Agents Enacting Social Roles. Balancing Formal Structure and Practical Rationality in MAS Design

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Abstract. We introduce an integrated approach to the conceptualisation, implementation and evaluation of a MAS (multi-agent system) which is based on sociological concepts of practical roles and organisational coordination via negotiations. We propose a middle level of scale, located between interaction and the overall organisational structure, as the starting point for MAS design, with formal and practical modes of coordination to be distinguished over all relevant levels of scale. In our contribution, we present the modelling principles of our MAS, the agent architecture and the implementation. In the next step the approach is extended to a methodology for the investigation of processes of hybridisation, which means the re-entering of artificial sociality in a real-world domain. The integrated approach is intended to contribute to a generalised understanding of the Socionics program, which in our view should be seen as the enrolment of independent, but subsequent steps in an overall interdisciplinary approach.

1 Introduction

Sociologist Pierre Bourdieu pointed to the subtle and often ignored difference between theoretical rationality and the "logic of practice" [10]. This difference, we will argue, has to be taken into account when trying to capture the robustness and flexibility of human organisations, and is especially important for any effort to model information systems on mechanisms of organisational coordination. In the INKA-Project[1], part of the German Socionics program, we took this insight as our very starting point. Computational agents that "act" and coordinate themselves in a way that, at least in principle,

[1] The acronym INKA stands for "INtegreation of Cooperating Agents in complex organisations" and is carried out by the Artificial Intelligence Group (Prof. H.-D. Burkhard) of the Department of Computer Science at Humboldt-Universität zu Berlin, and the Institute for Sociology, Technology Studies (Prof. W. Rammert) at Technical University Berlin; see cf. [12]. The results reported here are based on the project's state as of end of 2003.

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mimics human actors in organisational environments have to cope with the tension between the formal descriptions given by the organisation at large and the patterned expectations that derive from their daily interactions on the shop-floor level. In sociology, one way of coping with this tension is role theory, focussing on the different forms of enactment of formal role descriptions and practical roles. Furthermore, from organisational theory and empirical investigations we know that in the "real world" daily negotiations by the employees themselves are one way of working around the incoherencies of formal prescriptions, job descriptions and work schedules. Based on these considerations the INKA-project is oriented by two main objectives: to model and implement a technical system, in which the agents are capable of coordinating themselves via negotiating on the basis of practical roles, and to develop an approach for the investigation of hybrid sociality which emerges if those agents are re-entered into human organisations. Our application scenario are negotiations on shift exchanges in a hospital (for details see [34,23]).

Our contribution begins with a brief discussion of the conceptual problems that occur if computer programs are to be modelled on practical relations or on sociological concepts of practical modes of interaction; this leads us to the formulation of three general challenges (2.) within the Socionics program. In order to address these challenges, we propose an integrated approach (3.) that correlates all activities in Socionic systems development as four subsequent steps. In this contribution, we focus especially on the modelling step and on the hybridisation step. In the next sections we introduce in some detail (4.) our sociologically grounded modelling of practical roles and negotiating agents and (5.) our framework for a corresponding MAS-architecture. Afterwards (6.), we describe shortly the implementation of our system. As the last step of the cycle we present a methodological instrument (7.) for an investigation of hybridisation. We conclude with a brief discussion of the scalability issue (8.) for an approach that is, like the one presented, focussing on a middle-level of scale.

2 Practical Rationality: A Threefold Challenge Within the Socionics Program

Human organisations offer an effective way of coordinating individual behaviour while at the same time remaining capable of flexible adaptation to changing environments (cf. [2]). Concepts and theories from the sociology of organisations are thus perceived as a promising blueprint for the design of innovative information systems, especially in the realm of MAS research, where the overall functionality of the system is derived from the coordination of autonomous software entities. Moreover, human organisations, unlike many other social entities, tend to work out an explicit description of their own coordination principles—rules for membership, planning schedules, job descriptions adjusted to the internal division of labour, hierarchical chains of prescription and control, and so forth. These descriptions, often provided by management units, typically present a formally coherent and encompassing picture of the organisation's functioning. Sociological conceptualisations of organisational coordination, too, have elaborated this formal, explicit and hierarchical body of regulations as the basis for functionality, rational decision making (cf. [33]), or the type of sociality dominant in (Western) modernity. So, at

a first glance it might seem to be quite easy to model information systems on principles of organisational coordination.

Revisiting the iron cage, however, weakened this notion of a consistent body of formal rules and regulations, and even contested the notion of any formal rationality[2] within organisations. The findings of empirical investigations in the "real life" of organisations pointed to a picture of "organised anarchies" (Cohen, March and Olsen [15]) because formalised descriptions turned out to be inconsistent and often conflicting with one another, thus creating individual frustration and large-scale inflexibility. Sociologists have drawn different conclusions from these findings for an adequate conceptualisation of organisational coordination, which lead to different consequences for the design of information systems, respectively. One way of dealing with inconsistencies in organisations is to uncover misleading or conflicting regulations and especially "concurrencies" (ibid.), and instructing a corresponding re-design of formal structure; most of today's business support software can roughly be located in the line of this approach. But more recent directions of sociological research claim that the picture of the iron cage does not describe any organisational reality at all, but rather serves as a resource for legitimacy (DiMaggio and Powell [18]). Even more, formal structures in this view "dramatically reflect the myths of their institutionalised environments instead of the demands of their work activities" (Meyer and Rowan [36], pp. 431), leading to the consequence of "decreased internal coordination and control ... Structures are decoupled from each other and from ongoing activities. In place of coordination, inspection, and evaluation, a logic of confidence and good faith is employed" (ibid.: 430). Following this description it is obvious that formal structures by no means can serve as a guiding line for computational support systems or the design of MAS.

Sociological approaches that exile formal rationality to the realm of "ceremony" (ibid.) can be seen as corresponding to another body of research, which focuses on the specific (and always messy) realities on the micro-level of an organisation— the daily work practices at the shop floor-level, or speaking more generally: on "situated action" (Suchman [52]). Most research in Groupware and especially in CSCW (cf. [13]; [42]) follows this micro-level approach, stating that successful computer support and the design of any software system has to begin with the particular circumstances of every single case. But leaving aside every formal description of organisational coordination comes at a prize: Declaring all of the organisational structures on higher levels of scale (including the organisation at large) to be irrelevant, leads directly to a strong scepticism about the very sense of modelling (cf. [7]).

This brief discussion of current directions in the sociology of organisations seems to end up in a paradoxical situation, at least if they are regarded as a promising 'blueprint' for the design of MAS: While on the one hand all these approaches point to the importance of practical modes of coordination which emerge bottom-up, on the other hand

[2] We use the term 'formal rationality' to point at the correspondence between the self-descriptions of real organisations and those theoretical descriptions from the sociology of organisations which, besides all differences in scope, state that formal rules and regulation are 'rational' because they are the prerequisite of the functioning of the organisation as a viable social unit. An overview for the context of the Socionics program is given in [50].

all these approaches seem to discourage every attempt to model information systems on principles of organisational coordination.

In the discussions about an adequate theoretical background for MAS design, there seem to be two possible alternatives to overcome this paradoxical situation.

The first alternative draws on sociological concepts of the duality of social structures over different levels of scale. In this line of argument in his talk at 2000 Seeon Socionics conference, Les Gasser recommended concepts of mutual constitution of large-scale structures and situated interactions (Giddens and Weick) as the very starting point in DAI and in Socionics (see cf. [39]; [49]: 226ff). Fley and Florian (in this volume) present an analogical approach to model the dialectics of the micro- and macro-level, based on Bourdieus habitus-field-theory.

