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Socionic Multi-Agent Systems Based on Reflexive Petri Nets and Theories of Social Self-Organisation

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Abstract

This contribution summarises the core results of the transdisciplinary ASKO project, part of the German DFG's programme Sozionik, which combines sociologists' and computer scientists' skills in order to create improved theories and models of artificial societies. Our research group has (a) formulated a social theory, which is able to explain fundamental mechanisms of self-organisation in both natural and artificial societies, (b) modelled this in a mathematical way using a visual formalism, and (c) developed a novel multi-agent system architecture which is conceptually coherent, recursively structured (hence non-eclectic) and based on our social theory. The article presents an outline of both a sociological middle-range theory of social self-organisation in educational institutions, its formal, Petri net based model, including a simulation of one of its main mechanisms, and the multi-agent system architecture SONAR. It describes how the theory was created by a re-analysis of some grand social theories, by grounding it empirically, and finally how the theory was evaluated by modelling its concepts and statements.

Keywords:
Multi-Agents Systems, Petri Nets, Self-Organisation, Social Theories

Introduction: The ASKO Project

1.1

One main aim of the socionic research programme is to construct multi-agent systems (MAS), which adopt the robustness, flexibility, fault-tolerance, and adaptivity of natural socialities. But what kind of entities constitute and reproduce these attributes of social systems? This became the early core question of our project *Acting in social contexts (short: ASKO)* (University of Hamburg) So we went a step back from simulating and executing models in favour of taking a closer look at empirical and theoretical research on natural ways of constituting and structuring stable but flexible social systems.

1.2

With respect to other socionic projects, covering theoretical approaches like systems theory, methodological individualism, or network theory, ASKO developed an amending, discrete perspective. From social theories that especially deal with the micro-macro link of sociality, it extracted more or less implicit concepts of mechanisms that produce recursive processes and structural dynamics and, in the end, emergent, flexible, and stable structural orders. Those concepts were grounded by empirical research on self-administration processes in universities, and then combined to a middle range theory of social self-organisation (TSSO). Our work aimed at building and modelling a theory capable of describing extremely different self-organising processes and structures.

1.3

This theory then got modelled with Petri nets. Petri nets as a high-level, visual and highly abstract formalism allow to operationalise core mechanisms of social theories. The interrelations, discrepancies, (in-)consistencies and gaps of the sociological theory can be graphically shown and logically evaluated. By this means, logical or conceptual gaps were minimised. The structural analysis of these nets serves as the explication of possible and predictable social dynamics and processes, and as an evaluation of the TSSO.

1.4

Simuation methods are able to estimate the quality of a model by comparing its prediction with the real world. Nevertheless, simulation methods treat models as *black boxes*: It is not possible to discriminate models describing the same dynamics, i.e. having the same *extension*. As we aim to build a theoretical model which contemporaneously will be an approach for MAS architectures, our focus lies on the inner structures of the model itself.

