Coordination Mechanisms in Multi-Actor Systems

Henk W.M. Gazendam

Abstract

Multi-actor systems have to do with issues of communication, cooperation and coordination. They focus on the capabilities, interests, and interactions of actors, and study the phenomena that emerge from these interactions. In multi-actor systems, work is done based on an organization that results from processes of coordination, especially negotiation. In this negotiated order, there is the aspect of producing the desired results (the cooperation and coordination side), and the side of distributing the advantages resulting from that cooperation (the surplus allocation side). The cooperation and coordination of the organization must lead to sufficient results, that is, a surplus compared to non-cooperation (condition 1), and that the distribution of that surplus must be acceptable for the participating actors (condition 2).

Planning based on direct representations typically uses reasoning structures like multiresolutional hierarchies of state spaces. But a hierarchy of direct representations in the form of a multiresolutional hierarchy of state spaces is not sufficient for a multi-actor system. Multi-actor organization has also to be based on more abstract representations. Semiotics gives us a useful categorization of representation types: direct representations, language representations, and conceptual representations. The self-organization of these representation types is based on resolution, narration, and abstraction, respectively. Together, these representation types are involved in the mechanisms of induction, abduction, and deduction that generate new knowledge.

1. Introduction

Multi-actor systems that have to function in a real world and in real time have to cope with risk, uncertainty, imperfect knowledge, bounded rationality, and limited communication. In such situations, organization forms based on centralized planning and control suffer from brittleness, rigidity, complexity, large planning overhead for small tasks, limits to information processing in the central decision-making function, and limited learning capabilities. There is a need for interpretation, negotiation, and discussion. For instance, if a goal is not for 100% attainable, will 90% do? And at which costs? Therefore, it is necessary to look for organization forms based on decentralized planning and control by relatively autonomous actors using their own information, rules, and goals.

Multi-actor systems do not differ from centrally controlled systems with respect to the necessity to find solutions for problems in doing their tasks. However, multi-actor systems are different in their attention for the interconnected world models of actors and the patterns of interaction between actors. Patterns of interaction can be seen as organizational patterns. Interaction has

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three aspects: the aspect of cooperation and coordination, the aspect of communication (including interpretation and semiotic Umwelt creation), and the aspect of problem solving and learning.

**Cooperation and coordination** between actors leads to task fulfillment in which surplus is created and distributed (Gazendam and Jorna, 1993; 1998; Gazendam and Homburg, 1996). Cooperation, coordination, and surplus allocation can be studied using organization theories, economic theories and political theories. Coordination, especially negotiation, leads to patterns of organization. In this organizational pattern, there is the aspect of producing the desired results (the cooperation and coordination side), and the side of distributing the advantages resulting from that cooperation (the surplus allocation side). The cooperation and coordination of the organization must lead to sufficient results, that is, a surplus compared to non-cooperation (condition 1), and that the distribution of that surplus must be acceptable for the participating actors (condition 2) (Gazendam and Homburg, 1999) (Paragraph 2).

Processes of communication (including the connected processes of interpretation and semiotic Umwelt development), exploration, problem solving and learning lead to interconnected world models of actors. Communication, exploration, problem solving and learning can be studied from the viewpoints of semiotics and artificial intelligence. These processes are connected to the interconnected development and use of a world models by cooperating actors. In the development of a world model, there is an evolution. Direct representations of perceived objects based on dimensions like time and space are necessary for action. Planning based on direct representations typically uses reasoning structures like multiresolutional hierarchies of state spaces (Meystel, 1995; 1998a; Meystel and Mironov, 1998). But a hierarchy of direct representations in the form of a multiresolutional hierarchy of state spaces is not sufficient for a multi-actor system. Language representations based on signals and symbols are necessary for communication. More abstract, conceptual, representations are required to be able to handle concepts in the field of cooperation and coordination like for instance responsibility, initiative, and commitment. Together, these three types of representation form a world model. World model building is based on the active exploration by the actor of its environment, its semiotic Umwelt (Von Uexküll and Kriszat, 1936/1970) (Paragraph 3).

2. Patterns of interaction between multiple actors

2.1. Multi-actor theory

2.1.1. Characteristics of multi-actor theory

Multi-actor theory aims at gaining insight in the cooperation of autonomous entities (individuals, organizations or networks of organizations) and the resulting forms of organization of this cooperation. Multi-actor theory focuses on issues of communication, knowledge, cooperation and coordination. The theory studies the phenomena that emerge from the interactions between actors based on their knowledge, resources and interests. Multi-actor theory explains that work in organizations is based on intelligence, communication, cooperation, and massive parallel processing. It tries to be compatible with semiotics, psychology, and the philosophical positions of methodological individualism and Peircean realism (Hausman, 1993). It is interesting because it can serve as an innovative theory of organizations explaining characteristics of human organizations, information systems, and virtual organizations. Basic concepts in multi-actor
theory are actor, world model, semiotic Umwelt, multi-actor system, organization, communication, cooperation, negotiation, and surplus allocation.

