Semiotics, multi-agent systems and organizations

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Abstract

Multi-agent systems are promising as models of organization because they are based on the idea that most work in human organizations is done based on intelligence, communication, cooperation, and massive parallel processing. They offer an alternative for system theories of organization, which are rather abstract of nature and do not pay attention to the agent level. In contrast, classical organization theories offer a rich source of inspiration for developing multi-agent models because of their focus on the agent level. This paper studies the plausibility of theoretical choices in the construction of multi-agent systems. A main problem in the construction of psychologically plausible computer agents is the integration of response function systems with representational systems.

1. Introduction

This paper discusses the question which theoretical choices are the most plausible in the construction of multi-agent systems from a philosophical, psychological, and organizational point of view. In this discussion, three concepts can be seen as central: the concept of agent, the concept of architecture, and the concept of (emergent) organizational characteristics, or, for short, organizational performance. It turns out that, in defining these concepts, we touch upon all sorts of problems and approaches described in philosophy, in cognitive science or artificial intelligence and in organization and management theory.

Let us return to our question about the theoretical choices that have to be done when constructing multi-agent systems. For each of these choices, alternative theories exist. Philosophically, the organization can be seen from the viewpoints of realism and constructivism. The concept of architecture is necessary to understand organization as a principle of arrangement. However, an organization also can be viewed as an entity. The status of this entity depends on the philosophical point of view taken (3). Psychologically, several sorts of agents can be distinguished, based on the concepts of response function and representation. A main problem in the construction of psychologically plausible computer agents is the integration of response function systems with representational systems (4). Organizationally, we study aspects of the architecture of multi-agent systems, namely topology, system function decomposition, coordination and synchronization of agent processes, and distribution of knowledge and language characteristics among agents. For each of these aspects, several theoretical perspectives exist (5). A research program that aims at testing organization theories based on the construction of multi-agent systems is explained (6). In 7, we draw some conclusions.

2. Multi-agent systems as a new perspective in organization theory

The various organizational theories can be categorized in classical, system theory and knowledge based approaches.

Classical organization theories are, surprisingly, relatively rich because of their focus at the agent level. They are related to the machine metaphor and the topology of objects and the architecture of agents. The classical organization theories of Taylor, Fayol, and Weber, subsumed by Morgan (1986) under the machine metaphor, see an organization as a whole consisting of agents performing tasks. There is a fixed structure of agent tasks and agent communication. Virtually no attention is paid to symbol structures. Fayol's (1916) management principles can be applied in multi-agent systems. Interesting principles concern specialization related to learning and the communication speed resulting from communication topologies.

System theories of organization are related to the organism metaphor and the system function architecture. The organistic organization theories, for instance contingency theory (Burns & Stalker, 1961), adopt a system-theoretical approach to organizations. In this approach, the organization as a whole is seen as the basic object. This object can be decomposed in subsystems, each of which has a function in the system as a whole. These subsystems can be decomposed further, and so on. The way of thinking of the system theoretical approach is top-down, and opposes the bottom-up way classical organization theories see organizations.

Knowledge-based multi-agent theories. An agent is an autonomous and intelligent being. Examples are a human being, or a simulator of a human being as a more or less autonomous and intelligent entity realized by software running on a computer system. The latter agent type will be called a computer agent. A multi-agent system is a system consisting of agents that communicate and cooperate (Gazendam, Jorna, & Blochowiak, 1991).

Multi-agent systems in the role of simulation models of human organizations offer an intriguing perspective for studying those organizations. Instead of hierarchically structured computer programs, multi-agent simulation models of organization offer a bottom-up perspective: based on the capabilities of agents and the resulting communication and cooperation, emerging characteristics of the organization as a whole can be defined, discovered, or explained. Because most work that is done in human organizations is based on intelligence, communication, cooperation, and massive parallel processing, multi-agent simulation models seem to offer a promising, plausible model of organization. Moreover, the local intelligence and parallel processing features of multi-agent computer systems offer a promise of overcoming present bottlenecks in computerized problem solving.