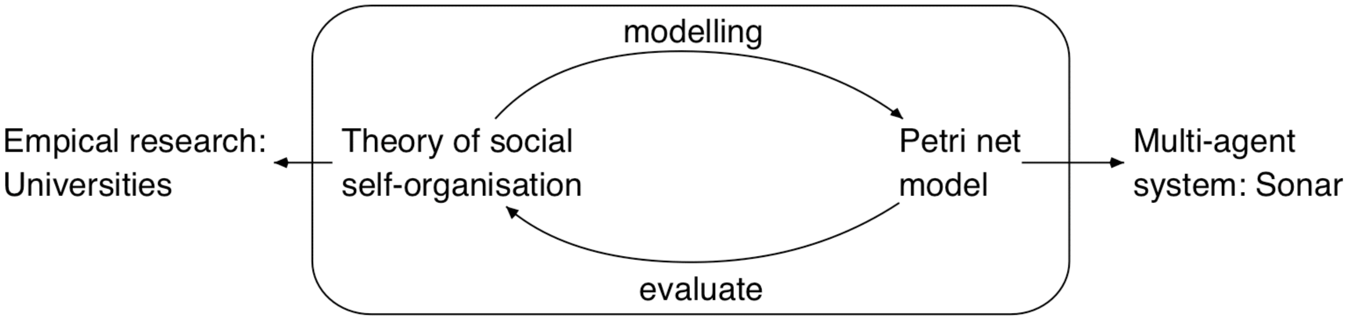

Figure 1: Structure of our Contribution

1.5

Our research approach is a recursive process (cf. Figure 1). It starts with the social theory. This theory is modelled, the resulting Petri net model is evaluated, and the results are used to improve the social theory. The revised theory is modelled again and so on. The result of multiple passages through this recursive process is a novel concept for MAS-architectures allowing to change and rearrange the structure while running. In this contribution we concentrate on this process and will describe briefly its relationship to our empirical research and to our multi-agent system Sonar.

1.6

The paper is structured as follows: A short description of the ASKO approach concerning socionic theory re-analysis and modelling is given in Section 2. An overview of the main results, namely the Petri net based model of the theory of social self-organisation (TSSO) is given in Section 3. Section 4 describes the relationship to our empirical research. Section 5 presents the multi-agent system Sonar, designed following the principles of the TSSO approach. The last part will provide a summary and an outlook.

Socionic Theory Formation, Modelling, and Evaluation

2.1

The development of the theory of social self-organisation roots in different origins, in social theory formation, modelling, and evaluation combined with empirical research and practical design concerning MAS (cf. Figure 1).

Theory Formation: Systematic Combination of Theories, Empiricism and Practical Problems

2.2

The sociological approach of ASKO is a reaction on a specific professional state. Sociology possesses a wide and fruitful variety of theories and explanations and a colourful bunch of empirical approaches. But whenever facing a new kind of explanation problem, finding a suitable theory and combining it with empirical insights becomes more and more demanding. Now, due to actual societal tendencies, (even social) science will be obliged to switch into "Mode 2 of knowledge production" (Gibbons). This means combining theoretical models and empirical descriptions, while transcending disciplinary borders, to focus explanation powers on dealing with complex and opaque (even social) problems. Sociology needs an amendment to its variety: a clear set of bounded theoretical models of social mechanisms, and specific rules how to combine them and how to apply them to the handling of practical problems. (Recently, this need for combination became a main issue at least in the theory section of the German Sociology Association, DGS.)

2.3

ASKO used and developed a heuristic approach to bridge inner disciplinary divides, notably between different theories as well as between theory and empiricism (v. Lüde et al. 2003). This method is the well known methodology of heuristic research (cf. Kleining 1994, 1995, 1999; Kleining and Witt 2001). It is capable of dealing with any kind of data from complex theoretical texts to simple empirical descriptions. And because it favours an analysis on similarities, it draws attention to hidden connections. Now of course ASKO could not take every social theory in this analysis on similarities, we had to select. We have omitted theories used by the cooperating socionic projects (systems theory, individualistic approaches, network theory). Chosen were theories which (a) dispose over a comparable level of abstraction, (b) are grounded in empirical research, (c) systematically deal with the micro-macro-link, and (d) focus on constellations of actors or social units with a specific balance point on inequalities, and on struggles for distribution structures and forms of social order. The chosen theories were the Habitus-Field, Capital, and Institutionalising Theory of Pierre Bourdieu, the Power and Norm Formation Theory of Heinrich Popitz and the Process and Figuration Theory of Norbert Elias. Some theoretical models provided by Anthony Giddens and Zygmunt Bauman were added. For the results of the reconstruction of these theories see (v. Lüde et al. 2003); for a detailed elucidation of the analysis process and how the theories got integrated, see (Langer 2003, 2005a).

2.4

The analysis on similarities between those theories resulted in an outline of a general theory of social self-organisation. This outline was additionally grounded on empirical research on universities and schools. The combination of the theoretical and empirical research resulted in a middle range theory of basic informal and *blind* mechanisms of self-organisation in educational institutions (TSSO) (Langer 2005a). This is of course still a preliminary outline but already based on soundly empirical grounding research.