2.1.2. Actor

An actor is an *autonomous* and *intelligent* being that is able to perceive and act. *Autonomous* implies: being independent of guidance through an external source. *Intelligent* implies: being able to interpret, determine goals, reason and decide. Human beings, robots, more or less autonomous and intelligent entities realized by software on a computer, and organizations can be seen as actors. The more or less autonomous and intelligent entities realized by software on a computer are called computer agents or virtual actors. They are part of information systems. All actor categories are functionally equivalent according to Newell and Simon’s (1972; Newell, 1990) physical symbol system hypothesis.

Autonomy can be defined in several complementary ways (Meystel, 1998b). Autonomy is:
1. being independent of guidance through an external source because you have:
2. the ability to develop your own world model by interaction with your environment and by reorganization of your world model;
3. the ability to develop your own goals and norms;
4. the ability to control a considerable part of your environment based on your world model and your goals and norms;

2.1.3. Organizations, virtual organizations, and information systems as multi-actor systems

The concept of organization is a complex concept because it can be defined in three ways, each of which refers to observable reality in a specific way (Jorna, Gazendam, Heesen, and Van Wezel, 1996). An organization can be defined as:
1. a collection of actors (people or machines) and the events they produce in a stable pattern of interactions or cooperative relations (work organization);
2. an institution, that is a construct of the human mind expressed in symbol structures (legal and financial documents, norms) that reflect an agreement between actors about behavior patterns (defined, for instance, in terms of work procedures, norms and contracts) to apply in a work organization (formal organization);
3. an idea, that is a construct of the human mind that, as metaphor or image, guides cooperative behavior of actors (artifact organization).

The distinction between work organization and formal organization has been proposed by Schmidt (1991). According to Schmidt, formal organization is a -not always congruent- layer on top of the work organization safeguarding the interests of the owner and regulatory bodies (Schmidt, 1991: 103). In this context, formal organization is not to be seen as opposed to informal organization, but as a layer adding symbol structures to patterns of cooperation.

Based on this layered concept of organization, we can define a multi actor system in relation to three types of organizational patterns. A multi-actor system is a *collection of actors* that is distinguished based on an *organizational pattern* of:
- communication, cooperation and coordination between actors (work pattern) AND/ OR
- formal relations (contracts, rights, property) (formal pattern) AND/ OR
- images, symbols, or conceptual objects that are the basis of cooperation (artifact pattern).
Based on this definition of a multi-actor system in terms of organizational patterns, we can define subtypes of organization based on the organizational patterns that are available. An organization is a collection of actors distinguished based on organizational patterns. A work organization is a collection of actors distinguished based on a work pattern. A formal organization is a collection of actors distinguished based on a formal pattern. An artifact organization is a collection of actors distinguished based on an artifact pattern.

Based on the types of actors we have distinguished, we can define subtypes of organization based on another criterion. Multi-actor systems can consist of human beings, computer agents (virtual actors), or both. An organization consisting of human beings only is a normal organization. An organization consisting of virtual actors only is an information system. An organization consisting of human beings and virtual actors is a virtual organization.

Because organizations can also be seen as actors, the multi-actor system concept is recursive. An organization can be seen as a multi-actor system, and (at a lower level of resolution) as a single actor.

Processes of organizing, planning, and negotiation all contribute to the organizational patterns. As negotiated, conceptual entities, organizational patterns are different from natural entities like persons or robots.

We see that with this perspective, human organizations, virtual organizations, and information systems can be understood by a common theory. This theory will be an innovative form of organization theory. It can be seen as a further development of general systems theory, but also as a successor of general systems theory focusing on other key concepts.

2.1.4. Multi-actor theory and general systems theory

Multi-actor theory differs from systems theory in its emphasis on dialogue, autonomy, independence, negotiation and cooperation rather than command, control, stability, planning and work processes. Table 1 offers a comparison of general systems theory and multi-actor theory.

<table>
<thead>
<tr>
<th>General systems theory</th>
<th>Multi-actor theory</th>
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<tbody>
<tr>
<td>command</td>
<td>dialogue</td>
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<tr>
<td>control</td>
<td>autonomy</td>
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<tr>
<td>stability</td>
<td>independence</td>
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<tr>
<td>planning</td>
<td>negotiation</td>
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<td>work processes</td>
<td>cooperation</td>
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<td>control measures</td>
<td>knowledge, skills, and culture</td>
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<td>motivation</td>
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<td>efficiency</td>
<td>interest / cooperation benefit</td>
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<td>effectiveness</td>
<td>interest / cooperation effect</td>
</tr>
<tr>
<td>flexibility</td>
<td>variety of agents, regimes and opinions</td>
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<tr>
<td>learning by adjustment</td>
<td>learning by evolution / selection</td>
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<tr>
<td>legitimization of governance and management</td>
<td>legitimization of actor autonomy</td>
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Table 1: Comparison of systems theory and multi-actor theory (Gazendam and Homburg, 1996)

General systems theory often leads to arguments in which central planning and control is seen as good; in fact there cannot be enough centralized planning and control. Multi-actor theory, on the
other hand questions central planning and control, for instance by estimating the costs and benefits of control (Jorna, Gazendam, Heesen, and van Wezel, 1996).