In a recent contribution, Castelfranchi pointed to a second alternative [14]. In discussing a "formalising of the informal" as the guideline for computer supported interaction and MAS design, he distinguishes three types of social order: formal (orchestrated) social control, spontaneous social order ("deliberate action" and the "invisible hand"), and informal patterns of social control which reside somewhat in between the first two types. He then continues to state that "what is needed is some attempt to 'incorporate' part of these layers and issues in the technology itself ... [The agents] should be able to manage—and thus partially understand—for example permissions, obligations, power, roles, commitments, trust". Drawing on these considerations we focus on the practical (in Castelfranchi's terms: the "informal") side of coordination by "incorporating" practical roles in the architecture of our agents, which enables them to create emergent patterns of interaction as if they would have been socialised in a bottom-up manner.[3]

Compared to full-fledged concepts of mutual structuration, this is a less ambitious approach, but it allows a quite straightforward (nonetheless a sociologically "dirty", to quote Schimank in this volume) modelling of a MAS. Furthermore, we hope that this approach is expandable up to the point where structures at a middle-level of scale are in fact produced by the agents interactions, and not only "incorporated" into the agents by the designers. Crucial for such an approach is that it deploys the micro-macro-dimension on both the formal and the practical side of coordination, giving both modes of coordination their own right. This results in a balance of formal and practical rationality in order to create and maintain a robust and flexible coordination within organisations.

Before proceeding, we want to sketch the consequences of these considerations for Socionics as a "triangular research program" (Malsch [32]). In our view, focussing on practical modes of interaction leads to a threefold Socionics challenge. With respect to the "computational reference", our approach plays out the ambiguous meaning of

[3] Castelfranchi is not very clear in his definition of "spontaneous", "self-organising" or "decentralised" social order. We assume that this is resulting from a purely enumerative conception of "interpersonal normative relationships": In sociology, terms like "the informal, implicit, spontaneous, bottom-up forms of social control" denote highly different concepts and phenomena, and we at least tried to be as explicit as possible with terms like the ones mentioned when developing our conception of practical roles. We also differ from Castelfranchi's approach by focussing on the modelling and creation of practical patterns, while he is focussing on a "convention to violate" the formal, as he calls it: "designed" patterns of interaction.

the word "formal". Specifying our approach means to mathematically formalise those practical patterns of interaction which lie beyond the explicit formal descriptions of organisations. As described above, Castelfranchi coined the slogan "formalising the informal" for this challenge, and this is in our view, a promising way to overcome the paradoxes mentioned above, thus contributing to a more balanced blueprint for sociologically grounded MAS.[4]

The other way round, modelling and computer simulation of practical rationality should also serve as instruments for sociology. In our experience, this "sociological reference" of Socionics is especially manifest when it comes to modelling because of the necessity of explicit specification. Modelling situated, practical patterns of interaction brings a sociological challenge to the forth because these patterns are often seen as lying beyond any possibility of generalisation. Thus, a tapered concept of practical rationality in the context of organisation studies can help to enhance sociological concept-building. Furthermore, simulations can throw light on those practice-based patterns in organisational life that are hard to tackle by usual methods of empirical investigation. An example is the smooth fit of practical roles within organisational units (see Sections 4.4 and 7.3).

The third goal of the Socionics program is to explore the consequences that are likely to occur if a sociologically grounded MAS is re-entered into human contexts. In the INKA-project, this means to explore those hybrid settings in which practice-based computer agents and skilled human actors have to cooperate. In sociology as well as in computer science, there are no approaches that can avoid the pitfalls of purely theoretical considerations and implementation studies likewise. So the socionic challenge here is to develop methodological instruments that enable an investigation of these hybrid constellations.

3 An Integrated Approach for System Development in Socionics

The three challenges outlined in the last section can be arranged as consecutive working steps in an overall path to a hybrid system. This path—supplemented by the necessary implementation—follows the socionic development cycle as it is shown in Figure 1, and consists of four stages. While targeting all of the aspects mentioned in the "Socionics' triangle" [32], we arrange these aspects as distinct activities with distinct goals that build subsequently on one another. What follows is that, on the one hand, every step should not only address its own logic, but should also be seen in the light of the following steps. On the other hand from every step the developer might be forced to rephrase the model.[5] The cycle begins with the modelling phase where the principles of agent coordination are derived from sociological theories (see Section 4) or, as in the case of our project, from additional empirical investigation in a specific domain. Either way, model-building can be seen as the basic activity in Socionics. As in other

[4] In the long run this can also be seen as a contribution to the development of more successful tools for computer support.

[5] In our view it is one important gain of an integrated approach that all stages of development are to be processed by a joint team of computer scientists and sociologists. Our experience is that this can put the "going concern" of Socionics [51] on a more structured basis.

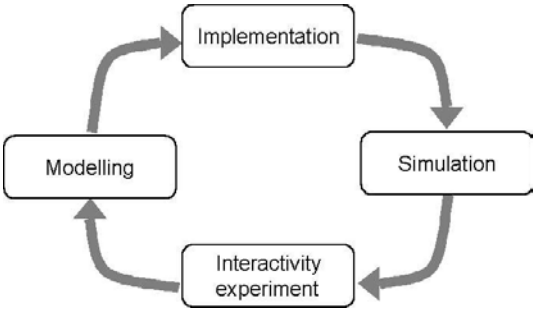

Fig. 1. The socionic development cycle.

fields of interdisciplinary research, models in Socionics serve as key "mediators" [37] between the disciplines involved, enabling a continuous dialogue between computer science and sociology; the prize for mediation is idealisation. Furthermore, the cycle itself produces requirements for the modelling process. It is of special importance that all models should be made complete, not only for reasons of internal theoretical consistence, but mainly because they are the starting point for any specification of the technical system.[6] For these two reasons, the basic model might seem "dirty" in an isolated view (to quote again Schimank in this volume), but at the end of the day we can see our agents to negotiate enacting practical roles.

In MAS design the sociological model has to be transformed in an explicit agent architecture. This is the computer scientists' part of the modelling. In our approach, the focus is on the formalisation of the negotiation process in the three-layered C-IPS framework with social roles being an architectural feature of the agents themselves (see Section 5). With respect to the intended usage of the system for interactivity experiments in hybrid settings, we require a distributed system that enables life-like negotiations between agents, between humans, as well as between agents and humans. Hence, it is necessary that the agents' negotiation behaviours are reasonable for humans. To ensure equitable interactions between humans and agents, humans interact with the system by "taking over" an agent. This requires agents with at least two degrees of autonomy: agents that act fully autonomous on behalf of humans and agents that are (partially) controlled by humans.

The next step in the cycle is the software engineering according to this agent architecture. In the case of our project, the model was implemented in a Java using the multi-agent platform JADE (see Section 6). The layered architecture of our agents enabled an incremental implementation, which made it possible to test every single layer in functional simulations in order to verify that the layers work properly.[7]

[6] In our project, the translation of the agent-based model into the formalised specifications of the technical MAS has led to a series of model revisions.

