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Working Paper No. 40

**Organisational Intelligence and
Distributed AI**

Stefan Kirm

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Abstract

The analysis of this chapter starts from organisational theory, and from this it draws conclusions for the design, and possible organisational applications, of Distributed AI systems. We first review how the concept of organisations has emerged from non-organised "black-box" entities to so-called "computerised" organisations. Within this context, organisational researchers have started to redesign their models of intelligent organisations with respect to the availability of advanced computing technology. The recently emerged concept of Organisational Intelligence integrates these efforts in that it suggests five components of intelligent organisational skills (communication, memory, learning, cognition, problem solving). The approach integrates human and computer-based information processing and problem solving capabilities.

As organisations are inherently distributed this contribution discusses further how Distributed AI interacts with the different components of Organisational Intelligence. This involves posing three questions: What are the contributions of Organisational Intelligence to Distributed AI? How can Distributed AI benefit Organisational Intelligence? Why is Organisational Intelligence an important Distributed AI application?

1 Introduction

Today, organisations are faced with rapidly changing markets, global competition, decreasing cycles of technological innovations, world wide (and just in time) availability of information, and dramatic changes in their cultural, social, and political environments.

Most organisational strategies that have been developed to meet these challenges aim to enhance the flexibility (short term) and adaptability (long term) of enterprises. Current "buzz-words" such as downsizing of organisational structures, increased local autonomy, decentralisation, cooperation and team work, business process orientation and workflow management point to the different concepts that are available today (e.g., see (Guilfoyle & Warner 1994, Davenport 1993, Morton 1991, Nirenberg 1993). Also, most organisational experts agree that the ability of an enterprise to achieve competitive advantages in the market and to continuously survive in dynamic, and even in hostile environments largely depends upon its information technology infrastructure, which is required to efficiently support the organisational information processing and problem solving capabilities (Blanning et al 1992, Ishida 1992, Marsden & Pingry 1988).

Consequently, an increasing number of organisational researchers draw their attention to the design of "intellectual" organisational capabilities such as organisational communication, memory (e.g. Favela & Connor 1994, Morrison & Olfman 1994, Paradise 1988), learning (e.g. Elofson & Konsynski 1993, Niwa 1992, Sunita 1992, Watanabe 1992) cognition, and reasoning (Matsuda 1988a). At the same time they re-shape the scope of their analysis by claiming to explicitly integrate computer-based information processing technology into the body of organisational theory (e.g. Blanning et al 1992, Favela & Connor 1994, Huber & McDaniel 1986, Marsden & Pingry 1988, Matsuda 1988a). In essence, the design of computer based information systems has to follow the rules of organisational design, and this requires as an integrated part to (re-)design machine based information systems (e.g. Malone 1988, Petrie Jr 1992, Morton 1991).

Within this context, the analysis of this chapter starts from the challenges modern organisations are faced with, and it develops towards what we call "organisational multiagent systems" which are no longer a more or less passive component of the organisational model. Instead, organisational multiagent systems are supposed to play an active, self-contained role, and to form an organisational body on their own right. This differs from current organisation theory in that organisational multiagent systems are supposed to establish an additional organisational subsystem which originates from both the social subsystem and the information processing (or: technology) subsystem of the organisation (see also ACM Computing Surveys 1994, Guilfoyle & Warner 1994, Carley & Prietula 1994). Based on the cooperation paradigm they provide an

organisational knowledge processing environment that is particularly well suited to support intelligent organisational capabilities (Matsuda 1988a, Warnecke 1993). Organisational multiagent systems are a key technology (Kirn 1995) to support information and knowledge processing activities in cooperative, networked organisations. This, in turn, requires integrating them with the related human organisation. Thus, organisational multiagent systems

1. must be able to adapt themselves to the organisational aims and objectives, strategies and operations, as well as to the organisational structures, procedures, and constraints,
2. they must actively contribute to an organisation's "intellectual" capabilities such as organisational cognition, organisational memory and learning, organisational problem solving, and organisational communication skills.

With respect to the inherent distribution of organisations our basic hypothesis is that there are a lot of interactions between Organisational Intelligence and the field of Distributed AI which urgently need to be investigated. This contribution seeks to initiate such work. To this purpose, and with respect to our interest in Distributed AI we first review how the concept of organisations has emerged from non-organised "black-box" entities to so-called "computerised" organisations (section 2). Next, we introduce the concept of Organisational Intelligence which originates from recent work of organisational researchers in Japan and the United States (section 3). We then ask how Organisational Intelligence can contribute to the design and research of multiagent systems (section 4), and how Distributed AI can support the design of intelligent organisational skills (section 5). Finally, we discuss why Organisational Intelligence is an important application of Distributed AI (section 6).