2.1.5. Multi-actor theory and levels of resolution
Multi-actor theories cover a multitude of levels of resolution, varying from cooperating computer agents, via simulation models of multi-actor organizations, to networks of organizations. At various levels, various issues are relevant. At the actor level, individuals cooperate and try to coordinate activities. Multi-actor theory focuses on perception of the environment (space, objects, itself, other actors), communication in the form of signaling and symbol use and actions (initiatives) by actors. At this level, actors reason about ontology (including space, objects, and actors) and try to synchronize their actions by communication processes. At the organization or network level, various groups of individuals (organizations) cooperate and try to coordinate activities. Here, the theory is concerned with cooperative relations within structures based on cooperation benefits and cooperation costs.

At the organization or network level, multi-actor theory deals with the same phenomena economic approaches toward networked organizations deal with. It differs, however, from economic theory by:
- integrating economic rationality and political rationality (Homburg, 1999; Gazendam and Homburg, 1999);
- including request handling time, coordination and decision making;
- a degree of psychological plausibility at the individual multi-actor level;
- a degree of organizational plausibility (hierarchical structures, coordination and legitimacy) at the organizational level.

2.1.6. Multi-actor simulation models
Multi-actor simulation models have been very important in developing the theoretical apparatus of multi-actor theory. Multi-actor simulation models started with systems of few complex actors with poor communication abilities (e.g., multi-actor SOAR). Nowadays, we see more systems of many simple actors with standardized interaction and communication abilities (Holland, 1995) 

There is a trade off between
(1) actor complexity;
(2) communication capabilities; and
(3) number of actors (leading to emerging interaction patterns).

2.2. Semiotics of multi-actor systems

2.2.1. World model and semiotic Umwelt
Actors know processes of interpretation, learning, and communication. These processes are connected to the development and use of a world model. Interactions of the actor with the environment that lead to a world model are not only receptive (forming impressions), but also active (testing, forming of signs and artifacts). Actors wander around in an environment (world) that contains artifacts and signs. They live in a semiotic Umwelt (Von Uexküll and Kriszat, 1936)

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2 Active research groups can be found at:
- the MIT software agents group: agents.www.media.mit.edu/groups/agents
- the Santa Fé Institute (SWARM, ALIFE): www.santafe.edu
- www.cs.wpi.edu/Research/airg/Agents-hotlist.html
This is an environment around a human being or animal based on the signs and symbols that it creates and perceives. The types of signs and symbols that can be created and perceived depend on the biological species. The basic structure of the semiotic Umwelt, its space and time, depends on the sign processing capabilities of the living being. Time is dependent on its biological rhythms. Space is structured in a way that the signs an organism can perceive are localized in a meaningful way.


The sign perception capabilities of a living being are connected with its action capabilities in a semiotic function cycle. The structure of its action capabilities is very important for concept formation and the organization of its world model. For instance, a being that can only go forward, backward, left, and right will develop a world model based on two spatial dimensions (“horizontal” and “vertical”) (Van den Broek and Gazendam, 1997).

The actor’s development of a world model is connected with its development and exploration of its semiotic Umwelt. What would a scientist be without his Umwelt of books, pencil and paper (and computer). The development of a world model is an interactive learning process in which the internal world model and the external semiotic Umwelt are strongly connected. During this interactive learning process, world model and semiotic Umwelt reorganize themselves. This interpretation of learning contrasts with more traditional opinions in symbolic artificial intelligence, in which learning is some kind of stacking of knowledge units (rules, productions). Interactive learning, other than memorizing and rote learning (speeding up based on experience) presupposes (Van den Broek and Gazendam, 1997):

- no unlimited mental powers;
- there must be a need for optimizing and reorganizing knowledge;
- sufficient memory;
- capabilities for abstraction, deduction, induction, abduction
- variation in experience.

Social norms develop based on interconnected semiotic Umwelts, in which common structuring mechanisms for time and space develop. For instance, meeting places in the environment are only recognizable based on conventions or norms consisting of signs that structure time and place. Webs of interaction are formed by the trajectories in time and space of the daily, weekly, monthly, and overall life paths of individuals in interaction with each other (Hägerstrand, 1975; Giddens, 1984: 112).