[7] The layered approach offered the opportunity to observe the behaviour of agents with an increasing autonomy: in a first run, the issue and partner of the negotiation were given, in a second run only the issue was given, and in a last run the agents' behaviour was unconstrained

Simulations, in the picture of the development cycle, can serve three different purposes: as mentioned, they first can be used as a check of the basic functionality of the technical system, and second they can serve as a check of the basic assumptions of the model. But in Socionics, simulations are mainly used as a special kind of methodology for sociological investigation: an artificial check of sociological hypotheses or an artificial 'expedition' into the foundations of social entities. In the case of our project these 'expeditions' are especially suited because they lead into the realms of practical coordination. This part of the social fabric is hard to tackle by conventional sociological methods because they remain mostly implicit in daily work practices and are hidden from the actors' perspectives as well as from the organisation's perspective.[8] All three purposes of simulation call for evaluation criteria. Because in MAS, especially if the agents are complex, the sheer number of relevant parameters is high, and random processes are likely to occur in the long run statistical methods to check the significance of simulation results should be developed and applied.

The last step of the Socionics' development cycle is the introduction of human actors into the simulation or the introduction of the MAS into a human social system which constitutes a hybrid sociality (see Section 7). Because an examination of the mixing of humans and agents, is in the Socionics program neither a question of software engineering nor a question of technology assessment, but in the first place a question of basic research, the challenge here is to develop a sound methodological approach.

In the following sections, we describe the steps of modelling, implementation (esp. the agent architecture) and interactivity experiments for the examination of hybridisation in some detail.

4 An Approach to Model Practical Roles

The first step in the design of a sociologically grounded MAS is to build a model of human social reality with respect to sociological concepts. As we argued in Section 2, this turns out to be a major challenge in the case of any modelling of organisational coordination, mainly because of the dichotomy between the purely formal and a purely practical conceptualisations. Furthermore, we generally argued for an approach which "incorporates" social mechanisms into the single agents and thus starts on a middle level of scale. In this section, we want to motivate in some detail why we choose social roles as the focus for modelling, and how this, in the overall picture, relates to negotiations. Based on this sketch of the 'backbone' of our modelling approach we outline the concrete modelling decisions that guide the basic principles of our agent architecture.

besides the allowance to negotiate. Again, these results sometimes made revisions of the model necessary.

[8] By running simulations, we especially want to gain insights in those mixing ratios of practical roles that enable or hinder a productive atmosphere, in which problems can be solved smoothly. In the case of our domain, this means that negotiations are often successful and do not take much time. For lack of space, we do not address this topic here.

4.1 Negotiations and Practical Roles in the Organisational Context

From sociological investigations in organisational coordination we know that one way of counteracting formal regulations and especially its incoherencies are negotiations by which the organisations' members themselves create a flow of problem solutions for their daily work practices. Negotiations can be defined as a situated mechanism for problem solving for those situations where actors (and our agents) have a high degree of autonomy and at the same time a high degree of mutual dependency. This view of negotiations at a first glace seems to be restricted for the interaction level of scale, but relating to sociological concepts (cf. [48]) we extend this insight to the organisational level of scale: Negotiations can also be conceptualised as a mechanism that constitutes a "negotiation system" within the organisation (cf. [25],[26],pp. 77-83), which is necessary for the achievement of an overall flexibility within the organisation.

But problem solving via negotiation clearly bears a danger: Permanent negotiations would be very time consuming and frustrating for the organisation's members, and it would be dysfunctional from the point of view of the organisation at large, simply because the members would be kept from getting their job done. So focussing on negotiations directly leads to the subsequent question: How can the dangers of permanent negotiations be avoided without destroying its advantages? In social life, there exists a solution for this problem: Every aspect of the negotiation process[9] can be based on patterned expectations about the future behaviour of the others. Drawing on these expectations can drastically reduce the expenses of negotiating. This is the point where social roles enter the picture because they are defined as patterned expectations.

4.2 From Role Theory to Modelling Principles

We argued that the concept of social roles is suitable and sufficiently concrete for our modelling purposes. But there is no smooth, or self-evident, way to transform role theory into a model for Socionics because in sociology there are two different and even competing conceptualisations of social roles.

The first conceptualisation is functionalist in nature. It states that all individuals are forced to play the roles assigned to them by institutions, and especially by formalised regulations of the division of labour. Force is defined as a (more or less rigid) normative pressure, or the "fear of sanctions" as in Dahrendorfs well known account on the "homo sociologicus" [17]. In consequence, focus has been on deviation from the roles ascribed to individuals, and on role conflicts within one individual. This first conceptualisation of roles has been strongly criticised, mainly because of its poor definition of the scope of social action, and because it has only a very narrow, if any, range of explanatory power (a summary of these arguments is given by Esser [20], pp. 82ff).

These critiques are crucial for the second conceptualisation of social roles, which mainly has been developed within the tradition of symbolic interactionism. In this tradition any assumption of "conformity" in human behaviour is rejected. Instead, focus is on the ongoing processes of interactively building (and re-building) social order. With

[9] In Section 5.2, we identify three important aspects: the selection of a promising issue, partner and next negotiation step.

respect to roles this is especially important for the role-taking process, which in this tradition is defined as follows: "Grouping behavior into 'consistent' units which correspond to generalizable types of actors" (Turner [53]: 32). In the organisational context, this means that the "formalized role prescriptions and the more flexible operation of the role-taking process" (ibid.) are different, and do have different consequences with respect to organisational coordination.

Our conceptualisation of practical roles draws strongly on the interactionist stance, with two major exceptions. Firstly, the interactionist tradition concentrates on the "sociology of the person", which relates to the various aspects of the role-taking process; role-making as a practical process of its own right is not addressed (we relate to this problem in Section 4.4). Secondly, all the aspects of formal prescriptions (and prerequisites) of coordination are marginalised or even deemed to be irrelevant.[10] See, for instance, the following quote: "The formal role itself, considered apart from the effective incorporation of the informal role, is merely a skeleton consisting of rules which are intended to invoke the appropriate informal roles. The formalized roles are to the full roles as detonators to explosives—merely devices to set them in motion" (ibid.: 28). As opposed to this view, we model formal roles and practical roles as two different processes, the first constraining the interaction possibilities, the latter to be emerging from this interaction (see Figure 2). The overall picture, then, does not show a merging process within one person (see, again, the quote from Turner above), but a balanced process within the organisation, with a clear emphasis on the practical side. In this picture, the concept of roles serves as a mediating level of scale between the daily negotiations and the structures of the organisation at large.[11]

4.3 Modelling Decisions

Within the picture given, some more detailed specifications had to be made explicit. Modelling, as opposed to considerations in texts, requires these kinds of decisions.

Formal Roles as Constraints. Organisations assign formal positions to their members in order to manage and control the internal division of labour. Here we made two modelling decisions. Firstly, formal roles are modelled as constraints for the agents'

[10] The duality between formal and practical descriptions within organisation science, which we outlined in Section 1, is repeated at this point.

[11] The details of the modelling and the concrete data are drawn from our empirical investigation in a specific domain, personal employment planning in hospitals. This domain shows all the characteristics of complex organisations mentioned above: The overlapping of different professions, hierarchies, and local styles (cf. [46]) leads to a high degree of incoherence in the official prescriptions and plans. Especially the official shift plans are conflicting with an adequate consideration of the individual leisure-time interests. Therefore, the employees negotiate and trade single work shifts aside of the official shift plan, thus making use of the scope the management intentionally leaves blank. These shift negotiations are a daily requirement under rigid time restrictions. Our theoretical assumption is that this works because the negotiations are carried out on the basis of a limited set of practical roles, an assumption that is backed by empirical evidence (for details see [34]).