2 Towards the Information-Integrated, Computerised Organisation

The analysis and description of organisations is one of the major research areas in management science. Organisational designers shape organisational structures so that the resulting organisation can pursue the aims and objectives formally introduced, negotiated and decided upon by the owners of the organisation, its members and participants. Organisational theory has developed a diversity of organisational models, each of them with a particular research interest, focus, and practical relevance. Within this chapter, we are primarily interested in discovering how the design and research issues involved in Distributed AI systems can benefit from recent developments in organisational theory. To this purpose, we have selected five organisational models which demonstrate how the integration of information technology into organisational research has changed over the past 50-70 years. These models are: (1) the black

box model originating from economic theory, (2) the production-oriented model of Gutenberg, (3) the socio-technical approach of organisational theory, (4) the organisational model originating from Management of the 1990's Program conducted by the Sloan School of Business of the Massachusetts Institute of Technology (MIT), and finally (5) the concept of the information-integrated, computerised enterprise.

(1) The *black box-model* is still in use in modern macro economic theory. It largely ignores the internal organisational structures, procedures and dependencies. The basic idea is that the enterprise as such is the entity which decides, acts and behaves on its own, and that there is no relationship between the actions and the internal structure of an organisation. Consequently, there is no need and even no means to study the role of information technology, nor is there any interest in how the information technology of an organisation shall be designed in order to improve internal processes, the behaviour of the enterprise or the integration of the organisation with its environment.

(2) The *production-oriented approach* has been developed as a part of Gutenberg's contribution to production theory (Gutenberg 1951). The basic idea is that the enterprise is just that location where the factors of production (work of various kinds including managerial administration, working capital, and raw materials) are combined and changed into commodities and services. Specifically, organisation is a part of the enterprise or, enterprises *have* an organisation. The important contribution of Gutenberg was to relate the internal organisational structure to the efficiency of production processes. However, this model does not support the description and analysis of the motivations, aims and objectives, skills, and actions of human actors. Further, the model is deficient in that it does not investigate how information technology can contribute to organisational issues.

(3) From the *socio-technical* point of view enterprises themselves *are* organisations. This includes the view that any economic activity presupposes decision making which, in turn, requires extensive information processing capabilities (Ginsberg 1987, Huber & McDaniel 1986) which comprise the preconditions, the input (data, information, knowledge), the context of decision making, the phases of decision making processes, and the implementation of decisions. The structure and the results of decision making processes are dependent upon three different organisational subsystems that together constitute the socio-technical organisational model. They are:

a) The system of organisational aims and objectives integrates the aims and objectives of the persons, groups, and organisational bodies that are involved in or related to the organisation.

- b) The information processing system supports the processing of data, information and knowledge in order to produce decisions that fit with the organisational aims and objectives. The information processing system does not necessarily involve information processing technology.
- c) In general, decision making involves more than one person. Thus, it depends upon the social system of an organisation, i.e. the social relationships, the balance of power, the availability of information, etc.

These subsystems constitute organisations as goal-driven socio-technical systems that acquire and process information. Thus, enterprises are organisations where humans collaborate to produce commodities and services. It is interesting that the socio-technical model provides an "interface" to the technological infrastructure but, up to now, without really integrating information technology with the social system. Within the socio-technical approach multiagent systems are part of the information processing subsystem of the organisation, and as a direct consequence, the goals and intentions of the agents involved are *not* part of the organisational taxonomy of aims and objectives.

(4) However, recent organisational research begins to acknowledge the dramatic advances of information technology over the past 15-20 years. The Management of the 1990's program has revealed that computer technology does not only provide an infrastructure for communication and data management, but it also enables implementation of new organisational strategies, and it even actively stimulates the development of completely new organisational solution. This has already changed the internal structures of many existing enterprises, and has resulted in major modifications of worldwide market relationships (Morton 1991).

(5) Recently, the concept of the information-integrated, computerised organisation has been suggested (Tapscott & Caston 1993). The first area concerns the integration of human and machine-based data and knowledge. It addresses the issue that an increasing portion of organisational knowledge is stored in, maintained by, and accessible through electronic services. The second issue is to reduce the dominance of the human factor because due to ongoing process of computer-based automation. More and more, pure computational entities produce commodities and services, interact with suppliers and customers, or deliver data and expertise to software agents which are "members" of a partnership in strategic alliances, of public authorities, or political partys. Thus, the boundaries between the classical human-centered organisation and the computer systems become blurred and we may expect, that the organisation of the 21st century will, as a new organisational submodel, involve an artificial, purely software-based organisation which is strongly intertwined with the social system of the organisation.