3. Philosophical views on organization

What are organizations? We all know that organizations do exist. This assertion is easily made, but presupposes a bundle of distinct beliefs, such as that the concept of organization has an extension (in the logical sense) or that entities that are not visible can be perceived or that reality can be described in layers. We are talking here about organizations as entities, not as principles of arrangement. Because of the weak, that is to say theory-dependent, definition of organization, it is common in organizational theory to discuss the concept in terms of metaphors and paradigms (Morgan, 1986).

In preceding decades a (profit or nonprofit) organization consisted of buildings, factories, offices or comparable things in which people and machines in one way or another were tuned into one another. In the recent past this situation has already changed a bit and it will change more dramatically in the near future. Intelligent computers, data processing structures, information exchange procedures and communication architectures will lead to questions such as "where is the organization?", "where is the information?", "where is the communication?" and even "where is the human being or agent?". Two (extreme) positions are: realism, seeing an organization as an object, and constructivism, viewing an organization as a construction.

Realism: Hard core classical realism represents a perspective in which it can be defended that organizations are objects. Realism is the view that physical (and many nonphysical) objects exist independently of being perceived. Thus understood, "realism obviously reaffirms the standpoint of common sense" (Flew, 1979). "To exist, to be an entity, to have ontological status are the same." (Bergmann, 1967: 3) Organizations as well as cars, electrons and stars are all part of reality and can be studied independent from perceivers. The differences become visible as soon as researchers try to describe the different objects in reality. Then, metaphors and analogies lead to different descriptions and sometimes even to different description languages.

Constructivism: The other extreme position is *nominal* or *social* constructivism. This is the view that entities exist only if they can be constructed (or, intuitively shown to exist), and that statements are true only if a constructive proof can be given (Flew, 1979). This meant that organizations, institutions or companies can be studied as constructed entities. The prefix "social" refers to the sort of entities we are talking about. The other prefix "nominal" means that "the use of general terms that accounts for their meaning, and denotation, is in the mutual resemblance of the particular things to which they can be applied, or the recurrence in them of the general property indicated." (Flew, 1979: 232) This nominalist position is most strongly defended by Goodman (1972; Goodman & Elgin, 1988). "In describing an object, we apply a label to it. Typically that label belongs to a family of alternatives that collectively sort the objects in a domain. Such a family of alternatives may be called a scheme, and the objects it sorts its realm." (Goodman & Elgin, 1988: 7) This leads to the conclusion that in fact there only are labels that are expressed in symbols. This not only includes symbols used in languages, but also symbols in diagrammatical, notational or other representational systems. Symbol systems are artifacts (Goodman & Elgin, 1988; see also: Simon, 1969) which, certainly according to Goodman & Elgin, means that organizations also are artifacts. Applied to organizational theory a constructivist position implies that an organization is constructed on the one hand by the symbol systems we use in describing complicated action patterns between natural and artificial agents, and on the other hand results as a symbol system out of these interactions.

Ontological and semiotic engineering: The realist as well as the constructivist view are two rather well defined positions regarding organizations (Morgan, 1986; Gazendam, 1993). According to the realist the integrated descriptive framework in the design of organizations can be seen as an ontology, a system of hypotheses about the objects and structures that exist. Analysis, design and change use this relatively stable framework of description. The philosophically applicable term for this activity is ontological engineering.

The situation is largely different for a (nominalist) constructivist position. In this case there is no well defined object called "organization". An organization is a descriptive construction and therefore it is very difficult to develop an integrated descriptive framework for organizations. The description influences the constructed reality and at the same time the dynamics of the construction continually change the description. Analysis, design and change therefore very much depend upon the symbol systems used in the description. The attempt to develop an integrated framework, one language of description, is seen as uninteresting and even impossible. In contrast with ontological engineering we call this activity semiotic engineering.

Because of the artifact nature of the organization concept, we tend to a constructivist, semiotic engineering point of view. Organizations are constructs of the human mind, and can be studied by several conceptual systems or language systems that are not necessarily compatible. The consequences for the construction of multi-agent models is that one should be very careful in handling objects that represent the concept of 'organization'. A direct representation of this concept should be avoided. If representation is necessary, it should be done as a kind of instrument in the agent's mind, not as a separate entity. In the eye of the investigator using multi-agent models, emergent properties of the organization as a whole are interesting. In determining these emergent properties, the investigator should delineate the organization as a collection of agents that share a certain property such as a contract, or that have established a certain type of cooperation.