“Interactions of individuals moving in time-space compose bundles . . . meeting at stations or definite space-time locations within bounded regions (e.g., homes, streets, cities).” (Giddens, 1984: 112)

This zoning of time-space in relation to routinized social practices is called regionalization by Giddens (1984: 199).
2.2.2. Interaction
In a multi-actor system, there are three aspects of interaction: the aspect of communication (including interpretation and semiotic Umwelt creation), the aspect of cooperation and coordination, and the aspect of problem solving and learning. These aspects are not independent of each other, but focus on their own way of understanding of what happens in the interaction between actors. They correspond to different disciplines and theories: semiotics, organization theory and economics, and cognitive psychology, respectively. Recurrent interaction patterns can be seen as a form of negotiated order. They also can be seen as habits (like Hägerstrand’s (1975) and Giddens’ (1984) paths in space and time), based on social norms (Stamper, 1973), or interacting semiotic Umwelts (Von Uexküll and Kriszat, 1936/1970).

2.2.3. Communication
Communication between actors can be studied from three points of view: syntactical, semantic, and pragmatic. From the syntactical point of view, the structure of the language used is studied in terms of syntax and lexicon. Specialized actor languages have been developed in multi-actor simulation models. From the semantic point of view, ontology is studied. From the pragmatic point of view, recurrent patterns of language interaction are studied, for instance as genres or work practices (Clarke, 1999), iterators (Bøgh Andersen, Nielsen, and Land, 1999), or standard protocols of interaction (Dietz, 1992; 1996).

In multi-actor systems consisting of information systems, it turns out that communication and cooperation requires rules and norms in three fields: the structure of language (syntax), a common ontology (semantics), and the handling and routing of events, queries and messages (pragmatics) (Gazendam, 1997).

The encoding and decoding of representations takes place according to rules and norms following levels of semiotic granularity (Peirce, 1904/1958: 392; Gazendam, 1993):
0: elementary symbol, where rules and norms can be found in the code table;
I: term, word (rheme), where rules and norms can be found in the lexicon;
II: proposition, sentence (dicent sign), where rules and norms can be found in the grammar of messages;
III: inference, story (argument), where rules and norms can be found in logic or the grammar of genres.

The creation and interpretation of representations is done in terms of a (partially common) world model structured according to Peirce’s (1904/1958: 391) formal categories:
I: definition and classification of predicates (quality);
II: identification of objects (individuality);
III: common knowledge in the form of habits norms, or rules.

2.2.4. Cooperation
Schmidt (1991) distinguishes three motives for cooperation:
- augmentative cooperation;
- integrative cooperation;
- debative cooperation.
Gazendam and Homburg (1996) add:
- conflict handling.
Augmentative cooperation is based on the fact that single actors are limited by mechanical and physiological capabilities and cooperation can be useful to overcome these limitations. Integrative cooperation brings in the specialized knowledge of the participants necessary for performing a common task. Debative cooperation brings in a variety of values and interests and aims at acceptable conclusions. Knowledge-based work processes are fragile and contestable. The function of debative cooperation is to alleviate this deficiency. Debative cooperation can be found in scientific communities and, for example, in the organization of governments in clearly independent executive, legislative and judiciary bodies. Actors can also cooperate in order to handle conflicts efficiently and non-destructive by using authority, negotiation, and regulated competition and dialogue between discussants.

Cooperation also encompasses nonverbal interaction patterns. These can be studied using the observation of recurrent paths in time and space (Hägerstrand, 1975; Giddens, 1984), or as nonverbal work practices (Clarke, 1999).

2.2.5. Coordination
The classical managerial function corresponds to a management process that consists of five subactivities: to plan, to organize, to coordinate, to command, and to control. These subactivities are defined as follows (Fayol, 1916/1984: 13):

1) To plan: ... lay out the actions to be taken.
2) To organize: lay out the lines of authority and responsibility, build up the dual structure, material and human, of the organization.
3) To coordinate: lay out the timing and sequencing of activities ...
4) To command: put the plan into action; set the work in operation.
5) To control: monitor and correct; see that everything occurs in conformity with established rules and expressed command."

Based on this analysis of the management process, we can conclude that the organizational structure (formal organizational pattern) is created by acts of planning, organization, and coordination, while work (structured in organizational work patterns) is done based on commands and obedience to commands. Obedience to commands and adherence to rules is stimulated by control activities.

If we redefine organization as the lay out of organization structure and process structure, redefine planning as a combination of allocation and synchronization, replace command by negotiation and improvisation, we get an updated list of coordination mechanisms:

3"Administrer, c'est prévoir, organiser, commander, coordonner, et contrôler; Prévoir, c'est-à-dire scruter l'avenir et dresser le programme d'action; Organiser, c'est-à-dire constituer le double organisme, matériel et social, de l'entreprise; Commander, c'est-à-dire faire fonctionner le personnel; Coordonner, c'est-à-dire relier, unir, harmoniser tous les actes et tous les efforts; Contrôler, c'est-à-dire veiller à ce que tout se passe conformément aux règles établies et aux ordres donnés." (Fayol, 1916/1956: 5)

Note how in the English translation of Irwin Gray the role of the coordinating activity has shifted from an information processing and adjusting activity, logically following the command activity, to a scheduling activity that logically precedes the commanding activity.