The Modelling Formalism: Petri Nets

2.5

This pure sociological analysis was accompanied by modelling the original theories and the outlined integrative theory with Petri nets. A sociological integration was carried out at the same time. We have chosen Petri nets as our project formalism for several reasons. Details can be found in (Girault and Valk 2003):

- Petri nets can be represented in a graphical way, which is beneficial for the interdisciplinary discourse with social scientists (after a certain familiarisation phase).
- Petri nets are based on the fundamental duality of passive and active elements.
- Petri nets inherently express structural as well as process concepts the same way ("processes of Petri nets are Petri nets them-self").
- Unlike other automata formalisms Petri nets allow the modelling of concurrency (i.e. independent events). They also allow for an intuitive representation of the notions of causality, alternatives, parallelism, non-determinism, resource, action, and others.
- Well established extensions of the basic formalism exist, e.g. for the incorporation of structured data, object-orientation, timed activity etc.
- A broad spectrum for the analysis of Petri net models exist, e.g. structural analysis or model checking.
- Petri nets are chosen for the formalisation of UML models.
- Petri net models are directly executable, thus it is possible to gather arbitrary simulation data form the models

2.6

In the following we give an informal description of Petri nets, for an introduction cf. (Kummer 2001). A Petri net is a (bipartite) directed graph with two different kinds of nodes: *places* (passive elements) and *transitions* (active elements). Places represent resources that can be available or not, or conditions that may be fulfilled. They are depicted in diagrams as circles or ellipses. Transitions are denoted as rectangles or squares. A transition that *fires* (or: occurs) removes resources or conditions (for short: tokens) from places and inserts them into other places. This is determined by arcs that are directed from places to transitions and from transitions to places. Petri nets are a well established means for the description of concurrent systems. An example for the dynamics of Petri nets is given in Figure 2. The transition act *may* occur (*fire*), because the places p_1, p_2, and p_3 (the preconditions of the transition act) are marked, but it does not have to fire. If the action is carried out, the marking of the net changes: now the places p_4 and p_5 (the post-conditions) will be marked.

Figure 2: A possible Action and the Outcome of the Action

2.7

Coloured Petri nets (Reisig 1991; Jensen 1992) allow to combine parts of a Petri net with the same structure by a *folding* operation. Arcs are inscribed with variables that are *bound* to available (coloured) tokens (e.g. integers, strings etc.). So one transition may describe a multitude of possible actions dependent on its binding - each of these bindings is equivalent to a single transition in the unfolded ordinary (non-coloured) Petri net. One transition of the coloured net usually stands for a multitude of transitions of an uncoloured net. Coloured tokens are removed and created in accordance to the binding of the firing transition.

2.8

The paradigm of *nets-within-nets* introduced by R. Valk in (Valk 1998, 2003) formalises the aspect that tokens of a Petri net can also be nets (see Figure 3). Such *net tokens* are a conceptual advancement (from simple Petri nets to coloured Petri nets to nets-within-nets), because they introduce recursivity to the Petri net theory (Köhler and Rölke 2004). Taking this as a view point it is possible to model hierarchical or recursive structures in an elegant way. Note, that this feature is essential to model reflexive structures as described by social theories (as the TSSO - see below).