4. Psychologically plausible agents

Normally, an organization consists of an architecture being the cement, or the glue between many agents. The levels of complexity of architectures and agents define the complexity level of the organization. Agent sorts can be discerned regarding the presence or absence of the following components: perception, interaction (including learning in the sense of habit formation), representation (including learning in the sense of chunking) and autonomy.

With *perception* (1) we mean that a system must be able to accept input in a general sense. *Interaction* (2) is the process by which a system has contact with its environment. The reaction patterns of the system may result in learned behavior, that is to say that the habits are formed.

A system that internally symbolizes the environment is said to have *representations* (3) at its disposal. Representations consist of sets of symbol structures on which operations are defined. Examples of representations are words, pictures, semantic nets, propositions or temporal strings (Jorna, 1990). A system is *self-reflective* (4a) if it is having a representation of itself, including its own position in the environment. This means that the system has self-representation, and can act based on this self-representation. A system is said to be *autonomous or self-organized* (4b) if it can maintain itself in its environment based on its own action and its own learning.

The four aspects contain a sort of agent hierarchy. An agent that only has perception at his disposal is at the lowest level and can hardly be called an (intelligent) agent, whereas an agent with self-organization is the highest level and normally has perception, interaction and representations. Not every agent is intelligent and not every intelligent system is an agent. The above described classification in perception, interaction, representation and autonomy can be related to qualification of agents. First we make a distinction in single agents and multiple agents. Second we subdivide agents in response function agents, representational agents and representational response function agents.

The response function agent: We start with an environment in which a system is present. The system is a cohesive, structured and organized entity. This entity operates in an environment, but no specifications of its operations are given. In a sense this entity is an agent, because it is self-contained, strives toward continuation and, if we look at the agent characteristics, it has perception and interaction including the possibility of learning in the sense of habit formation. It is emphasized that this agent does not have internal representations. Its cognitive domain is absent or empty. We call this agent a response function agent and it can be compared with the ant in the sand (Simon, 1969).

The representational agent: Keeping the environment the same we can conceive another agent that we call a representational agent. This agent has representations at its disposal and is able to project external events internally into its cognitive domain. A representational agent has perception, representation and autonomy. The interaction is problematic, that is to say that there is no device that semantically interprets causal input and output. Another problematic aspect of representational systems concerns the meaning of representation. Representation has many interpretations and it is not always clear which reading is the correct one: representation as process, as description structure or as one, two or three place predicate (Goodman, 1968/1981; Jorna, 1990).

The representational response function agent: If we keep the environment still the same, the third possible interpretation of an agent is the representational response function agent. This agent incorporates a really intelligent, interactive and cognitive system. It is able to perceive, to interact, to represent and to be autonomous. Representational response function systems behave

on the knowledge level, as Newell called it. "There exists a distinct computer systems level, lying immediately above the symbol level, which is characterized by knowledge as the medium and the principle of rationality as the law of behavior." (Newell, 1982: 99)
Multi-agent systems: The hierarchy of single agents returns in the composition of multi-agent systems. In the first place it is possible to have multi-agents consisting of several response function systems. The situation is comparable to the single agent system in that the agents do not have internal representations.

In the second place we have multi-agents consisting of representational systems. Each of these agents has internal representations in the sense of symbol structures and operations upon them, but there is no guarantee that symbol structures are similar and thereby communicative, although it might be expected that they all use one or another form of Mentalese, as Fodor (1975) suggested. In the same way as it holds for the single agent representational system it is of course doubtful whether interaction between the agents is semantically meaningful. For this is a weak point in the extreme version of present day cognitive science. In discussions about social cognition the issue of semantic interaction is ticked off, but not resolved. Intelligent coordination is hardly handled.

In the third place there are the representational response function systems in a multi-agent situation. The agents perceive each other and react to each other in a semantically rich and intelligent way.