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to organize: lay out the lines of authority and responsibility, lay out the organization structure in terms of places for actors, lay out the process structure in terms of programs, establish standards;

to allocate: take on means and allocate means (including actors) to the organization structure and the process structure,

to synchronize: lay out the timing of the activities in terms of a coherent system of triggers;

to negotiate: actors discuss about the activities to be performed and decide about an acceptable way to perform them;

to improvise: choose the relevant activity dependent upon the situation and set the work in operation;

(to execute: carry out the activities, that is, to cooperate;)

to control, monitor and correct: see that everything occurs in conformity with established rules and expressed command; feedback to earlier phases.

Planning encompasses allocation and synchronization. A mix of the coordination mechanisms has to be used, in which each mechanism can have a prominent role, a less prominent role, or even no role at all. For instance, negotiation and improvisation based on behavior rules and a market mechanism with brokers can be an alternative for planning\(^4\). Coordination can also be mainly based on organizing\(^5\). In using a mix of the coordination mechanisms, a balance has to be struck between autonomous action and concerted action in order to gain an optimal performance in terms of risk control, flexibility, and learning of the multi-actor system.

2.2.6. Negotiation

Cooperation will only take place if two conditions are met (Gazendam and Homburg, 1999). These conditions are a subject of negotiation between actors. Firstly, the cooperation must give results that

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\(^4\) An example of coordination using a market mechanism and behavior rules is the following one. For the operation of a sugar factory during the beet campaign in autumn, sugar beetroots have to be collected at the farmers. For this transport, transport companies register, often so-called free riders, one-man businesses made up of a driver and a truck. The procedure is as follows. At four o’clock in the morning, the drivers report at the factory. There, they line up at the work distributor’s office. This work distributor has prepared a stack of notes with the addresses of the farmers where the beetroots have to be collected. The driver that is in front of the line takes the topmost note of the stack. If he does not like the address of the farmer, he puts the note back and queues up at the end of the line. The work distributor takes care that a driver does not refuse an address too often, because he thinks that every driver should do some unpopular addresses during the campaign. When the driver is ready with his route, he goes again to the work distributor’s office, except when he thinks that he has done enough for that day. The drivers get paid per route. In such a situation, the planning and scheduling of routes is not necessary. The necessary coordination is done by the market mechanism and the behavior rules. In his preparation, however, the work distributor does some planning by deciding about the order in which farmers will be visited.

\(^5\) The following situation is an example of coordination by organizational task allocation. There are seven bridges along a canal. In the past, there used to be a house next to each bridge where the bridgeman lived. When a vessel approached during daytime, the bridgeman opened and closed the bridge on the spot. At nighttime, the bridges were not operated. When the bridgeman took a holiday, he had to find a replacement himself. In the case that a bridgeman was called away suddenly, he provided for a colleague that took over temporarily. In such a situation there is no need for a common year plan or schedule. Each bridgeman made his individual plans for holidays and similar occasions. Nowadays, we have six bridgemen that work 36 hours a week and have four holiday weeks a year, instead of the seven bridgemen that were available permanently. In the holiday periods one works with extra temporary personnel. There are three shifts (early shift, late shift and night shift). In every shift, one bridgeman operates all seven bridges using modern equipment, and one other bridgeman is standby. This situation needs a year plan and a weekly schedule. This because of less personnel capacity, more service hours, and the combination of seven autonomous organization units into one larger one.
are not possible when working alone. In other words, the cooperation must create a surplus compared to working alone. Secondly, the distribution of that surplus must give each participant benefits compared to the situation of non-cooperating. In situations where there are no alternatives for the actor with respect to participating in the organization, political motives, that is, influencing the pattern of distribution of the surplus, become dominant. From a political point of view, actors will strive after obtaining sufficient political resources in order to realize a political program, and such at a minimum of political risk (Puviani, 1903/1960; Pierson, 1994).

In negotiation, values and norms have to be satisfied, e.g., Kant’s categorical imperative and Asimov’s laws (Gazendam, 1997). Kant’s categorical imperative reads in normal English: “Do unto others as you would they should do unto you”. Asimov’s laws (1953) hold for robots and virtual actors⁶:

“First Law: A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
Second Law: A robot must obey orders given it by human beings, except where such orders would conflict with the First Law.
Third Law: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.”