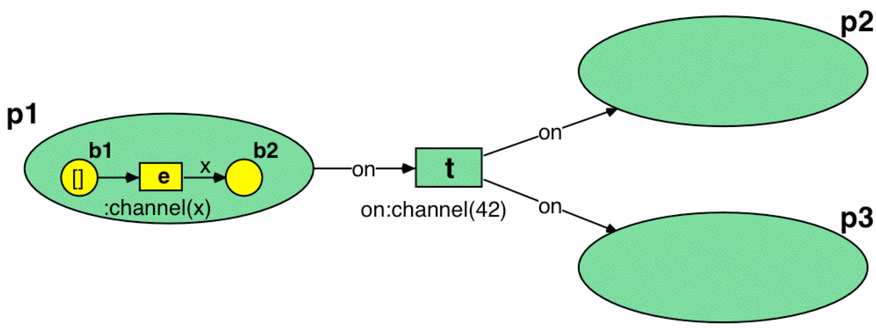

Figure 3: A Petri Net as a Token

2.9

A net that contains nets as tokens is called a *system net*. The net tokens are *object nets*. Nested hierarchies with more than two levels are possible, even more, any reference structure including cyclic and hence reflective ones are allowed. In the simple example of Figure 3 place p_1 of the system net contains an object net as a token. The inscription on:channel(42) of the transition *t* in the system net is a so called *down-link* to the object net. The corresponding *up-link* :channel(x) in the object net is inscribed to transition *e*. Up-link and down-link constitute a *synchronous channel*, a communication means in reference nets. Both transitions that form the parts of the synchronous channel may only fire synchronously. When firing, it is possible to exchange information from one transition to another (bi-directional). In the example, *t* and *e* may only fire together and if they do so, the net token is bound to the variable *on* and the value 42 is passed to the variable x. Note, that the Petri net concept of a *variable* differs from the one in programming languages, and is related to the variable concept of predicate logic. Variables are only bound locally. In more complex nets several down-links and up-links may match. They are bound at runtime as a part of the token-to-variable binding search of the Petri net simulator Renew (Kummer et al. 2004) which is an open-source run-time engine for Petri nets based on Java. Renew allows for modelling, execution, and simulation of Petri nets (cf. the tool's homepage www.renew.de).

Modelling: Being Precise

2.10
One of our project's aims was to find out what Petri net-based modelling of social theories can perform with regard to the evaluation of theories. In short, the results are as follows.

2.11
Computer science is forced to incorporate detailed information in formal models instead of relying too fast on more elegant but reductive models. The sociological grounding through continuous and consequent feedback for almost every step of modelling not only increases the realism of the evolving social system of agent programmes, but also raises the probability of grasping essential qualities of social systems. Furthermore, the precise sociological grounding can casually open new ways to approach some principle problems of socionics.

2.12
Sociology is forced to explicate theorems and axioms, that are *hidden* in social theories, because the somewhat un-sociological construction focus of the computer science raises specific questions which highlight theoretical areas unmarked by routines of sociological thinking. Relations between concepts and statements - e.g. hierarchical, process and recursive orders - are shown more clearly and distinctly by means of the strict logic order and the graphics of Petri nets (sometimes more than the linear textual account is able to). The same applies to similarities and differences between complex interrelations (or argumentations) between two theories or even within one theory. Furthermore hidden gaps in the underlying theories can be identified, thus providing an additional positive side effect.

Evaluating Social Theories by Analysing the Petri Net Model

2.13
We use Petri nets in order to obtain an operational model. This makes two approaches possible: (a) transferring the socionic elements directly into the multi-agent system architecture without the risk of adulteration of the social concepts (see below) (b) providing a kind of theory simulation to validate the TSSO.

2.14
Below an example for a qualitative theory simulation is given. Here we check by simulation whether the theoretical description of a social unit is rich enough to create those kinds of dynamics which are foretold by the theory.

2.15
Due to the mathematical character of Petri nets a formal evaluation by analysis is possible. This includes static as well as dynamic aspects. Analysis further divides into two possibilities, namely analysis by analysing the net structure and verification of the entire state space (model checking). The dynamic analysis of a Petri net allows for an inspection of liveness (absence of actions that cannot be taken), boundedness (finiteness of the state space), reachability of a given state and some more. A typical questions is: "May a desired state be reached from a given state?"

2.16
The striking examples of static analysis of Petri nets are invariants and structural boundedness. Unlike usual programming languages, Petri nets allow for a computation of these properties. Of particular interest are the so called T-invariants. T-invariants provide information which actions (modelled by transitions) have to take place in order to restore a given (initial) state of the system. The computation of the boundedness of a model may answer the question if, for example, an arbitrary accumulation of tokens is possible.