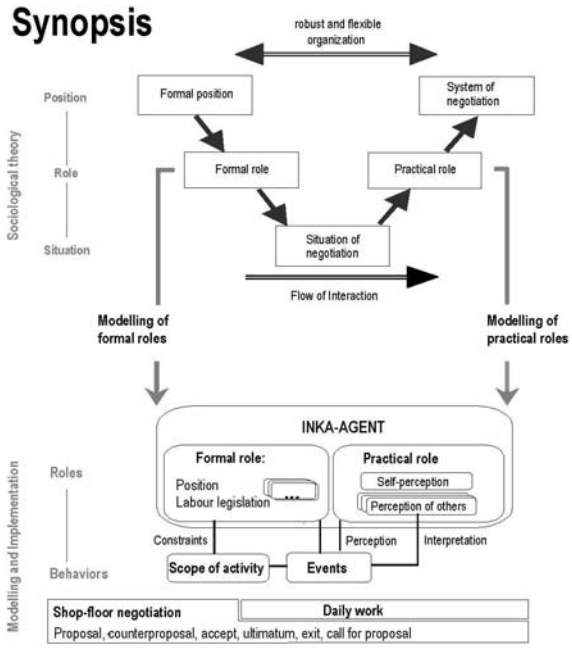

Fig. 2. The overall picture of the modelling approach

behaviour. Because in every developed organisation these formal prescriptions are multidimensional in itself, we distinguish three necessary aspects of the internal division of labour (this draws on a distinction introduced by Geller [22]): the professional division in the "functional circles" of physicians, nursing staff and administration; the hierarchical chains of commanding authority and duties; and the spatial division. We modelled all three aspects as constraints for the internal reasoning processes of the agents, thus limiting the scope of possible individual action in every situation. Additionally, we included external prescriptions like, e.g., labour time legislation and the salary stages regulated by labour agreement. The second modelling decision is that the agents are equipped with some amount of capital with respect to their formal position.

Multiple Capital Interests. Agents decide by considering their interests. This can be described mathematically as an expected increase in capital. This capital stock originates from the formal positions. Organisations, as depicted above, have to equip their members with some capital in order to fulfil their positions. Even on the formal side of organisational coordination a purely economic measure of interest would be Platonic (see Schimank this volume). Therefore, we modelled interest drawing on Bourdieu's capital sort theory [8,9] and distinguished economic, social, cultural and organisational capital, the latter transformed into symbolic capital on the practical side of coordination

(for details of the computing see [34]).[12] These different types of capital are also important for the valuation of the single shifts that are the object of our agents' negotiations (see Section 5).

Practical Roles. The practical roles are modelled as emerging from the ongoing flow of situated interaction on the shop-floor level, thus filling the scope which the formal prescriptions—whether intentionally or not—leave blank. In human organisations, the process of roles emerging can be depicted as follows: Situations that are perceived as similar will increase patterned ascriptions, thus generating a relatively stable positioning of types of actors on the practical side of coordination (see Figure 2). In other words, some kind of resistance against disappointment of these expectations gets established and remains relatively stable after a while. In our MAS, these practical roles are "incorporated" in the agents.[13] We modelled these pattered perceptions of the interaction partners according to the concept of "group figures" [41], which can be observed among lasting informal groups (e.g., juvenile gangs) and also within organisational units (e.g., a bureau or a station in a hospital). Because the term "figure" captures ascriptions which can be assumed to differ only slightly between different social entities, we termed these patterned expectations "social types"[14]. These are described by two classes of parameters: the interest is computed as a type-specific weight in the four capital interests. The type-specific negotiation behaviour is computed as additional type characteristics (like willingness for compromise and sharing of information, or general willingness to negotiate at all).[15]

4.4 Role-Making and the Benefits of Diversity

In our modelling approach the practical side of organisational coordination is decoupled from the formal side. This calls for an explanation of the concept of practical roles on the organisational level of scale. Merton's well known concept of "role sets" [35] does not address this question because it focusses on different (and even conflicting) role ascriptions to one individual. The same holds true, as mentioned above, for interactionist

[12] Drawing on the distinction of different capital sorts does not mean that we in any way try to 'apply' or formalise Bourdieu's theory in all of its aspects. Especially his notion of an overarching "logic of practice" is, at least in the context depicted here, not suitable because it neglects the relevance of every formal prescription (see the discussion in Section 1). On the other hand, his proposals for a positioning in the "field of practice" can, in our view, be applied to organisational theory—but this is not an issue here.

[13] This means that at the present stage of system development it is not possible (and not intended) that the practical roles themselves emerge. Nonetheless, this capability can be achieved with an extension of the approach. As an intermediate step, we plan to introduce the automatic detection of the social types which are present at the given situation.

[14] See [3] for a summary of sociological conceptualisations of social types and the relation to the concept of social roles.

[15] At the moment, we are working with a set of nine social types. The profiles (and the names) of the types and their initial capital interests were constructed on the basis of empirical evidence from our domain.

conceptualisations. Nonetheless, these conceptualisations offer a starting point by highlighting that the consistency of roles is an achievement from "the process of organizing behavior vis-a-vis relevant others" ([53, pp. 32]). The differentiation of roles (ibid., p. 28), then, is a result of a mutual stabilisation of interpretations as part of the interaction process. This means that in practice there can be a fit of roles which makes collaboration (or negotiation) easy or complicated—as members of organisations we all refer to this with the folk concept of a "social chemistry". Because this fit of practical roles, within the overall picture of organisational coordination, works against the one-dimensionality of formal role prescriptions (and 'repairs' its incoherences), it can be assumed that a high degree of diversity is the prerequisite for this kind of practical coordination. What follows is the question: Are there mixing ratios of social types which do work better than others (or even optimal)? We address this topic in Section 7.3 in some detail.

5 An Architecture for Role Based Negotiating Agents

The computer scientists' part of the modelling is the conceptualisation of an agent architecture that hardwires the sociological model. As we pointed out above, our guideline was to "incorporate" the essential features of social roles directly into the agent architecture, thus tackling the challenge of "formalising the informal". In the last section, we outlined the most important features: formal and practical roles, social types, and capital interests. Now we want to describe how these approaches can be applied to our multiagent system.

As mentioned before, our application scenario is the exchange of shifts in a hospital, and some of the features of our system will be described in terms of this domain. But our approach does not only intend to cover this concrete example; it is a generalised approach to agent negotiations.

5.1 Formalising the Negotiation Process

Based on empirical studies, we identified three important facets that define the proceeding in human negotiations: the application of social types, the influence of experiences, and the utilisation of strategic behaviour. All three facets relate to the practical role of our agents.

Social types define typical preferences and characteristic behavioural parameters for classes of agents. They are used in two ways. First, they serve as a guideline for the agent's own behaviour (self-image). Second, they provide an estimation of the partners' attitudes (partner-images).

We enable our agents to collect experiences, so that the agents can develop a tendency to prefer certain agents as negotiation partners. As our agents only interact by negotiations, these experiences can only be related to negotiations. Additionally, agents might tend to be more cooperative towards partners they have good experiences with. The experiences are collected regarding a certain agent (personal experiences) as well as regarding social types (typified experiences). The latter allow the application of experiences even if the agent is not well known yet. These generalised experiences as well

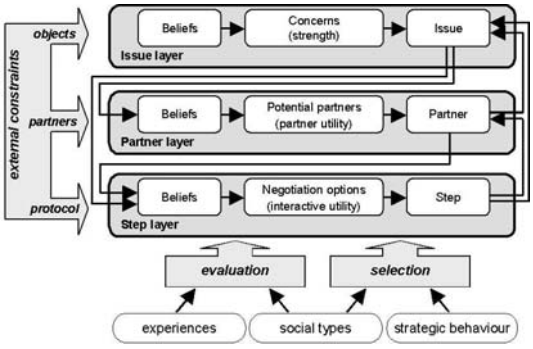

Fig. 3. The C-IPS framework.

as the overall concept of social types simplify the handling of large numbers of agents, i.e., it increases the scalability (see Section 8).