2.2.7. Virtual organization architecture

Architecture is a metaphor that is often applied to socially constructed entities. Architecture can be applied to organizations, information systems, and virtual organizations. Architecture is the way a system is composed of subsystems. Each of these subsystems has a specific functionality or responsibility (a design), and the rules governing the cooperation of these subsystems (a norm system). Architecture normally is specified at several levels of functionality or granularity, in a consistent way. Architecture levels can be distinguished based on Stamper’s (1973) semiotic ladder:
- social;
- pragmatic;
- semantic;
- syntactic;
- empiric;
- physical.

Virtual organization architecture has to do with the top three levels (social, pragmatic and semantic). Component architecture has to do with the syntactic and empiric levels. Technical infrastructure has to do with the physical level. At each level there will be a design and a norm system.

In the description or the design of a virtual organization at the social level, it is important to design organization units based on capabilities and responsibilities. Human actors and virtual actors have different capabilities and responsibilities. For the determination, or the imagination, of adequate capabilities of virtual actors (information systems) information system metaphors can be very useful.

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⁶ See for an interesting overview and comments: http://online.anu.edu.au/people/Roger.Clarke/SOS/Asimov.html
The design of the organization at the social level encompasses the subjects of cooperation, including surplus allocation, and coordination. The norms at the social level have to do with authority. Authority is based on the capabilities and responsibilities in the design. Authority may be fine-tuned by using ideas like the balance of power (e.g., trias politica), and systems of checks and balances.

Combined, the mechanisms of cooperation, coordination, and surplus allocation, and the norms in the field of authority lead to patterns of organization. According to Fayol, the stability of these patterns of organization depends on the balance between (Fayol, 1916/1956; Gazendam, 1998; Gazendam and Simons, 1999a):

- legitimate authority and mechanisms of enforcing responsibility (a political dimension);
- individual interest and general interest (an economic as well as political dimension);
- initiative and central planning and control (an organizational dimension);
- exploration/learning and exploitation (an organizational dimension).

3. Self-organization of multiple active representations

3.1 Semiotics as the basis for understanding representations

The use of symbol structures by (semi) intelligent beings has to be seen as the use of a world model consisting of a collection of multiple, active, representations. World model building is based on the active exploration by the actor of its environment, its semiotic Umwelt (Von Uexküll and Kriszat, 1936/1970). The active representations that form the world model perform processes of self-organization that lead, by their interconnections, to the creation of new knowledge in a way that we have been describing thus far as deduction, induction, abduction and abstraction. Information systems that have to cooperate with human beings must have a structure that can connect to these reorganization processes of active representations. The inner side of the capabilities of an information system or virtual actor, that is, its world model, has to be defined based on these multiple active representations.

Semiotics studies communication with signs, symbols, and texts in a central role. Semiotics studies representation, interpretation and virtuality as aspects of the process of semiosis. Semiosis is the process of interpretation and development of signs (thoughts). A sign represents an object in a certain respect (ground), and determines a resulting idea (interpretant). The sign of semiotics is part of a representation, or a representation itself. The sign concept in semiotics is, because of its definition in the context of semiosis, a dynamic concept. Therefore, semiotics gives us useful concepts and theories to study multiple active representations.

For classifying signs and processes of semiosis, Peirce (1904/1958: 390) has developed his categories of Firstness, Secondness, and Thirdness. Peirce distinguishes these categories in several ways:

a. material categories (1st system);
b. roles of a sign in semiosis leading to subtypes of sign;
c. formal categories (4th system);
d. representation types;
e. determinant types (levels of semiotic granularity).

Some scholars studying Peirce would probably say that these categorizations are all manifestations of an underlying essential categorization, the cenopythagorean categories (Peirce,
I do not agree with that, and see these categorizations as distinct categorizations based on criteria that differ from each other. The categorizations, however, are logically connected. The categorization b gives the criteria for the categorization c, d and e. These categorizations have been used by Peirce (1904/1958: 390) in combination with each other. Furthermore, a development in the thoughts of Peirce is visible in his categorizations. He starts with an ontological or material categorization, close to his roots in Hegelian thought, and ends with a system of logical, formal categorizations.

Material Categories (1st system) (Murphey, 1967: 71):
I: matter;
II: mind/ representation;
III: abstraction/ idea.

Furthermore, Peirce (1904/1958: 390) distinguishes several roles of a sign in semiosis:

“Now signs may be divided as to their own material nature, as to their relations to their objects, and as to their relations to their interpretants.”

This leads to several classifications of subtypes of sign:
I: as sign, as formal composition, leading to formal categories;
II: as representation of an object, leading to representation types;
III: as determinant of an interpretant, leading to determinant types.

I: quality (reference to respects by which an object is interpreted) (qualisign);
II: information or individuality (individuality or haecceity (Murphey, 1967: 74)) of object or event/ causal relation/ external constraint) (sinsign);
III: knowledge or generality (idea based on interpretation of information in the form of general habit, rule or law) (legisign).

Representation types (Peirce, 1904/1958: 391):
I: iconic;
II: indexical;
III: symbolic.