If we look at the six appearances of single and multiple agents and try to find examples of each of them in organizational settings (humans and computers) we see the following. Concerning single agents a connectionist machine is an example of a response function system, an expert system an example of a representational system without, however, the autonomy characteristic and a human information processing system an example of a representational response function system. Concerning multiple agents, examples of multi-agent response function systems are computer networks. Combinations of expert systems and humans are examples of multi-agent representational systems, whereas examples of multi-agent representational response function systems do not exist, besides perhaps an idealized group of human information processing systems. With respect to the hierarchies of single and multiple agents it should be noted that a higher level system exhibits the functions of a lower level system whereas the other way around is not applicable. This holds for single agents as well as for multiple agents.
Intelligent multi-agent systems: One conclusion from the foregoing discussion is that modeling an intelligent agent is not yet completely realized within cognitive science and artificial intelligence. This sort of agent, however, is necessary for the construction of intelligent multi-agent systems. So, there is a gap between what is required and what can be realized by present day science. On the other hand organizational theory speaks about the coordination of multiple intelligent agents, but defines agents as sort of response function systems without any internal representation. We do not strive after these sort of agents. So, cognitive science cannot model the multiple agent situation(Organizational and Management Theory (OMT) should ask for, whereas OMT takes for granted a sort of multiple agent system that is not sufficiently equipped in order to behave intelligently.

The interesting point of looking at an organization as a semiotic entity cannot only be found in semiotic engineering, but also in the different sorts of signs that turn up in the communication and information structures of the various single and multiple agents. In semiotics it is normal to distinguish signals from signs and to subdivide signs in icons, indexes and symbols. Icons emphasize the similarity aspect, indexes the contiguity aspect and symbols the conventional aspect of signs. Signaling is equivalent with reporting and registration, while working with signs

involves representing and interpreting. Signaling is a causal relation, whereas representing is mainly semantic.
Considering the sorts of single and multiple agents, only the response function systems work with causal relations, that is to say that the information exchange and the communication structures are in terms of signals. Representational systems work with icons, indexes and symbols, that is to say with semantic entities and relations. Response function systems and representational systems are mainly segregated. This means that the causal realm is largely isolated from the semantic realm. Developments within cognitive science and connectionism show that the latter is oriented at the symbolic or semantic domain, while the former is directed at the causal domain. The integration really takes place in the representational response function systems and these are the sorts of systems cognitive science as well as connectionism are striving to. So, multi-agent representational response function systems are the most plausible type of multi-agent systems from a psychological point of view. The problem, however, is that they do not yet exist.

5. The organization as a multi-agent system

Architecture is the way in which components make up a whole. The architecture of a multi-agent system is the way in which agents, processes performed by agents, and symbol structures used and produced by agents make up an organization. The dual nature of organizations, artifact and reality, accounts for the importance of prescriptive theories in the field of organization and management theory.

Multi-agent models of organization represent a more sophisticated and refined way of looking at organizations (Bond & Gasser, 1988; Gasser & Hill, 1990). Besides persons or agents (which can also include intelligent computer agents), communication channels or blackboards are distinguished as basic elements of the organization. Within each agent, agent knowledge is considered to be important. Furthermore, there are dynamic processes of task allocation, cooperation, and communication. Therefore, one can no longer speak of part qualities, actions, and intermediate structure qualities only. A much more complicated model emerges that can have recursive properties. Based on these considerations, the following four aspects of the architecture of multi-agent systems are distinguished: a) the topology of the components, b) the system function decomposition, c) the way of coordination and synchronization of processes, and d) the distribution of knowledge and language.
The topology of a multi-agent system is the way in which the basic components of an organization are ordered in space and time. The basic components of an organization are agents and material objects. Their ordering in space and time takes the form of work constellations and fixed communication paths. The most relevant alternatives that have been defined for the topology aspects are computational markets and computational hierarchies (Malone, 1987: Miller & Drexler, 1988). In the computational market topology, all agents have access to a common marketplace where information can be exchanged and negotiations take place. This topology is also known as the blackboard architecture (Engelmore, Morgan, & Nii, 1988). The computational hierarchy topology is characterized by the restriction of communication and negotiation of agents to a hierarchically structured organization: each agent can only communicate with its boss and its direct subordinates. According to Fayol (1916), this topology can lead to long communication lines and tedious communication processes. The fundamental concept in the computational ecology topology (Huberman & Hogg, 1988) is the environment, which is partially natural and partially agent made. Agents wander in the ecological environment seeking for fulfillment of their needs. The topological aspect of the ecological environment is

that at certain places, resources can be found; and that at other places, agents, by convention, gather to do things together like buying and selling, negotiating, cooperate in work or in pleasure. We see the computational ecological topology as the most promising type of multi-agent topology. It extends the decentralized computational market topology by introducing active, mobile agents and notions of resources, cooperation, and communication.