Observing humans negotiating, it can furthermore be seen that the currently best option is not always chosen. Often, this deviation from the optimum is caused by anticipation of middle-term or long-term effects. Introducing this concept as strategic behaviour of our agents, we can foster the realism of their negotiations and give them more autonomy in selecting a negotiation step.

Usually, classical approaches conceptualise agent negotiations by distinguishing the negotiation object, the negotiation protocol, and the internal reasoning process [6,27]. These approaches do not address the negotiation partner explicitly, and the reasoning process itself is not structured at all. But both are necessary for us. We require agents that are fully autonomous in all decisions regarding the negotiation, and we need a clearly structured decision process to localise where the social aspects have to be integrated. Hence, we extended and restructured the classic approach to negotiation modelling and developed the C-IPS framework [54].

5.2 The C-IPS as a General BDI-based Architecture

It can be assumed that in our domain, as well as in every other negotiation, agents have to make decisions about three important aspects: They have to choose the negotiation issue, the negotiation partner, and the next negotiation step. The latter is the communicative act to be issued next in the negotiation process. While these three aspects are interrelated, the corresponding decision processes can usually be separated. This clear separation enables an explicit definition of various interdependencies. Therefore, we follow a three-layered approach to agent architecture (see Figure 3), where each layer represents one of the three decision processes mentioned above ((I)ssue, (P)artner, and (S)tep). Initially, we defined a simple sequential dependency between the layers, which implies that decisions are taken and withdrawn step-by-step, starting at the issue layer or the at step layer, respectively. All decision processes are restricted by external (C)onstraints.

The decision process at each of the three layers is structured according to the BDI approach [45,38].[16] Beliefs represent the layer-specific part of the agent's knowledge about the world. During the evaluation process, the agent builds desires based on the beliefs and according to its individual preferences. These desires represent preferable choices for the decision process. In our three-layered approach, desires are concerns the agent wants to negotiate on, they are potential partners, or they are useful negotiation options (exchanges) respectively. At each layer, the desires are ranked according to a numeric function, i.e., strength for concerns at the issue layer, partner utility for promising partners at the partner layer, and interactive utility for negotiation options at the step layer. Some desires may turn out to be impossible due to decisions made on other layers or due to the flow of negotiation. These desires are marked as temporally impossible. The marking is revised after a certain period of time. From all possible desires at each layer the agent finally selects a specific intention, which actually determines the agent's behaviour. Thus, the agent's enacted intention is a specific negotiation step aiming at a particular issue in a negotiation with a particular partner. A more detailed and formalised description of the C-IPS framework and its application to the shift negotiation domain can be found in [54].

5.3 External Constraints

External constraints avoid unnecessary, useless or undesired negotiations. This allows keeping the reasoning somewhat simple. There are two sources of external constraints: domain dependent formal restrictions and restrictions set by the system designer. The compliance of the agents' behaviour with these restrictions ensures the fulfillment of the formal role.

Our agents only negotiate on shift exchanges. Exchanges between different professions or qualifications (e.g., physician and nurse) are not allowed. For a certain issue, an agent can only select partners that are able to take the shift of the issue, i.e., they are not already scheduled for that shift. The negotiation object is the shift the partner has to take in return. The shift of the initiating agent is fixed. Agents only offer shifts they are scheduled for. Furthermore, in the first version of our system the agents can only negotiate with one agent at the same time.

A very important constraint that influences the step layer is the negotiation protocol. As mentioned before, we require a protocol that enables life-like negotiations. Our protocol structures the negotiation into three phases: the pre-negotiation phase, the main negotiation phase and the post-negotiation phase. During the pre-negotiation phase, the protocol requires that the initiator of a negotiation—we distinguish between the initiator and the responder—asks the selected partner whether a negotiation is useful, i.e., whether there has been new information since the last negotiation on the same topic, and whether the other agent is not 'busy', i.e. is currently not engaged in another negotiation. If these conditions hold, the initiator starts the main negotiation phase by

[16] The possibility of a combination of layered architectures and BDI approaches has already been described by [11,21,56]. These authors frequently used layered architectures to represent different levels of complexity and abstraction. We, contrarily, use the layers to represent different interdependent parts of the complete negotiation process.

doing the first negotiation step. Following speech act theory, we define each step as a performative act where motivation is combined with content (e.g., a specific exchange). The performatives for the first step can be a call-for-proposal (CFP), a proposal, or an ultimatum. With the exception of the terminating performatives agree and cancel, every single negotiation step will be answered by the partner. Every proposal can be followed by an agree, a cancel, a CFP, an ultimatum or a counter-proposal. An ultimatum is a very restrictive performative because it forces a cancel or an agree. If a cancel or agree is uttered, the post-negotiation phase starts. The agents' experiences are adjusted based on the result of the negotiation. If there is an agreement, the initiator asks the administration for confirmation and then forwards the administration's answer to the responder.

These external constraints are clearly distinguished from the agent's internal reasoning model, which is structured by IPS. Furthermore, an initiator conducts a different or at least more complicated reasoning process than the responder. If the responder is 'not busy', he always accepts a negotiation request. When it comes to the beginning of a negotiation, the responder simply sets the negotiation issue and partner to the corresponding values.

5.4 Issue Selection

At the issue layer, the agent selects a shift as a negotiation object. This is a shift that is assigned to the agent according to the shift plan and that is in conflict with the agents' leisure time interests.

All shifts assigned to the agent are considered as concerns. The agent assigns a strength value to each concern. The strength is inversely related to the utility of a shift, i.e., the bigger the utility the less is the agent's interest to exchange that shift and vice versa. The utility of a shift depends on the worth of the shift and on the leisure time interest for that particular shift. The worth of a shift is calculated by comparing the agent's capital stock (composed of the four capital sorts) with and without that particular shift. The capital stock itself is evaluated according to the capital interests, which are set in the social type. As the capital accumulations that can be achieved by future shift exchanges cannot be known in advance, we use shift type specific estimations instead. These estimations result from different characteristics of the shift types, e.g., different manning levels, salary surcharges, and tasks [24,31].

Of all its concerns, an agent only considers those concerns as being relevant for intention building which do have a significant leisure time interest. This can be interpreted as a simple strategic behaviour because it avoids the effort of a negotiation for unimportant conflicts. A social type dependent threshold sets the relevance. From the remaining concerns, a possible concern with maximum strength is selected as the actual intention at the issue layer, i.e., the issue. Due to the interdependencies between the layers, an issue may become impossible because no partner is found for that issue. In that case, the decision regarding the issue is revised.

5.5 Partner Selection

At the partner layer, the agent selects a promising partner for a negotiation on a given issue. Potential partners are all other available agents that fulfil the requirements of the

external constraints. These potential partners are ranked by the partner utility function. The partner utility is strongly influenced by personal and typified experiences likewise. Additionally, every calculation of the partner utility depends on the partners shift plan. The number and the utility of the possible exchanges are taken into account, and the latter is given more importance. The utility of an exchange combines the worth of an exchange with the leisure time preferences of the affected shifts. Similar to the worth of a shift, the worth of an exchange is the difference between the evaluation of the agent's capital stock with and without the exchange. Thus, the worth of an exchange is dependent on the social types.

From all potential partners, the agent selects a possible partner with maximum partner utility as intention of the partner layer. A partner may become impossible because he is currently involved in another negotiation or there has recently been an unsuccessful negotiation on the same issue with this partner. Again, in this case the decision has to be revised.