Determinant types (Peirce, 1904/1958: 392) or levels of semiotic granularity (Gazendam, 1993: 64):
I: rheme (term, word);
II: dicent sign (proposition, sentence);
III: argument (inference, story).

Sebeok (1994) distinguishes three modeling systems that can be seen as refinements of the representation types:
- primary Modeling System (PMS): Simulative forms of semiosis that use iconic and indexical representations;
- secondary Modeling System (SMS): Verbal forms of semiosis that use linguistic symbolic representations;
tertiary Modeling System (TMS): Abstract forms of semiosis that use conceptual symbolic representations.

Some of these categorizations have already been used in the explanation of the patterns of communication in multi-actor systems (the categorizations c and e). Furthermore, these categorizations are useful in the study of representations, especially when considering the viewpoint of multiple active representations.

3.2. Representation types and methods of organizing

3.2.1. Representation types

The (internal) representations that an actor uses can be arranged in three layers corresponding to Sebeok’s primary, secondary, and tertiary modeling system. Each layer corresponds to a specific representation type:
- direct representations in the primary modeling system;
- language representations in the secondary modeling system;
- conceptual representations in the tertiary modeling system.

Direct representations are more or less direct mappings of perceived objects and situations in time and space. Direct representations correspond to Peirce’s iconic and indexical representations. Language representations are based on symbols and the information transfer oriented organization of language. Conceptual representations are based on abstract concepts. Language representations and conceptual representations correspond to Peirce’s symbolic representations. These representation types differ in their rate of change (time scale). Each representation type has its own method of self-organization.

The direct representations, language representations, and conceptual representations are connected. In the mapping from the direct representation to the language representation, there is an information loss and a gain of structure.

Peirce (Hausman 1993: 96) says:
“...the function of conceptions is to reduce the manifold of sensuous impressions to unity.”

This structure is based on reusable, standardized elements, tokens based on types, signs based on sign types, and conventions for composing these elements. For instance, in the mapping from the music you hear (a direct representation) to a language representation you need to decompose the music into (1) standard waveforms for the various instruments, (2) a musical score which is a text based on a musical notation, and (3) some information about dynamics (volume and speed). In this decomposition, there will be information loss. Furthermore, if you consider the musical score only, without the additional information about instrument waveforms and dynamics, there is an extra information loss. However, the musical score in its more abstract text form is more easily discussed, modified, and analyzed than the original direct representation. It needs less information to transmit from a sender to a receiver. Maybe it is less easily understood because of the need to know the conventions of the language used and to have a degree of versatility in using its language expressions. Language expressions are in fact a special type of direct representations. They have to be direct representations because they must be perceivable. A copier can reproduce
a printed text, which is a language representation, based on its direct representation characteristics, without knowing anything about language.

Conceptual representations are, in the same way, a specialized type of language representations making clear the network-like conceptual structure behind language use. For depicting conceptual structures, graphs are often used. But also other language types can be used like hypertext, programming languages, and logic. The structure of language expressions is a linear narrative; the structure of conceptual expressions is graph like or hypertext like. In the mapping from language expressions to conceptual expressions there is information loss. For instance, the translation into a logic with compositional semantics that has no special provisions for handling situations, processes, or worlds, all information that is not based on that compositionality, information that is bound to a specific situation, process, or world, will be lost. Also, the special color of language use stemming from choice of words, choice of narrative structure, and so on, will be lost. This information loss goes hand in hand with a gain in structure that makes stringent logical deductions possible.

Processes of knowledge creation like induction and abduction require cooperation between the three representation types. For instance, in abduction, you have a surprising fact (a direct representation), about which there is a discussion (in a language representation), while you try to use and combine knowledge (a conceptual representation) with creative jumps (often based on a direct representation or randomized language representation) to find a hypothesis. You can also connect the use of the elements and structures of language representations and conceptual representations with a ‘feeling’ for using these elements and structures. You can see this ‘feeling’ as a wave function (Bøgh Andersen, 1999), which is of course a direct representation. The processes of self-organization of this ‘feeling’ wave function can create creative jumps and new language use.

In the development of a world model there is an evolution. Direct representations are necessary for action. Language representations are necessary for communication. Conceptual representations are necessary for handling organization and planning concepts like responsibility, initiative, and commitment.

3.2.2. Resolution
Resolution organizes spatial-temporal representations. Resolution is the mechanism of distinction of features of a perceived object, based on the granularity of the spatial-temporal grid used and of the feature grid used. By using multiple layers of granularity of the grids used, a hierarchy of direct representations can be obtained (Simon, 1962; Meystel, 1995; 1998b; Meystel and Mironov, 1998).

General systems theory people often use the state space representation, which is a kind of direct representation, as their basic view on a system. The problem, however, is that language representations lead to a state space where the dimensions are changing after each time step. There is a combinatorial explosion not within the state space, but on the dimensions of the state space. This has as a consequence that there is no easy translation between state space representations and dynamic language representations. Because intelligent systems use language representations and conceptual representations, this means that the direct representation—and the
connected type of theorizing in general systems theory— is not sufficient for the description of intelligent systems.