The system function decomposition aspect of the architecture of an organization is the way the organization is composed of sub-organizations fulfilling a specific function. These sub-organizations can be decomposed into smaller sub-organizations, and so on. This description stems from general systems theory. It is especially applicable in multi-agent models where agents have predetermined tasks, competences and power (and the emergence of such tasks , competences and power is not a subject of study). Especially the decomposition of competences and powers based on a system of checks and balances is interesting for multi-agent models of organization.

Coordination and synchronization of agent processes: Agent processes can be seen as related to the wandering around of autonomous agents in a natural and agent-made environment, in which they cooperate in an occasional or regular way. The basic thrust of agents is to fulfill their needs like individual survival by maintaining their metabolism and self-renewal, and survival of the species by reproduction (Dyson, 1988).

The agent viewpoint presupposes capabilities of agents to perform certain processes, for example coordination and synchronization. The following approaches to synchronization can be identified: discrete event simulation, Thompson's coupling mechanisms, speech act theory; the ecological environment in which symbol structures and signs reside, protocols as describing communication standards and grammars and lexicons as describing communication standards.

The choice between these alternative mechanisms of coordination and synchronization is difficult, because the most sophisticated, language-oriented mechanisms that seem to be the most plausible ones from a philosophical and psychological point of view, are also the most difficult to implement. In practice, more simple mechanisms like speech act theory or the ecological environment mechanism seem to be more appropriate for the state of affairs in multi-agent modeling at this moment.

The distribution of knowledge and language characteristics over the agents of the multi-agent system, is an important aspect of multi-agent architecture. In the case of (1) the co-decision type of coordination and synchronization (Schäl & Zeller, 1991), (2) the coordination and synchronization based on conventions, symbol structures, signs, and (3) coordination based on the agent communication that depend on agent world views and language capabilities, the level of description that focuses on identifying processes and the coordination and synchronization often becomes too complex to be useful. In these cases, it is often more useful to concentrate on the contents of communication (knowledge expressed in signs and symbol structures) and the language system enabling communication. The construction of process models of communication, interpretation and learning seems to be a promising one for developing new perspectives, models and theories for multi-agent systems. It weakness might be the tendency to make over complex models in which it is difficult to determine the relations between the variables used.

6. Research perspectives

Organization theories sometimes predict organizational performance based on the organization type and task environment type. We can use organization theories for the design of multi-agent systems, and we can use multi-agent systems to test organization theories.

Existing organization theories in the OMT literature contain knowledge that can be used for constructing plausible multi-agent models. This knowledge, part of which can be described in the form of an organization grammar, is used by the organization theorist in constructing models of organization (Gazendam, 1993). Furthermore, multi-agent models presuppose that agents have some notion of what an organization is and how it functions. This knowledge has to be incorporated in an agent grammar. Agent grammars (including a symbol and symbol structure lexicon), combined with a control mechanism, are sufficient to specify intelligent behavior (Gazendam, 1992). Such a specification would be fitting in the semiotic approach to multi-agent systems.

For the conceptual specification of organization theories, an ontological as well as a semiotic method can be used (Jorna, van Heusden & Posner, 1993). An ontological method for analyzing organization theories is, for instance, based on ontological engineering (Lenat & Guha, 1989) or on Bunge's ontology as a frame of reference (Wand & Weber, 1993). A semiotic approach to analyzing organization theories is offered by the CAST method (Gazendam, 1993). CAST (Conceptual Analysis and Specification of organization Theories) aims at the translation of verbal organization theories into a conceptual model using a BNF-like conceptual modeling language. The CAST method shows that there is a variety of metaphors for describing and designing organizations, and that each metaphor leads to its own language system, system of concepts, and reasoning form. Multi-agent models of organization can be used for testing organization theories.