3 Organisational Intelligence (OI)

Today, organisational experts approach the current market, political and environmental challenges by a set of organisational strategies such as downsizing of hierarchical structures, decentralisation of autonomy, business process orientation, networking among more or less mutual independent organisational units, and the implementation of teamwork-like cooperation styles.

These concepts provide the groundwork from which current issues on Organisational Intelligence has evolved. Within this field two major research communities can be identified. The first one has been established around the annual *Hawaii International Conferences on System Sciences* (HICSS), starting from a tutorial on "Intelligent Organisations" presented by G. P. Huber in 1987. The second has its roots in Japan, where T. Matsuda has developed a holistic approach to what he calls "Organisational Intelligence" (OI).

The reader may be aware of the great deal of related work carried out in disciplines such as organisational theory, organisational computing, office information systems, and others. However, while all these disciplines have worked out particular facets such as organisational learning, bounded rationality, or self organisation, they are not providing an overall concept of intelligence for human-centered organisations.

This deficiency has motivated Matsuda to evolve a model of Organisational Intelligence that integrates human, and machine-based knowledge processing and problem solving capabilities (Matsuda 1988a, 1991, 1992). In contrast to others he stresses that machine intelligence is an integral part of the intelligence of an organisation. As Matsuda points out, and in conformity with recent work on *user agents* and *personal assistants* in computer science, cooperative organisational work includes both, human beings and machine based problem solving agents.

In Matsuda view, Organisational Intelligence (OI) may provisionally (so long as it is useful for further discussion) be defined as the intellectual capability of an organisation as a whole. As such, OI includes two different components: Organisational Intelligence as a process and Organisational Intelligence as a product. While *Organisational Process Intelligence* "... provides theoretical analysis of an organisation with a set of subprocesses", *Organisational Product Intelligence* "... supplies the organisation with ... synthetic policy (and design) guidelines for information system design" (Matsuda 1992). It is clear, and Matsuda outlines it in detail, that these two components are mutual dependent.

Organisational Product Intelligence considers how information systems must be designed with respect to the needs of Organisational Intelligence. This requires to develop OI-orientated information system design guidelines. This raises the question *how can Distributed AI systems*

be designed so that they effectively support the intellectual capabilities of organisations (section 4). On the other hand, modeling *Organisational Process Intelligence* means to analyse, design, and to effectively perform organisational knowledge and information processing and problem solving activities. This raises a further question, *how can Distributed AI benefit Organisational Process Intelligence* (section 5).

3.1 Organisational Process Intelligence

Human intelligence as well as machine intelligence (which includes artificial intelligence) represents certain processes (information processing activities) within an organisation. These processes can be characterised by three attributes *interaction*, *aggregation*, and *coordination*. Hence, *Organisational Process Intelligence* has been defined as "the interactive-aggregative-coordinative complex of human intelligence and machine intelligence of the organisation as a whole" (Matsuda 1992).

Interactions within an organisational body involve different types of actors (humans, and machine agents), which serve very different purposes (e.g., transfer of data and knowledge for remote use, coordination of interrelated activities, etc.). Within a computerised organisation interactions involve

1. human intelligence vs. human intelligence,
2. human intelligence vs. machine intelligence,
3. machine intelligence vs. machine intelligence.

The *aggregation* of intelligence "is observed as the process of collection of members proceeds from an individual to the entire organisation via various sizes of groups" (Matsuda 1992). Thus, individual knowledge is iteratively transformed into group level knowledge, and in turn, for instance by negotiation, it is transformed into organisational knowledge.

Mere human or machine intelligence is not enough. Instead, both are to be coordinated towards the respective organisational objectives. *Coordination* provides tools to control interactions as well as the execution of aggregation processes. As such, it involves the human and machine intelligence of an organisation, and it aims to speed up organisational processes as much as possible.

Matsuda divides Organisational Process Intelligence into five components: (1) Organisational Cognition, (2) Organisational Memory, (3) Organisational Learning, (4) Organisational Communication, and (5) Organisational Reasoning. These five sub-processes can provide a set of powerful tools to analyse and improve organisational decision making processes (Matsuda 1992).

3.2 Organisational Product Intelligence

Organisational Product Intelligence requires the development of design guidelines in order to support the building of organisational information systems. It is one of the most important shortcomings of the work of Matsuda that it does not provide any suggestions to develop these guidelines. This is also the case if we turn our attention to Distributed AI. We see that there are no design guidelines that help us to develop multiagent systems with a particular, pre-defined profile of "organisational" characteristics.