5.6 Step Selection

The selection of an appropriate next step in a negotiation with a specific partner on a specific issue is subject to the step layer. It is done according to the protocol.

The following applies only to the main negotiation phase, as due to the protocol there is no room for decisions during the pre- and post-negotiation phase. All possible exchanges are desires at the step layer (negotiation options). These desires are ranked by the interactive utility. We calculate this utility as the weighted sum of the agents personal utility and the partner's estimated personal utility. The personal utility corresponds to the utility of an exchange described in the last section. As the individual preferences and leisure time interests of the partners are not known, they are estimated based on the partner's social type. The weights depend on the agent's social type and on its personal and typified experiences. The weight of the partner can be interpreted as concessions towards this partner.

The step selection is realised using strategies and tactics. A tactic generates a single negotiation step for a specific situation, given in the tactics precondition. We assume the set of exchanges that lead to neither agree nor cancel, which is bounded by two lines: the agree line and the cancel line. As the change of the boundaries of the negotiation space heavily influences the flow of the whole negotiation, we call these two lines "strategic lines". A strategy provides a sequence of steps for all situations. In our framework, a strategy is composed of a set of tactics and the two strategic lines. Tactics in a strategy may be weighted. If more then one tactic is applicable in a certain situation, the selection of the tactic to be used is done as follows: tactics without a weight are only considered if the sum of all weights is less than 1. All weights are temporally adjusted so that they sum up to 1. One tactic is chosen randomly and the probability is given by the weights.

Some preconditions of tactics refer to strategic lines. An offer is accepted if the corresponding interactive utility is above the accept line. The negotiation is cancelled if the personal utility of the offered shift is below the cancel line. Because this process is based on two different utility functions, we term it "two-scale-based decision making". Simulation runs show that these definitions are useful, because they avoid situations similar

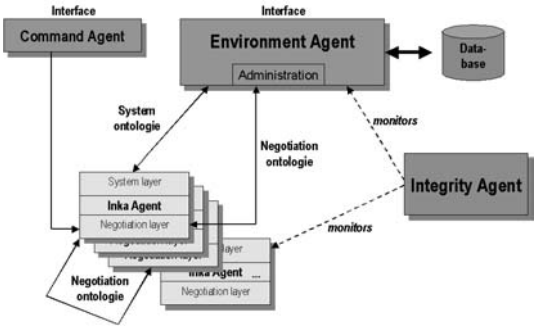

Fig. 4. Core system architecture of the INKA MAS.

to the prisoners' dilemma, which can arise when two "excess altruists"—weighting the partner's utility higher than one's own—are negotiating [28].[17]

6 Implementing the INKA-MAS

The next step in the development cycle is the genuine software engineering job. For the implementation of the INKA system, we have evaluated different multi-agent platforms. One important evaluation criterion was the support of physically distributed agents with individual interfaces. This is necessary for the interactivity experiment. Furthermore, we require a platform that supports complex agent architectures and the modelling of agent communications, e.g., ontology management. We have decided to use the platform JADE, which fulfils these requirements. Using JADE, the configuration of the system can be changed dynamically while the system is running, i.e., agents can enter and exit the system or change the position within the network. Our system is completely implemented in Java; thus, it is independent of the operating system.

Figure 4 visualises the core system architecture of the INKA system. It comprises four types of agents: the environment agent, the INKA agents, the integrity agent and the command agent.

The environment agent is the central element in our system. It provides interfaces to configure and control individual INKA agents as well as the whole system. Additionally, the environment agent provides the access point to the system database that contains all relevant data of the scenario (for details see [31,23,34]). Finally, the environment agent implements the administration, which is the final authority to check and confirm the accordance of negotiated shift exchanges to restrictions set by the formal roles of the involved agents.

The INKA agents are the agents that negotiate on shift exchanges. They consist of two components. The negotiation component implements the negotiation behaviour according to the C-IPS approach described above. The system component cares for

[17] There are no impossible desires at the step layer.

the management of the agent's internal knowledge and the processing of request or directives by non-INKA agents, especially by the environment agent.

The integrity agent ensures a safe technical state of the system, especially by coordinating the initialisation of different agents during the start-up process.

The command agent enables us—during system development—to test the C-IPS layers of the INKA agents independently by initiating different types of negotiations: without any guidelines or with a given issue and/or a given partner.

7 Design of Interactivity Experiments

Treating the investigation of hybrid settings as one step of its own in the overall design process for MAS refers to the original Socionics program [32], in which the term hybridisation has been used for all processes of re-entering the computer agents into the real-world domains from which their coordination principles were derived—a process that could broadly be labeled as the 'socialisation' of agents which "incorporate" sociological concepts. In the resulting settings, there is interactivity between technical and human agency, and organisational coordination is based on an entanglement of human and technical sociality (see for these definitions [43]).

As noted earlier, the main challenge at this point is to make an examination of these new settings possible. In order to achieve a methodologically controlled examination, we started with two considerations. As opposed to philosophical definitions of what is the 'true nature' of an agent's agency, we defined the following: if the mutual impact of technical entities as well as their relations to human actors can sensefully be described as social interaction, we will talk of hybrid settings. And as opposed to the often overgeneralised and highly speculative notions of technical agency (e.g., in actor-network theory; see [44]), we developed a methodologically controlled approach to an examination of the theoretical problem of hybridisation.

7.1 An Experimental Approach

The main issue under discussion is: How can we analyse and examine the interactivity between human agency and technical agency in the early phases of system development in a methodologically adequate way? Because the changes to be examined are processual in nature and a variety of parameters are involved, an experimental procedure seems to be appropriate where the examination can be restricted to assumed effects of independent variables on one single variable. By this we draw on a narrow understanding of "laboratory experiments" in sociological methodology and socio-psychological experiments about group behaviour ([40, pp. 289ff.]) which are commonly defined as consisting of three parts:

1. The formulation of precise hypotheses concerning the relationships between the variables involved in the phenomena to be examined.
2. The creation of an examination setting that provides optimal conditions for testing each hypothesis (cf. [5, pp. 204ff.], [57, pp. 32ff.]).
3. The explicit control of the validity of the experimental results, e.g., by introducing control groups or by repetition of series of experiments.

7.2 Hypotheses

In the INKA-project, processes of hybridisation are to be examined in the context of successful organisational coordination based on practical roles. By this we aim at exploring the "social chemistry" (see Section 4.4) and its change through the introduction of sociologically grounded agents. So we focus on patterned variations of social types and their effects on shift negotiations. In an artificial setting, it will be examined whether different optimal shift-plans are the outcome of the negotiations of humans and agents. These changes may, of course, have different time frames. In the following sections, we only describe a static interactivity experiment which is designed for a short-time adaption to an equilibrium of social types.

The coordinational effects that different mixing ratios generate are operationalised with three hypotheses:

1. The precondition of balancing formal and practical roles is that homogenisation limits the productive use of social difference because the scope of activities is smaller. In our domain we assume that resisting the tendency towards homogenisation makes shift-plans with a poor quality more unlikely. The corresponding hypothesis is: *A non restrictive set of social types achieves better results with regard to the quality of shift-plans than a restrictive set of social types.*
2. It can be assumed that a productive use of social difference does not only depend on the sheer number of types but in the first place on a smooth fit of the types involved. Therefore we are not only interested in the mixing ratio of social types but also in the patterns of distribution of types. The corresponding hypothesis is: *The pattern of distribution is the essential factor for the quality of shift-plans, independent from the social types involved.*
3. Even if agents are modeled on social mechanisms, they still are technical creatures and thus differ from humans in nature. Therefore, it has to be assumed that there are different stable mixing ratios reflecting various interdependencies. The results depend on the type of negotiation partners. The corresponding hypothesis is: *There are various stable mixing ratios of social types depending on the nature of negotiation partners—if they are only agents, only humans, or if they are mixed.*

7.3 Indicators

In experimental runs, these hypotheses will be ultimately proved by the quality of the new shift-plans that are the result of the negotiation process. But as the quality is a collective aggregate, it is by no means clear how this quality can be measured at the outset. Using statistical methods, we developed the following indicators to measure a collective quality.