TSSO: The Theory of Social Self-Organisation

3.1
The theory of social self-organisation (TSSO) is a middle range theory of self-organisation in institutions of education (published in Langer 2005a). Its core concepts and propositions are drafted in the following sections.

3.2
The TSSO conceives *self-organisation* as *rearranging social structures*, which includes all processes and actions that social units generate, build up, stabilise, modify, and even disintegrate. Hence, self-organisation is used synonymously to structuration, a term invented by A. Giddens (Giddens 1984) (The function of references to sociological theories in this text is to show how the TSSO is related to existing sociological theories, to accent its level of abstraction, and to give an idea about possible relations even between seemingly incompatible theories.). Both terms mean influencing structures by structures.

3.3

The TSSO consists of three main parts: Firstly, it proposes a general dynamics of constitution, with which every social unit (re-)creates and (re-)produces itself. Secondly, it provides a dynamics of structuration, that arises whenever social units get to deal with one another and with a problem they define. Finally, the theory reconstructs four main structure dynamics, conceived as typical results after iterated altercations.

The Dynamics of Constitution

3.4

The dynamics of constitution is modelled as a high-level Petri net. The basic entity of the TSSO is the social unit. Its main activities are modelled as the net shown in Figure 4. The elements of the net model (places and transitions) are taken directly from the textual description, e.g. the activities (*accept practically*, expect regularities, ascribe, *symbolise reflexively* etc.) are modelled as transitions; the main concepts (e.g. *stable regularities* or *structural capabilities*) are modelled as places. The net model is explained in the following. Note that the following description does not explain the usage of the high-level net features of Renew, like arc- and channel-inscriptions. For an introduction cf. (Kummer 2001).

