises in organizations: Autonomous agents will usually work in some environment, receiving orders from hierarchically superordinate instances, e.g. a care robot in a hospital (see Figure 4). However, the agent needs access to some (hardware) resource and needs to be maintained. These tasks are usually undertaken by the developer or operator of the agent, e.g. the hospital internal IT department or an external service provider. These assignments have to be represented in the organizational structure, therefore autonomous agents in organizations will be assigned to at least two organizational departments: (i) IT department, developing and maintaining the agent or manage service contracts with the corresponding provider, and (ii) the department, the agent is actually working for.

In the comparison with autonomous cars, the IT department takes the role of an "owner", when the agents is developed by an external provider, as their main task is to manage service contracts. The role external service provider in this case is similar to a manufacturer of autonomous cars. However, if an autonomous agent is completely developed and maintained within the organization, the IT department would play a dual role as "owner" and "manufacturer". In both cases, it is important to clarify who is responsible for the agent's activity, as the agent itself isn't able to take the juristic responsibilities.

Is the agent completely developed and maintained within the organization, internal organizational regulations may help to solve the problem of unclear responsibilities. However, if the agent has been developed outside of the organization and autonomously decided to join an organization, the responsibilities in a legal sense are unclear and strongly depend on the involved countries. When country of residence of the developer, the provider or that of the application differ, it might be even unclear which law is applicable.

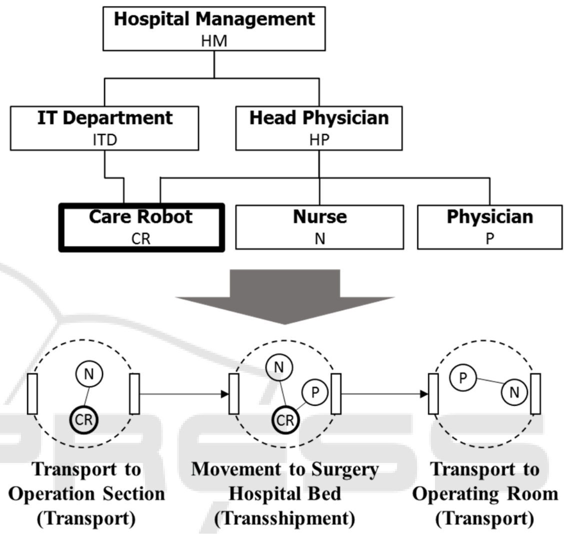

Figure 4: Linkage-Example of organizational structure and procedure.

5 CONCLUSIONS

In contrast to MAS that maximize flexibility, stable structures for the interaction of autonomous agents are necessary to create reliability in economical applications We contribute to this problem by providing models for three different perspectives on MA-organizations: (i) the constitutive processes that allow for creation, adaption and dissolution of organizations, (ii) the organizational structure that represents a hierarchical order of capabilities and resource requirements, and (iii) the organizational procedures that represent fractal operational processes. We discuss the problems arising with connecting organizational structure and procedure as competences and responsibilities may remain unclear. The complexity increases significantly when autonomous agents are assigned to multiple organizational fractals and contribute to various fractals.

Visualizing the emergent difficulties is a significant step towards efficient integration of autonomous agents in organizations. However, further research needs to develop new methods to address these upcoming challenges. Working with the models presented enables their evaluation in an organizational context. Managing the integration of autonomous agents in economically orientated organizations is key to their application in general. Merely if companies see the benefits of applying autonomous agents in real world scenarios, their full potential may be exploited. This particularly includes the transition from solely flexible – and from an external point of view unpredictable – behavior to stable organizational processes.

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REFERENCES

Bond, A., Gasser, L., 1988. *An Analysis of Problems and Research in DAI*. In: Bond, A., Gasser, L. (Eds.) *Readings in Distributed Artificial Intelligence*. Morgan Kaufman Publishers, San Mateo, pp. 3-35.

Brenner, M.J., Tushman, M.L., 2003. *Exploitation, Exploration, and Process Management: The Productivity Dilemma Revisited*. The Academy of Management Review, vol. 28, no. 2, pp. 238-256.

Castelfranchi, C., 1995. *Guarantees for Autonomy in Cognitive Agent Architecture.* In *Proceedings of the workshop on agent theories, architectures, and languages on Intelligent agents*, pp. 56-70, Springer.