Collective satisfaction with the negotiated shift-plans: Individual satisfaction can be expressed as the percentage of leisure-time interest every single individual can realise. As a collective measure, we define the following: The degree of collective satisfaction is high if the majority of staff reaches an individual satisfaction that is higher than the above-average satisfaction, and at the same time the dispersion of individual satisfaction is small. We weight the results on an ordinal-scale from 1 to 10. A shift-plan that produces a high mean and a small dispersion of satisfaction is scored as the best result.

Frustration caused by the negotiated shift-plans: The individual interest in efficient shift negotiations is defined in negative terms. The measure is the individual frustration which is the ratio of unsuccessful negotiations of that individual to all negotiations it was involved in. A negotiation is unsuccessful if it is canceled because it takes too long. The degree of collective frustration can be defined to be small if the average of the staff shows little frustration and the dispersion of individual frustrations is small. In statistical terms, the best result is composed of a small mean and a small dispersion of individual frustrations.

Organisational perspective to negotiated shift-plans: The organisation at large has a strong interest in a minimum of rotation of the employers concerning the different shift types (early-, late- and night-shift) because in case of accident every employee needs to know the specific workflows of every shift in order to get all the incidental jobs done. We calculate this minimal organisational request in the following way: An individual employee who covers all the different shift types in the common accounting period gets the value 1. If he fails to do this he gets the value 0 what means that he is sanctioned by the organisation. For the collective measure we defined different thresholds. If only 75 percent or less of the staff fulfil this request of minimal rotation, the whole shift plan will be dropped by the organisation. Such a shift-plan gets the value 0, and it will simply be refused by the organisation whatever the values for satisfaction and frustration are. If 75–89 percent of the staff fulfil the rotation conditions, we multiply with 0,8. In the optimal case of 90–100 percent we multiply with 1.

The collective results of these three indicators are calculated in the following way: *(Score satisfaction + score frustration) × value of organisational perspective = score for the quality of shift plan.*
Initial computations show that this mode of statistical evaluation offers good distinctive features for a measurement of the quality of shift-plans based on the constellation of social types.

7.4 Experimental Setting

Because under experimental conditions, the test-persons can concentrate solely on negotiation task, these negotiations will lead to rapid results. Therefore, a considerable amount of single negotiations with different starting conditions and different exercises can be run in relatively short time (we plan a two day experiment). The concrete setting can be described as follows: The test-persons sitting isolated at computers are in a black-box situation because they do not know if the other negotiation partners are humans or agents. Every test-person gets specific negotiation jobs and a list of the social types of the other participants involved. For putting this experimental situation to work, we have to choose professionals working in a hospital as test-persons because they need to have experience with the various social types and their behaviours.

For the analysis of the experiment, we can draw on two different data sources: the negotiation protocols, which are compiled by the computer, and the new shift-plans that are resulting from negotiation. As we are only interested in the results of negotiations, these data are sufficient for a check of hypothesis and an interpretation with the indicators mentioned above.

7.5 Ensuring the Validity of Experimental Results

Experiments in the social sciences call for internal validation criteria. We adopt the proposal of a "pretest-posttest control group design" ([16, p. 248]). The pretest has to assure that the measured effects are not only an outcome of the instrument (or the experimental setting) itself; therefore, running the whole procedure without agents is one good test. Additionally, we systematically compose control groups of humans and agents likewise and deploy them in every phase of the experiment.

7.6 Outline of Dynamic Interactivity Experiments

We designed a second type of interactivity experiments for an examination of dynamic changes that arise from hybridisation over a longer period. As with any introduction of a technical system in an organisation, the introduction of our MAS can be expected to cause effects on two different levels of scale: on the level of interaction, we will analyse the emergence of negotiation routines from interaction and from interactivity; on the level of the organisation at large, we will analyse the emergence of coalitions and "communities of practice" in the overall context of organisational learning. Extending the experimental approach to dynamic processes calls for a different setting and duration of the experiments.[18] As the specification of these experiments is future work, we, in this article, only present the general outline of the extension to the organisational level at the end of the following section.

8 Discussion: Constructing MAS and Social Levels of Scale

In the previous sections, we have introduced the modelling principles, the implementation, and the experimental use of our MAS. Each of these subsequent steps tries to tackle the challenges that arise from the practical rationality of organisational coordination, and utilise the concept of social roles for the design of a MAS. With this approach, the capability to enact social roles is directly built into the agents architecture, in other words: mechanisms and data sets from the levels of groups (practical roles) and organisational subunits (formal roles) are "incorporated" into the single agents. For this reason, our approach is not intended to work for high numbers (to be sure: for millions) of agents or interactions; the approach is located at a middle level of scale from the very beginning. But the issue of scalability is about spanning different levels of scale, especially from the micro- to the macro-level. How does our approach contribute to this issue? Beside being located at a middle level of scale, the basic idea about role based perception and action is the reduction of complexity at the interaction level—and this can be discussed with respect to different kinds of scales. Before we address some of the dimensions in which our MAS is meant—and in some respect in fact turned out—to be scalable, we first have to outline our understanding of scalability.

[18] It will be necessary to bring the system to the real world-context of the test-persons who will daily negotiate via and with the MAS for at least one month.

8.1 Dimensions of Scalability

Generally speaking, the scalability of a system is related to a scale where the system can be located. To scale, then, means to relocate the system without—this is the crucial point—negatively affecting or even destroying the overall functionality of the system. In MAS research, the most prominent example for such a relocation is the increase of the number of agents within the system. As the contributions in this volume show (especially Paetow, Schmitt, and Malsch), in the Socionics program there are many relevant scales which can be grouped in different dimensions. Even with respect to the "quantitative dimension if scalability" (Schimank in this volume), there typically exist different scales. That means that the sheer number of agents is only one relevant aspect; scales as number of interactions, size of environmental parameters, or number of messages sent between the agents can be equally important. Furthermore, the "qualitative dimension of scalability" (ibid.) is at least of equal importance, which means that the complexity of the agent architectures or the basic parameters of the interaction processes have to be chosen with respect to the level of scale of social coordination that the overall design is aiming at.[19] Qualitative scaling, then, is not only defined as any change in these complexities, but also inherently linked to pre-given levels of scale from the social world.

Seen from the level of system design, all of these possible scales do interfere with one another, and, of course, have an impact on the overall functionality of the system. In our understanding, any scaling operation has to be measured in the light of the problems to be tackled or by the required properties of the system at hand. These properties might be senseful and immediate reactions of the system, length and desired outcome of interactions, or the fact that the system after some time reaches a stable state. With this focus on a given technical system, two different meanings of scalability should be distinguished which build on one another. The first meaning is that the system is built in such a way that it can be easily relocated. The question, then, is whether it is possible to make changes at any of the scales mentioned without major changes of the system or even without stopping the system. This is an architectural prerequisite for the second meaning of scalability which asks whether scaling in fact negatively influences the functionality of the system. Due to this second definition, a system is scalable if an increase on one scale does not affect the property of the system, or whether the property remains within an acceptable range.