4 How Organisational Intelligence can benefit Distributed AI

Current Distributed AI is dominated by an "individualistic" approach which mainly focuses on the single member of an agent organisation and its local activities. As an immediate consequence Distributed AI is in a position to further develop a sound understanding of what "organisational" intelligence of a multiagent system should be, and what the relevant components are that contribute to the intellectual skills of the system as a whole. Thus, we adopt the approach of Organisational Intelligence as a starting point to extend our research into the design of intelligent group level skills of Distributed AI systems.

To this purpose, each subsection below (1) first introduces the current state of the art in organisational theory, and (2) secondly introduces related work in Distributed AI, in order to discuss those issues that are relevant for (3) the design of *organisational intelligent* multiagent systems and, finally, (4) we identify important tasks for future research on group level intelligence in multiagent systems .

4.1 Organisational Memory

(1) **Organisational Theory:** Organisational memory enables an enterprise to preserve, remember and utilise its experience (information about successes and failures in the past) and,

thus, to learn from its individual history. Organisational researchers have already spent a great deal of efforts on the question how can important organisational knowledge be identified, how it should be represented, and how an organisation can make sure that this knowledge can, and will be accessed in the right way in future. Traditionally, organisational knowledge is represented in charts representing the division of labour, as descriptions of pre-defined organisational processes and procedures, and, in addition, as a large body of written material. Thus, organisational memory is completely different to the individual memory of the members of the organisation, and organisational knowledge is distinct from the knowledge of the individuals joining the enterprise.

Since the mid-eighties organisational researchers have learned that recent advances in information technology change the functions, and, thus, the role of organisational memories significantly (Favela & Connor 1994, Morrison & Olfman 1994, Paradice 1988). In future, a broad range of different types of software systems need to be considered:

1. databases and knowledge bases,
2. model bases and case bases, and
3. workflow management systems.

Apparently, these systems differ in that they use different knowledge representation paradigms, and provide distinct tools for the acquisition, storage, maintenance, and retrieval of information, and implement either more passive (databases) or more active (cooperative knowledge bases) modes of behaviour, etc. However, during the last 3 to 5 years we have seen a number of successful attempts to achieve standardisation which has demonstrated that very different types of software systems will be able to communicate, and even to cooperate, in the near future. This again will give rise to further enhance the capabilities of organisational memories by knowledge processing technology.

(2) Multiagent Systems — State of the Art: It is commonly agreed in Artificial Intelligence that the existence of a (mostly supposed: long-term) memory is a necessary prerequisite for any type of intelligent skills such as learning, reflection, and rationality. We may expect that this holds for single entities and organisational bodies as well. Thus, it is quite an interesting point that the question remains to be investigated whether multiagent systems as such would need any organisational memory and what such a facility would look like. Instead, most multiagent systems only involve a short-term memory for the single agents involved, without considering any memory function that stands for its own on the multiagent systems' level.

With respect to organisational memory we stress that there is an important difference between the structure of a human organisation (which has been designed top down, and which represents the — pre-defined — division of labour), and the structure of a multiagent system which must be derived (more or less dynamically) from the individual competences of the single agents involved. Thus, it is right so far that this structure *may* represent a subsequent division of labour (e.g., see (Gasser 1992)). However, as the agents in a multiagent system are autonomous, an agent may not agree to be involved in collaboration, even if she is the only that is capable of solving a particular task. Thus, the structure of a multiagent system as such does not represent organisational knowledge concerning the *division* of labour but only the availability of individual competences, and their distribution across the multiagent system.

(3) Design Issues: The design of an organisational memory for a multiagent system requires a decision to, *where* the respective organisational knowledge should be stored. Subsequently, some additional questions must be addressed. These involve the formal representation of (maybe different types of) organisational knowledge, the creation (and maintenance) of indexes which support knowledge retrieval, and the design of knowledge access mechanisms including database-like transaction concepts in order to coordinate conflicting knowledge access operations. Finally, appropriate role concepts need to be developed in order to enable the system to update and to maintain its own knowledge.

(4) Research Issues: As a direct consequence of not representing organisational memories, there is no real discussion on how multiagent systems can exhibit higher-level intelligent skills, such as learning or reflection. One may feel that this is particularly surprising since Distributed AI researchers widely agree that any multiagent system may also be interpreted as a single (complex) entity! Thus, it seems that there is still a great difference between the definition of intelligence in mainstream Artificial Intelligence and in Distributed AI which urgently needs to be resolved by future research.

Another important point concerns the maintenance of distributed knowledge bases, and the problem of knowledge base consistency. We may hope that the recently increased collaboration of the database community with researchers in AI and CSCW (for example, see the Cooperative & Intelligent Information Systems Initiative, (Jarke & Ellis 1993)) provides for developing transaction-like consistency-preserving mechanisms for distributed knowledge bases.