The main question in building multi-agent systems is the integration of the following components: 1) a database program, 2) a discrete event simulation shell, 3) an expert system or problem solver and 4) a learning component.

In hybrid, object-oriented expert system shells the expert system is dominant (for example: Nexpert Object). In Plural SOAR (Carley, Kjaer-Hansen, Newell, & Prietula, 1992) , the problem solver and integrated learning component are dominant. In most existing multi-agent systems, the discrete event simulation shell is dominant enabling the (semi) parallel existence of processes for each agent and each blackboard during runtime. In our research, we aim at comparing these multi-agent architectures based on their use in simulation experiments. One of these architectures is Multi-Agent SOAR, another is a multi-agent organization modeling shell (ISM). The Information Strategy Model (ISM) is a multi-agent organization model written in Smalltalk80 (Gazendam, 1990). It simulates the choice and implementation of information management strategies. The basic structure of the Smalltalk80 multiprocessing and simulation classes is used to model agents, objects, resources and blackboards. Some agents use a personal knowledge base to fulfill their tasks. These knowledge bases use Humble, a Smalltalk expert system shell with Mycin-like features. The main results of ISM are insight in the stability or instability of strategies and the effects of long implementation trajectories on strategy choice. Based on ISM, an multi-agent organization modeling shell has been developed, adding a better integration of simulation shell and expert system components, a revised expert system shell, goal-oriented behavior, learning, and representation of space as well as time. Experiments with this multi-agent shell are a subject of ongoing research.

7. Conclusions

An organization is an artifact that is so predominant in our social life that we believe in its existence, although it is not a tangible object. Because of the "artifact" nature of the organization concept, we adhere to a constructivist, semiotic engineering point of view. Organizations are constructs of the human mind, and can be studied by several conceptual systems or language systems that are not necessarily compatible. Semiotic engineering uses semiotic theory because of the absence of a physiological carrier for coordination and communication between agents.

Multi-agent systems presuppose a representational response function agent. However, corroborated theories of representational response function agents do not exist, nor do computer models of representational response function agents exist. Therefore, plausible multi-agent systems have not been realized, yet. Connectionism and cognitive science are restricted to response function agents and representational agents. In theory as well as in simulation and modeling environments there are several problems in combining response function agents with representational agents.

With respect to the organization or architecture of a multi-agent system we have distinguished the aspects of topology, system function decomposition, coordination and synchronization mechanisms, and knowledge and language. We see the computational ecological topology as the most promising type of multi-agent topology. It extends the decentralized computational market topology by introducing active, mobile agents and notions of resources, cooperation, and communication. The system function decomposition aspect of a multi-agent system is a kind of description that stems from general systems theory. It is especially applicable in multi-agent models, where agents have predetermined tasks, competences and power (and the emergence of such tasks; competences and power are not subjects of study). Especially the decomposition of competences and powers based on a system of checks and balances is interesting for multi-agent models of organization. The choice between alternative mechanisms of coordination and synchronization is difficult, because the most sophisticated, language-oriented mechanisms that seem to be the most plausible ones from a philosophical and psychological point of view, are also the most difficult to implement. In practice, more simple mechanisms like speech act theory or the ecological environment mechanism seem to be more appropriate for the state of affairs in multi-agent modeling at this moment. A declarative, logical approach can fruitfully be applied to the analysis of existing organization theories, pointing out the weaknesses or even contradictions in those theories. Because of the complexities in the field of logical languages, we expect that the role of the declarative logical approach in constructing new theories will be relatively small. Its power lies in analyzing theories, not in inventing new ones. The construction of process models of communication, interpretation and learning seems to be a promising one for developing new perspectives, models and theories for multi-agent systems. It weakness might be the tendency to make over complex models in which it is difficult to determine the relations between the variables used.

Our conclusion has to be that plausible knowledge based multi-agent theories do not exist yet. Ingredients and components do exist, but cognitive science as well as OMT do not succeed in the complete understanding and explanation of these multi-agent systems.

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