Cooren, F., Fairhurst, G.T., 2009. *Dislocation and Stabilization: How to Scale Up from Interactions to Organizations*. In: Putnam, L.L., Nicotera, A.M. (Eds.): *Building Theories of Organization – The Constitutive Role of Communication*. Routledge, New York.

Dennis, L.A., Fisher, M., Aitken, J.M., Veres, S.M., Gao, Y., Shaukat, A., Burroughes, G., 2014. Reconfigurable Autonomy. KI - Künstliche Intelligenz, vol. 28, issue 3, pp 199–207.

Fischer, K., Schillo, M., Siekmann, J., 2003. Holonic Multiagent Systems: A Foundation *for the Organisation of Multiagent Systems*. In: Marik, V., McFarlane, D., Valckenaers, P. (Eds.) *Holonic and Multi-Agent Systems for Manufacturing*, LNAI 2744, pp. 71-80.

Hill, W., Fehlbaum, R., Ulrich, P., 1994. *Organisationslehre*. Paul Haupt. Bern, 5th edition.

Hübner, J.F., Boissier, O., Kitio, R., Ricci, A., 2010. *Instrumenting multi-agent organisations with organisational artifacts and agents – „Giving the organisational power back to the agents“*. In *Autonomous Agents and Multi-Agent Systems* 20, pp. 369-400.

Jennings, N.R., 2000. *On agent-based software engineering*. Artificial Intelligence 117, pp. 277-296.

Gerla, M., Lee, E.-K., Pau, G., Lee, U., 2014. *Internet of Vehicles: From Intelligent Grid to Autonomous Cars and Vehicular Clouds*. IEEE World Forum on Internet of Things, pp.241 – 246.

Grochla, E., 1966. *Automation und Organisation – Die technische Entwicklung und ihre betriebswirtschaftlich-organisatorischen Konsequenzen*. Gabler, Wiesbaden.

Kirn, S., Gasser, L., 1998. *Organizational Approaches to Coordination in Multi-Agent Systems*. it+ti Intelligente Agenten 4, pp. 23-29.

March, J.G., Simon, H., 1958. *Organizations*. John Wiley and Sons, New York.

Müller-Hengstenberg, C.-D., Kirn, S., 2016. *Rechtliche Risiken autonomer und vernetzter Systeme – Eine Herausforderung*. De Gruyter, Oldenbourg.

Pfeffer, J., Salancik, G.R.,1978. *The External Control of Organizations - A Resource Dependence Perspective*. Harper & Row, New York.

Premm, M., Kirn, S., 2015. *A Multiagent Systems Perspective on Industry 4.0 Supply Networks*. In: Müller, J.P., Ketter, W., Kaminka, G., Wagner, G., Bulling, N. (Eds.) *Multiagent System Technologies*, LNCS 9433, pp. 101-118.

Russel, S., Norvig, P., 2009. *Artificial Intelligence – A Modern Approach*. Pearson, 3rd edition.

Sandkuhl, K., Kirikova, M., 2011. *Analysing Enterprise Models from a Fractal Organisation Perspective – Potentials and Limitations*. In: Johannesson, P., Krogstie, J., Opdahl, A.L. (Eds.) *The Practice of Enterprise Modeling*, LNBIP 92, pp. 193-207.

Schillo, M., Fischer, K, 2004. *A Taxonomy of Autonomy in Multiagent Organisation*. In: M. Nickles, M. Rovatsos, and G. Weiss (Eds.): *AUTONOMY 2003*, LNAI 2969, pp. 68–82.

Tapscott, D., Caston, A., 1993. *Paradigm Shift: The New Promise of Information Technology*. cGraw-Hill, New York.

Vernon, D., 2014. *Artificial Cognitive System – A Primer*. The MIT Press, London.

Warnecke, H.J., 1993. *Revolution der Unternehmenskultur – Das Fraktale Unternehmen*. Springer, Heidelberg.

Widmer, T., Premm, M., Kirn, S., 2016. *A Formalization of Multiagent Organizations in Business Information Systems*. In: Abramowicz, W., Alt, R., Franczyk, B. (Eds.) *Business Information Systems*, LNBIP 255, pp. 265-276.

Witte, H., 2001. *Logistik*. Oldenbourg, München.