Finally, if one implements organisational memory within a multiagent system, this does not only affect the static and dynamic structure of the whole system. It also effects the design of role definitions, and of coordination mechanisms. Thus, global search processes will change

significantly. This also gives rise to a number of new questions that haven't been addressed in the recent Distributed AI literature.

4.2 Organisational Cognition

(1) Organisational Theory: According to Matsuda, the collective cognition of an organisation is essentially composed of four components (Matsuda 1992):

1. *Organisational Perception:* Environmental monitoring and self-monitoring by the organisation.
2. *Organisational Comprehension:* This includes auto-evaluation in the environmental setting, evaluation of other organisations, and, in general, the evaluation of the environmental structure.
3. *Attention Focusing (Matsuda: Mastery Perception):* This is the "mind's eye" of an organisation, namely the analytic eye for the relevant process, and the transcendental eye for the "unseen" opportunity.
4. *Generation of premises:* These are premises for decision making, i.e., they include both, value premises and factual premises.

Within this context the information processing activities of an enterprise need to be coordinated towards organisational aims and objectives. As the attention focusing capabilities are the real scarce resource of an organisation (Blanning et al 1992), it is of particular importance to identify and retrieve all information which is relevant to a problem at hand, and to integrate this information in order to develop towards a satisfactory solution. Especially for large organisations this has proven to be a nearly unsolvable challenge.

(2) Multiagent Systems — State of the Art: Distributed AI still lacks an operational description of what the notion of intelligence could mean to a *group* of interacting agents. There is no explanation of what cognition would mean for a multiagent system. If we thus apply it to the taxonomy of Matsuda then we may feel that, up to now, Distributed AI has mainly concentrated on the ability of comprehension (provisionally defined as ability to analyse and interpret) and on the attention focusing capabilities of multiagent systems. Little work has been carried out on perception which, may not be so important for multiagent systems than for human organisations.

(3) Design Issues: Cognitive abilities are quite well suited to design role concepts and to assign these roles to agents. Depending on the requirements of the respective application one may start from comprehensive, or perceptive capabilities, or one may primarily apply to the design of attention focusing capabilities of a multiagent system. By this we expect that multiagent systems might be better adapted to (or even embedded into) their current environment. This, in turn, could significantly improve the chance to implement productive multiagent systems applications, especially in domains like business, robotics, and computer-integrated manufacturing.

(4) Research Issues: From the perspective of future research we are convinced that primarily the perceptive abilities of a multiagent system should be addressed. This would also involve the question of how perceived data and information can be evaluated and interpreted internally in such a way that it transforms into the organisational knowledge of the multiagent system. We further believe that enhanced perceptive capabilities will significantly improve the self-adaptation capabilities of multiagent systems.

4.3 Self Organisation, and Organisational Learning Skills

(1) Organisational Theory: Organisational learning refers to an organisation's capability to identify and to store knowledge derived from both individual and organisational experiences, and to modify its own behaviour according to feedback received from its environment (Teramoto 1992, Tsuchiya 1992). Thus, organisational learning supposes that an organisation is able to control its behaviour with respect to its own aims and objectives, to perform self monitoring activities, to filter out the relevant information from environmental scanning processes, and to adapt itself to changes in its social, economic, and political environment.

Organisational learning is performed on three interacting levels. *Individual (human) learning* may contribute to an organisation if it is not obstructed by organisational constraints, such as responsibilities or well-established information processing procedures. On the *micro-organisational level* (the group level) the members of an organisation negotiate and integrate their individual experiences in order to build up group level knowledge. The results of this (permanently evolving) process, i.e., whether the group performs better than the best of its members largely depend upon both the intra-group and the inter-group relationships within an organisation. It is important to note that, to a large extent, micro-organisational learning evolves informally, i.e. not primarily determined by fixed organisational rules and procedures. *Macro-organisational learning* evolves on an organisation's macro structure, i.e., its performance, successes and failures are largely determined by the structure of its inter-group relationships.

The ability of an organisation to learn from individual knowledge and both individual and organisational experiences assumes that:

1. Knowledge to be learned is described in terms of a common ontology.
2. Conflict resolving mechanisms help to decide which knowledge shall be included into the body of organisational knowledge, and which knowledge shall be excluded from it.
3. Knowledge management tools are needed which guarantee, that organisational knowledge is accessible to (and will be accessed by) exactly those members of an organisation who need it for doing their work.
4. Pieces of organisational knowledge must be related to each other by a network of relationships in order to provide for organisational reasoning. These are the basic mechanisms within an organisation (such as forward or backward chaining in rule-based systems) from which more complex organisational problem solving procedures are created.