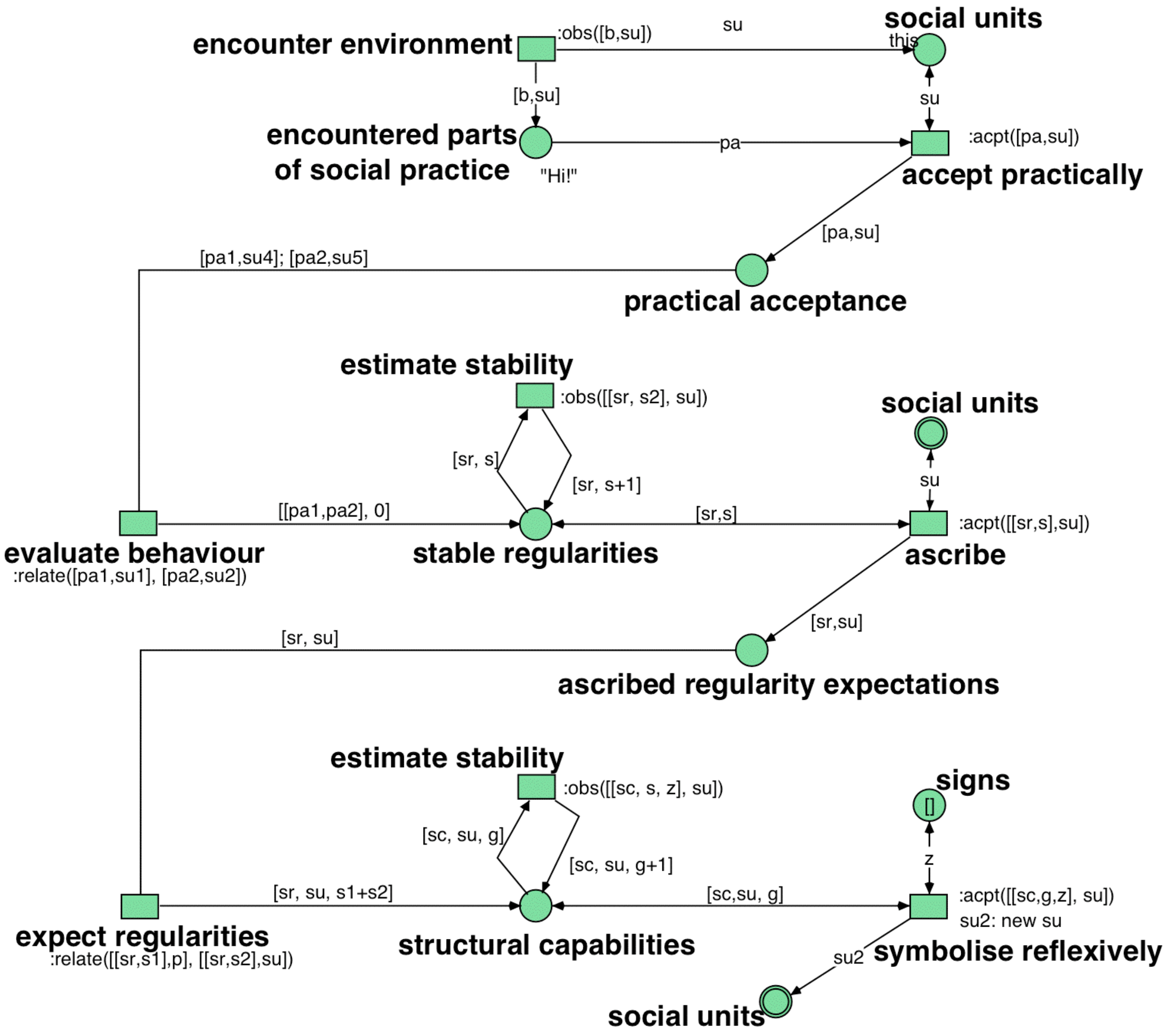

Figure 4: The Petri Net Model of the Dynamics of Constitution

3.5

The social dynamics of constitution is a mechanism consisting of three main factors. The first factor points out that social units basically *encounter* their environment (a) by letting most of it be as it is, (b) by involving own actions in and adjusting them to existing social regularities, processes and structures, and (c) by transintentionally reproducing parts of it, following a pattern like: "one may not want to strengthen the economic system or to support slaughter by buying sausages, but in fact one does so". These three characteristic and coherent ways of reproducing or at least not-resisting existing social structures and processes are called *practical acceptance*.

3.6

This concept, on the one hand, emphasises that any social practice is valued - even values itself -, beacause it is accepted (and accordingly acknowledged) by treating it as if it was worth being treated in this particular way, and by drawing distinctions between certain stressed and certain neglected parts of social practice (cf. Bourdieu 1993). One can underline this aspect by changing the term into *(acknowledging or) accepting practice* or even *accepting behaviour*. On the other hand, practical acceptance as a concept allows to explicitly include all receptive or even passive forms of behaviour into a theory of social action, so that an *actionistic* misinterpretation of social reality can be avoided (a theoretical step demanded by Sofsky (1996) and Joas (1992)).

3.7

This activity is modelled by the transition encounter environment (in the upper left part of Figure 4). The transition has no pre-conditions and therefore it is always enabled. Firing of the transition causes a state change by adding one new token on the place encountered parts of social practice and one token on the place social unit - describing the social unit related to the encountered parts of social practice. The process of practical acceptance is strongly related to the process of encountering the social environment. In the model this is reflected: The post-conditions of the transition encounter environment are the pre-conditions of the transition accept practically. Firing of the transition accept practically generates new practical acceptance. Note, that the concept of *practical acceptance* is twofold - it is the same time a process *and* a result. This dual notion is typical in the socionic context and is reflected directly by the Petri net model using the duality of active and passive elements which is inherent to the Petri net theory.

3.8

Now acts of accepting behaviour (i.e. practical acceptance) usually vary and can get very different. The behaving social units have to accept this practically, if they don't want to lose their ability to be accepted by other social units. Thus, they begin to *evaluate* bygone and to expect coming *regularities of behaviour*, estimating how *stable* those regularities are. They then *ascribe* different stable regularities of behaviour (structures, processes) to certain social units (modelled by the transition ascribe). Once this is done, those social units do dispose of social capabilities. Such capabilities - forms of behaviour expected by certain social units to be performed by certain social units in a regular way - are properties or qualities of these units, and similarly they are parts of their structure. This complex is conceptualised as *structural capability* or *capability structure*, which is the second factor of the social dynamics of constitution.