3.2.3. Narration
Narration organizes language representations according to Levels of Semiotic Granularity (Peirce’s determinant types). Narration is necessary for knowledge transfer. Narration presupposes a system of conventions ordered according to Levels of Semiotic Granularity, the use of common object identification and naming, and the use of common predicates, classifications, and thesauri based on categories. Using language representations presupposes the existence of a (at least partially) common world model (a set of conceptual representations) for reaching common understanding of language expressions.

The following levels of semiotic granularity can be distinguished (Gazendam, 1993: 64):
- symbol (smallest unit of information transfer) with norms in a code table;
- word (smallest unit corresponding to a signified entity, e.g., an object) with norms in a lexicon;
- sentence (smallest unit representing a situation or state) with norms in a grammar;
- story (larger units referring to e.g. chains of situations or processes) with norms in a narrative grammar of genres or in logic.

3.2.4. Abstraction
Abstraction organizes conceptual representations. Abstraction is a fundamental organizing principle in information systems. Abstraction leads to modularization of knowledge (knowledge packages). According to Peirce, abstraction is separation of elements, sorting out elements and aspects (Hausman, 1993: 101). Abstraction uses categories, type hierarchies, part-whole assemblies, and semiotic operators.

The abstraction operation organizes representations according to three levels of abstraction (Gazendam, 1993: 93):
- situation/object;
- type/predicate;
- category.

There are two basic types of abstraction: concept abstraction and individual abstraction. In concept/concept abstraction, a concept (object, predicate, situation, type, category) is seen as derived from several more primitive concepts. This corresponds to Peirce’s idea of precision (Hausman, 1993: 101). In concept/individual abstraction, a concept (type, function, method) is distinguished from individuals. Plato already distinguished ideas or forms (concepts) from souls or beings (individuals). This can be done by type abstraction, function abstraction, and method abstraction (Gazendam and Simons, 1999b).

Examples of concept/concept abstraction are structure abstraction, predicate abstraction, collection abstraction, commitment abstraction, and modal abstraction. In structure abstraction, a structure (whole) is distinguished from its constituent parts, and a process is seen as composed of subsequent situations. In predicate abstraction, a complex predicate is seen as a combination of more basic predicates, and types are seen as derived from more basic types. In collection abstraction, a collection is distinguished from individuals, and a type from a collection. In
commitment abstraction, a commitment about a situation is seen as a combination of a commitment type and a situation. In modal abstraction, a proposition is seen as a combination of a more basic proposition and a modal operator that says something about that basic proposition.

Concept/individual abstraction can take the form of type abstraction, function abstraction, or method abstraction. Type abstraction takes a set of propositions and abstracts from it an object or a situation. This leads to a type. Devlin has described this operation as restriction. It requires the distinction between object or situation and (composite) predicate. Function abstraction is well known in lambda calculus. It takes a method, and abstracts the objects from it, giving a function. It requires the distinction of operator from operand. Method abstraction or pattern abstraction takes a process that occurs or has occurred in time, and abstracts time from it, giving a method or pattern. A method is some way of doing, while a pattern is a more specialized method that encompasses some kind of solution to a problem.

The reciprocal of concept abstraction is the combination using combination operators. Common combination operators are structure-forming operators, collection-forming operators, commitment-forming operators, and modal operators. Structure-forming operators combine parts into a whole, situations and a sequential structure in a process. Predicate-forming operators construct a predicate based on more basic predicates, and a subtype based on supertypes. Collection-forming operators combine individuals into a collection, and types into a subtype. Commitment-forming operators combine a situation and a commitment type into a commitment with respect to that situation. Modal operators combine a proposition and a modal operator into a statement about that proposition.

The reciprocal of individual abstraction is the application of a concept to individuals. There are three types of application: type application, function application, and method application. In type application, it is stated that an object is of a certain type, giving a proposition. In function application, a function is applied to objects, giving a method. In method application, a method is applied to a set of situations, giving a process.

The various abstraction operators, the combination operators, and the application operators can be seen as semiotic operators.

4. Discussion
The negotiated order in multi-actor systems can be seen as an alternative for centralized planning. Although multi-actor systems will have to solve problems like centrally controlled systems do, multi-actor systems are different in their attention for the interconnected world models of actors and the patterns of interaction between actors in the form of communication, cooperation, negotiation, and coordination. Semiotics, language action theory, and organization theory contribute to the development of a coherent theory for these new points of attention. In this paper, only a sketch of such a theory has been given. Further elaboration is necessary. Such a theory could also be used for the evaluation of the many multi-actor simulation models and hybrid agent architectures that exist nowadays.

Literature
Bøgh Andersen, Peter. Personal communication. 1999.