(2) Multiagent Systems — State of the Art: Quite similar to organisational theory, Distributed AI distinguishes between short term and long-term organisational learning. While the former concerns organisational flexibility, the latter deals with the modification of organisational structures as a result of changes in the environment (Gasser 1992). The most important approaches work towards self organisation skills of multiagent systems (Corkhill 1982, Ishida 1992, Ishida et al 1992, Sugawara & Lesser 1993). Within such work, most researchers are primarily interested in how those systems can be enabled to reorganise themselves in order to meet changing problems or dynamic environments.

However, there is no body of work within Distributed AI which deals with organisational learning as such. This is surprising because a number of important Distributed AI applications such as business, office procedures, decision processes, human computer cooperation heavily involve the issue of organisational learning.

(3) Design Issues: To implement organisational learning into a Distributed AI system a designer would need to create agents which are responsible for meta-level capabilities such as self-monitoring and self-control. One further needs to develop (explicit, or heuristic) reorganisation strategies, and the respective control and coordination knowledge. Then, two major questions need to be addressed:

1. *What kind of knowledge can, and shall, be learned on the level of the multiagent system?*
The most important uses are: successes and failures in the past, the usefulness of different

pieces of knowledge with respect to different tasks and situations, the competences and accountability of other agents in the system, the relationships between the multiagent system and its environment, etc.

2. *What type of learning strategies need to be developed?* We may divide between learning through interaction and learning through introspection, as well as between inductive and deductive learning.

(4) Research Issues: In organisational theory the distinction between individuals, (formal and informal) groups, and organisations is fundamental for the description and analysis of processes of organisational learning. Up to now, there are no similar three-level architectures available in multiagent systems. However, we are convinced that the concept of partial global planning (Durfee & Lesser 1987), which divides between nodes, acquaintances, and the whole multiagent organisation may provide a platform from which one can start to work towards a similar static and dynamic architecture. Further, if we compare the discussion on learning in mainstream Artificial Intelligence and Distributed AI it seems that the body of knowledge on learning within Distributed AI still remains to be integrated with the knowledge already available in mainstream Artificial Intelligence.

4.4 Interactions between Multiagent Systems and their Environment

(1) Organisational Theory: Organisational communication refers to the total amount of exchange of data, information and knowledge which evolves among the human and machine-based actors within an organisation and between an organisation and its environment. Individual and organisational communication differ in that the latter performs as a set of unobservable processes in the human brain only, while the former occurs as observable interactions among machines, humans, groups and divisions of an organisation, using classical communication structures such as sender, receiver, messages, and channels (Matsuda 1988a, 1992).

Dynamic environments require an organisation to permanently monitor its environment, to filter and to assess the informations received, and to distribute the results of this perceptive activity to other members of the organisation (Hammer & Champy 1993). Thus, organisational communication is closely related to the status (and its changes over time) of the organisational environment. On the other hand, organisations are supposed to inform their environment about past and future activities, about their internal status (e.g., accounting, profits and losses, etc.). This, in turn requires them to represent and to store the respective knowledge in such a way that it can be retrieved and accessed quite easily at any time in the future.

(2) Multiagent Systems — State of the Art: Research in Distributed AI mainly addresses the interactions between the agents of a multiagent system (some examples are included in (Bond & Gasser 1988)). However, very little work has addressed the issue of communication between a multiagent system and its environment¹. A well-known example is the unsolved problem of designing user interfaces for cooperative problem solvers. Another point is that, in general, a multiagent system can be viewed as a community of interacting agents, or as a single (complex) entity, depending on the current focus of interest. However, from the perspective of communication between a multiagent system and its environment only the former of these two views is supported.

It may be expected, however, that the integration of multiagent systems into other disciplines such as Computer Supported Cooperative Work (CSCW), intelligent user agents (personal assistants) and decision support systems may help to address this issue.

(3) Design Issues: First of all, any interactions between a multiagent system and its environment suppose that the availability of a canonical interaction language. Such an interaction language needs to provide data and knowledge communication facilities, explanation facilities, and fine-grained dialogue management support. Further, if the user of the system is a human expert, he or she might wish to be actively involved in the global reasoning process. Thus, it becomes evident that we need to develop a "well-shaped" role concept for the multiagent system which also needs to be able to assign roles to the actors in the environment of the multiagent system.

(4) Research Issues: The ability of a multiagent system to effectively communicate with its environment is one of the most important issues for developing successful applications. This is particular true for any applications that aim to support human experts' intellectual work. Further, we can see today that research on interaction architectures and languages already involve standardisation issues. Two prominent examples are the CORBA standard of the Object Management Group, and the Knowledge Sharing Effort which has been launched by DARPA in 1991. It has been argued that an integration of the research, development and standardisation efforts in the related fields of information technology will significantly increase technological competitiveness (Davidow & Malone 1992, Guilfoyle & Warner 1994, Kirn 1995, Petrie Jr 1992, Warnecke 1993).