3.9

There are two main efforts of this concept according to sociological explanation. Obviously it integrates an actor-attribute-highlighting concept of capability (Coleman 1988 1990; Bourdieu 1987; Putnam 2001) - as the basis of social power and any form of social capital - and a relation-and-regularity-emphasising concept of structure (cf. e.g. Giddens 1984; Reckwitz 1997; Popitz 1981) as two views onto the same object. In addition, the concept of structural capability relates some so far fragmented theoretical models; e.g. the relation between regularities and resources (Giddens 1984) is explained, and the similarities between different types of capital are reconstructed: the essence of capital is the capability to act.

3.10

The process of evaluation is modelled by the transition evaluate behaviour, which operates on the current marking of the place practical acceptance and stores the outcome of this evaluation as a token on the place stable regularities. The ongoing process of evaluating of the stability degree of the tokens on place stable regularities is modelled by the transition estimate stability. Here the Petri net concept of concurrency is of special interest. Nevertheless the fact that the dynamics of constitution is presented in a sequential way and that the explanation of the Petri net model follows this sequence, the dynamics is not sequential at all! For example the activity estimate stability is independent from the activity of practical acceptance and even independent from estimation activities concerning a different kind of stable regularities. This independence is stated explicitly by concurrency of activities in the net model and helps in the understanding of the TSSO. The transition ascribe takes a token from stable regularity and one token from social units to model the activity that one stable regularity is ascribed to a certain social unit. As a result a new token is generated on the place ascribed regularity expectations. This is a direct example for the direct transformation of a central TSSO-theorem into the net model. The similarities in the evaluation activity - with respect to practical acceptance and stable regularities - are reflected by the model: ascribed regularity expectations are expected (transition expected) which generates new tokens on the place structural capabilities which are again subject to an estimation process.

3.11

As social structures and capabilities are changeable in large amounts and as they are not directly visible, actors are coerced to stabilise and visualise them, if they somehow want to get (and stay) capable of acting socially. They do so by *symbolising* structures and capabilities (or parts of them) by adding *signs* to them. The results of these symbolising acts accumulate to the *reflexive symbolism* or the *symbolic reflexivity* of a social unit.

3.12

This is the third factor of the dynamics of social constitution. It is called reflexive, since the social world relates to itself in this specific manner of mirroring by signs (cf. Rehberg 1994). This activity is modelled by the transition symbolise reflexively which operates on tokens of the place structural capabilities and on signs. The result is a reflexively symbolised capability structure, which is in fact a social unit generated onto the place social units. Reflexive symbols and symbol-mediated reflections are the only way in which social reality appears explicitly and can get caught, thought, communicated about and intentionally influenced by itself, respectively by the acting and reflecting units it consists of (this means a specific type of basic social self reference (Luhmann 1984, 1997) which is regulable from almost non-reflexivity to, e.g. the degree of reflexivity postulated by Beck and Giddens for the *second* modernity). Every reflexive symbolism only illuminates a small selected part of all structural capabilities, though.

3.13

The concept of symbolic reflexivity allows systematising well known sociological core concepts. Norms and procedures (Habermas 1992), e.g., have in common that they are symbolised expectations on regular behaviour, positions (Popitz 1981) are symbolised units of fixed structural capabilities - and for this reason of course parts of social (capability) structures -, whereas titles and names (Bourdieu 1987, 1993) are symbolised ambulant structural capabilities. Furthermore, the theory inter alia shows that symbolic capital must be more fundamental than economic and cultural capital (which ultimately are but specified sorts of social capital, which is nothing else than structural capability); that reflexivity is a basic feature of all social units (hence it is inauspicious to characterise an era as a *reflexive modernity*); and consequently it conceptualises symbolic reflexivity as a social act and releases it from being tied to the consciousness of single persons.