8.2 Scales and Scalability in the INKA System

On the basis of the definitions given, we now can summarise the most important features of our system that allow (or even call for) scaling. Furthermore, we summarise some of the results from simulations that show how scalability in fact can be achieved with the system.

Qualitative Dimension. With our approach, we aim at enhancing the modelling of MAS at the micro-level by the introduction of meso-level concepts. We hope that the

[19] This is not surprising because from sociology we know that the mechanisms of coordination on the level of interaction are different from those on the levels of groups, the level of organisations, and the level of society at large.

previous sections showed that meso-level knowledge about human social systems, represented by social types, can be successfully utilised in MAS design. By giving our agents an understanding of empirically relevant social types, they can adapt their behaviour not only based on individual experiences but also based on knowledge that has emerged in the human social life. Because this knowledge is generalised in nature, we are able to address and test two more special aspects of qualitative scalability. We are able to increase or decrease the sophistication of the agents' negotiation strategies and adapt the latter to the required properties, especially to a sufficient number of successful negotiations within an acceptable range of time. Moreover, with the layered architecture of the C-IPS framework (see Section 5) we are able to test the single layers of the agents' internal calculations stepwise. This reduction of the complexity of the overall negotiation behaviour turned out to be very useful, not only for testing purposes, but also for a better understanding of the aggregated outcome of the agents' interactions.

Quantitative Dimension. To use generalised knowledge for micro-level interactions (in our case: negotiations) is not only of interest for issues of agent architecture, but also for the change of the sheer number of parameters involved. In our case the, most important quantitative scale is the number of agents.[20] Our system, first of all, is designed to allow the increase of the number agents without stopping the system—many agents can enter or exit the system dynamically without causing technical problems or the necessity to restart the system.[21] With this prerequisite given we tested how the increase of the number of agents effects the rate of successful negotiations and the negotiations' length[22]. If the agents would calculate without generalised knowledge, the sheer number of negotiations would increase to the second, thus lengthening the whole negotiation process and resulting in a strong decrease of the probability of successful negotiations. In our system, on the contrary, there is only a slight increase of the number of negotiations, and the rate of successful negotiations stays within an acceptable range. But it turned out that there is another critical factor: scaling up the number of agents too much leads to an enormous amount of messages exchanged due to the number of possible negotiations—a kind of "information overload" seems to limit the scaling possibilities.

Nonetheless, the "incorporation" of generalised knowledge in a MAS seems to point to some match between the quantitative and the qualitative dimensions of scalability. Our purely numerical findings could be interpreted in terms of "social experiences" the agents make, and these experiences do bring about a positive reduction of complexity. The argument goes as follows: Social types, by definition, provide a way to classify agents, and this allows the generalisation of experiences made with individual agents to all agents of its class. This procedure becomes critical if the number of agents in the system increases because the agents' costs (investments in, for example, time) to gather

[20] Additional scalable parameters are from the data environment of the agents, e.g., the size of the shift plan or the number of tasks, i.e. leisure time interests, to solve.

[21] From our approach, it should be clear that we are talking about small numbers of agents (up to 20).

[22] Acceptable length of the negotiations is part of the definition of success, thus constituting another scale; see our formalisation of "frustration" from negotiations that take too much time in Section 7.3.

reliable experiences about other agents explode. Applying social types simply works against this paralysing complexity, and thus increases the probability of successful negotiations.

Dimension of Hybridisation. The re-entry of the MAS into a real organisation does not simply add more entities to the system, but multiplies the relations and the parameters involved. In the context of scalability, this means that hybridisation constitutes another relevant scale. At this last stage of our development cycle, the utilisation of meso-level concepts is of special importance. Giving our agents an "understanding" of social types, derived from the human social reality they are now confronted with, makes a compatibility of the different "experiences" more likely, and by this decreases the unpredictability of the whole process.[23] Moreover, the C-IPS agent architecture allows to switch between different degrees of autonomy of the agents' decision making, thus enabling MAS designers to scale this degree—this can be very important for the achievement of an overall functionality of the whole setting. Doing this dynamically in a hybrid system, one can smoothly change the ratio of decisions done by humans versus decisions done by artificial agents. In our view, this is the technical prerequisite for a better reflexion of the usage of MAS in the real world because we can stepwise transform a human social system with computer-supported interaction to a hybrid system.

8.3 Extending the Approach on Different Levels of Scale

Any modelling and implementation of a computer system bears its own limitations. In our case, this is especially obvious with respect to the dynamic interactivity experiments (see Section 7.6). This makes some major extensions of the modelling and the implementation necessary, extensions which, again, can be located on different levels of scale.

Introducing Negotiation Routines. As outlined above, the test of the quantitative scalability of our approach pointed to the problem of information overload by the sheer number of messages exchanged. This calls for a generalisation of "experiences" by the single agents themselves, in other words: to an extension on the interaction level. It seems that the agents' enactment of practical roles would be incomplete without the capabilities of learning and following routines. We are trying to achieve this by introducing Case-Based Reasoning (CBR). CBR [1,30] is, generally speaking, a structured approach to machine learning that stores and provides former experiences as single cases, and uses known cases as a solution for new but resembling situations where the solution is not evident. Those cases with the most similar problems are retrieved from

[23] In our approach social types are also used to measure the final output of the hybrid system (see our statistical evaluation Section 7.3). Here, the interplay of many of the scales mentioned has to be considered because the goal fulfilment in open (or even in closed) systems where agents and humans interact, calls for an aggregation of individual goals. Arrow's theorem raises doubts about the existence of a unique aggregation [4]. Criteria already developed for isolated negotiations (e.g., [47]) cannot be applied when working with many interdependent negotiations which we use in the INKA project.

the case-base and their positive solutions are used to solve the current problem. The main questions are: What defines a situation as to be able to recognise "resembling" situations? And how could we conceptualise negotiation strategies to allow the agents to routinely act on behalf of anticipated negotiation results?

Introducing Coalition-Building. The necessary reduction of interactions' complexity can also take place on the level of groups. Especially coalitions can, as we know from sociology, drastically reduce the costs of negotiating by delegating parts of the individual interests to a group. The dynamic interactivity experiment is planned to cover a time-span long enough to allow an examination of coalitions emerging.[24] In our context, the main questions are: Does the introduction of the MAS result in hybrid coalitions of humans and agents? And what does this mean for the efficiency and flexibility of the organisation's PEP procedures?

Introducing Organisational Learning. For an overall picture of organisational coordination, one aspect of practice-based coalition building is of special interest: the emergence of "communities of practice" (cf. [55]) which are composed of the members of the organisation who care collectively about practical problems of the organisation, without having the official duty to do so. This can be viewed as a special type of organisational learning because it leads to a dynamic re-balancing of formal structure and practical rationality in the organisation at large. In our context, this practical problem is the efficiency and fairness of the distribution of shifts. We focus on the question: Does the introduction of the MAS result in hybrid communities, and what are the organisational consequences of this strengthening of practical coordination?

These extensions require additional conceptual work, and they have to be translated into concrete hypotheses and indicators in order to enable a methodologically controlled examination. In some respect, this starts the development cycle anew. But on this basis it will be possible to achieve a full-fledged approach to the investigation of hybridisation processes, thus closing our version of the Socionics' development cycle.

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[24] Patterns of coalition building are also of great interest for the modelling and validation of complex decision making in computer science; see cf. [29].

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