4.5 Organisational Reasoning

(1) Organisational Theory: Organisational reasoning does not only include organisational problem solving, it also involves strategies such as problem avoidance, problem evasion, and

problem encapsulation (Matsuda 1992). Typically, organisational reasoning applies to one of the following basic strategies:

1. *Process-orientated reasoning* is performed on the bases of pre-defined organisational workflows and well-established algorithms, etc.
2. *Case-based reasoning* tackles a problem by accessing a solution that has proven useful for a similar problem which has been solved in the past.
3. *Heuristic reasoning* is used to approach a problem where the necessary information is not available, uncertain, or possibly false.
4. *Explorative reasoning* includes search strategies (goal driven, data driven), trial-and-error concepts, and creativity generating methods such as brainstorming, scenario technique, and delphi, etc.
5. *Structural reasoning (adaptation)* evolves whenever an organisation modifies its internal structure in order to fit better with (identified or anticipated) changes in its environment.

Organisational problem solving supposes a set of basic tools such as problem analysis and the selection of critical success factors, the exploration and identification of well-suited organisational competences and resources, the processes of coordinating these resources with respect to the problem at hand, and the ability to focus the attention on the most relevant processes at a time, to name a few.

Thus, it is commonly agreed in organisational theory that the ability to design efficient organisational information processing and reasoning capabilities is one of the key characteristics of successful enterprises.

(2) Multiagent Systems — State of the Art: Reasoning processes within a multiagent system can be studied from two different perspectives. The external perspective considers the multiagent system as a single entity, and it gives descriptions of how the system behaves in its environment. In contrast, the internal view focuses on the description and analysis of the internal processes. This perspective represents the mainstream of work on multiagent reasoning processes (Singh 1990b, Stephens & Merx 1989). As a result, we have available today a large body of knowledge on cooperation strategies (Durfee et al 1987), coordination mechanisms (e.g. see Fickas & Helm 1991, Malone 1987, Malone & Crowston 1993, v. Martial 1992, Smith 1979), conflict resolving mechanisms, concepts for modeling intentions

and commitment (e.g. see Cohen & Levesque 1987a, Cohen & Levesque 1987b, Jennings & Mamdani 1992, Jennings 1992, Singh 1990a) and, for example, dependency relationships between different agents of a Distributed AI system. However, on the other hand we still lack a sufficient understanding of *how* the design and processing of internal procedures relates to the behaviour of the whole system. It is important to realise that this question is of prior importance for any decisions within an enterprise that involve investing money into the development of a Distributed AI system.

(3) Design Issues: From the above considerations we learn that whenever we design a multiagent system we should carefully think about adding an organisational layer to the architecture of the system (Kirn 1994). This organisational layer should include at least the organisational knowledge, the set of available problem solving strategies and the respective mechanisms to control and monitor cooperative processes within the multiagent system. We also see that this again asks for the development of appropriate role concepts. In other words: step by step we discover that role concepts are of prior importance for the design of fine-grained internal structures of multiagent systems. — It should be noted, that the organisational layer need not necessarily be a centralised resource within the system, it can also be decentralised.

(4) Research Issues: This subsection has demonstrated the importance of an organisational layerⁱⁱ together with the respective role concepts for the design and, as one may want to add, for the expected commercial success of multiagent systems. While the demand for an organisational layer is new in multiagent systems research, significant research has already been carried out (unfortunately, in splendid isolation) on the development of role concepts. Thus, we still lack an integrated, holistic approach to designing an overall model of roles in multiagent systems in order to provide for a systematic, application-driven design and implementation of future Distributed AI systems.

5 How Distributed AI can benefit Organisational Intelligence

There is already a large body of literature originating from both, the field of organisational research and management science as well as from the community of Distributed AI which argues that a lot of business and organisational problems could be solved quite naturally through a multiagent system approach. Some prominent examples are the virtual enterprise (Davidow & Malone 1992) and the "fractalisation" of organisations (Warnecke 1993), the modeling and simulation of enterprises (Fox 1981), the efforts towards an integrated theory of coordination (Malone 1987), support of business processes and workflows (Malone et al 1993),

and enterprise integration (Petrie Jr 1992). As we will show, the same holds for some of the components of Organisational Intelligence.

Distributed AI offers interesting advantages to organisational designers which aim to improve the intelligence of their organisations, and who agree to apply agent-oriented information technology. On a more abstract level we may argue firstly that Distributed AI provides technical facilities (coordination protocols) that support interactions among a set of information servers. Secondly, it contributes knowledge discovery tools assisting users to identify, select and access information relevant to their task at hand. Thirdly, many applications require the ability to select data from different nodes of a network and to combine them with respect to a particular "problem profile" (for instance, a set of customer preferences). We will expand on the above discussion in more detail below.

With regard to *organisational memory* we feel that, at the moment, Distributed AI may have little to contribute. However, this may change in future, for example if one starts to integrate results from case-based reasoning.

Distributed AI can benefit *organisational cognition* in that it provides easy-to-use knowledge exchange facilities and collective reasoning capabilities. This, however, involves the question of how to integrate problem solving at the human level (for example, see Newell 1972) with problem solving procedures at the machine level, or, more precisely: Distributed AI technology can be used only if it does not break the organisational procedures and dependencies that are involved. The reader will remember that this point was the motivation behind our notion of "organisational multiagent systems".

Distributed AI methods can also contribute to *organisational learning* on both the micro-organisational and on the macro-organisational level (Nunamaker et al 1988, Teramoto 1992, Tsuchiya 1992, Yamamoto et al 1992). While, primarily, the latter may be supported by the instantiation and maintenance of inter-group relationships, the former may be supported by single- and multistage negotiation, by the instantiation and maintenance of intra-group relationships, and by the availability of sophisticated conflict resolving mechanisms.

Further, we would like to stress that computerising an organisation also effects the performance of organisational learning. As far as humans are consideredⁱⁱⁱ individual learning can be supported by local "personal assistants". Thus, organisational learning within a group of software agents may also contribute to the individual learning of the human users. As organisational learning among software agents is part of (and controlled by) those organisational processes that have been established formally, the transfer of the knowledge back to humans establishes a kind of individual learning which is "supervised" by organisational rules

and procedures. This is a major issue also within the new of field of Human-Computer-Teams (Kirn 1995).

Typically, Distributed AI systems exhibit a more or less decentralised organisational structure. Thus, they can also contribute a great deal to *organisational communication*. This holds for conventional, human-centered organisations, but its effectiveness is directly related to the degree of computerisation of the enterprise (Ginsberg 1987, Numaoka 1991). Possible low-level communication support services may include retrieval and identification of addresses, knowledge-based intra- and inter-network communication management (for instance, routing), and intelligent communication control facilities. On a semantically higher level, these services include amongst others, group-level information filtering, appointment system applications, tools for distributed interpretation, context modelling, knowledge discovery by which the coherence of interactive activities can be improved. As some of these services can also be provided by conventional software, others would benefit a lot more from Distributed AI methods (for example, knowledge discovery).

With regard to *organisational reasoning*, Distributed AI provides several quite useful tools whenever an organisational problem requires the involvement of distributed expertise, to focus the attention of distinct organisational units on a particular task, or if distributed interpretations are to be supported (for example, see (Ginsberg 1987, Guilfoyle & Warner 1994, Kirn 1995, Kirn et al 1992). All these problems assume efficient coordination by which the various types of uni-lateral or bi-lateral dependencies among different tasks, activities, objects, and actors can be detected and managed. We feel that coordination techniques of Distributed AI are particularly well suited in all cases where the system support of the coordination task is required, and workflow management technology is too rigid.

6 Organisational Intelligence: An Important Application of Distributed AI

The above discussion developed from organisational theory suggesting (1) that research in Distributed AI can benefit a great deal from organisational intelligence, and in turn, (2) that Distributed AI methods can contribute a great deal to implement intelligent organisational skills in human organisations.

From our perspective, this point is quite important for application-oriented Distributed AI research. Currently, enterprises worldwide have begun to re-engineer their internal processes, and to adapt their structures to the challenges of worldwide competition, and the rapidly increasing dynamics of their political and economical environments. These long-term

perspectives have already begun to result in a widespread decentralisation of enterprises, which more and more consist of self-contained autonomous organisational units being globally distributed. Such an organisational approach involves two major problems: efficient coordination without having sufficient global knowledge available, and the need to intelligently adapt organisational procedures in such a way to changing environments that the long-term aims and strategies can still be pursued.

Thus, the third important result of our discussion is that Organisational Intelligence is an important application for Distributed AI in that it provides a key technology for the competitiveness of smart, information integrated organisations in the future (Kirn 1995).

References:

- i Another point which is not mentioned here are the interactions of agents of a multiagent system with their environment, or with the environment of the whole system. E.g., see work on computational ecosystems by (Glance, Hogg & Huberman 1991).
- ii see also work of (Stary 1993) and (Stolze 1991)
- iii this represents the traditional approach of organisational theory, see (March & Simon 1958).

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