Evaluation of the Model

3.14

In this article, we often use the terms *social unit* when it comes to the subjects of social processes. We do so because of widely spread understanding routines. But we do have an elaborated concept of what a social *unit* is. We call it *practical order* (respectively order of practice). Depending on what perspective one takes up, a practical order can be seen as a structure, a process, a society or group, or even as an actor. This concept allows not to prejudge certain qualities of whatever becomes subject or object in the social world, so the forthcoming multi-agent architecture does not need to handle with conceptually separated different units. To put it in a nutshell, you can say *all is practical order* (like *all is data* from Strauss' and Glaser's Grounded Theory) - or, as for modelling multi-agent systems, *all is agent*, whereas the term agent does no longer have a hidden *person* connotation. The hypothetical slogan *all is practical order* is empirically grounded: it reconstructs, that people fundamentally can treat all social units as actors (*the curriculum craves*), as a differentiated sociality (*the instructions in the curriculum are contradictory*), as a structure/capability (*this curriculum enables us to follow international standards*), or as a process/activity (*students go through a curriculum*). The slogan is theoretically grounded: Just take a look, e. g., at all the units theories treat implicitly and explicitly as actors! For these reasons it became necessary to create a concept for *all units being treated as actors*.

3.15

We want to point out that our theory does not claim any prerogative for macro or micro phenomena, for actions or for structures, for persons or societies, for systems or for frames etc. etc. They all are but varieties of practical orders; the rest is up to subject-adequate specification of the theory.

3.16

As a result of the modelling effort we like to point out the following similarities concerning the inner structure of the TSSO which in fact can be seen very clearly already from the graphical representation of the Petri net model. The activities of the constitutional dynamics, namely: *accept practically*, *ascribe*, and *symbolise reflexively* share certain similarities (Note that these similarities are visualised by the symmetries in the net layout.):

1. Each activity is embedded into forms of social practice: *encountered parts of social practice*, *behaviour expectations*, and *structural capabilities*, respectively.
2. Each activity is related to that *social unit* (or the *sign*) that is referenced by it.
3. Each activity generates archetypes of social structures: *practical acceptance*, *ascribed expectations*, and *social units*, respectively.
4. Each archetype of social structures is transformed into a stable form (*stable regularities* and *structural capabilities*) as a result of an evaluation process (modelled by the transitions *evaluate behaviour* and *expect regularities*, respectively).
5. The elements of social structure (*stable regularities* and *structural capabilities*) are both subject to change, modelled by the transition *estimate stability*, which relates the actual environmental forms of social acceptance to the current regularities constituted by the social unit.

3.17

The formal analysis of the Petri net structure reveals several interesting insights. Here we name two of them:

1. All places in the model are unbounded. This indicates that the TSSO model has no mechanism to "forget" data.
2. T-invariants include only both transitions estimate stability. This indicates that the system has a permanent dynamics since in a stable state only observing behaviour is possible.

These facts were of interest for the social scientist of our project, since they imposed questions which helped to improve the TSSO.

The Dynamics of Social Structuring

3.18

The outlined concept of a dynamics of social constitution specifies the system-theoretical idea of *autopoiesis* according to social phenomena. It grasps an almost completely transintentional and therefore utterly striking mechanism of social (re-)production and self-organisation. For the concept of *transintentionality* cf. (Greshoff et al. 2003). The consequences of constitutional dynamics can be shown by taking a closer look at what happens when multiple social units deal with one another and with a problem or an issue they are interested in. It is easy to see that the (re-)production process of a social unit is related to those of other units. The system generated by the totality of all social units is modelled in Figure 5. Note that the constitution dynamics is not only a process of re-production for the social unit of actual interest. It also is an auto-poetic process with respect to the whole system generated by the totality of all social units. Here the use of a reflexive and recursive Petri net formalism is of special importance: *reference nets*. The place social units contains the tokens that model those social units which are participating at the quarrel. The tokens are Petri nets, that share the structure if the net shown in Figure 4. The initial state of the model is set by the transition init, where the inscription su: new su denotes the creation of a new instance of type su (social unit).

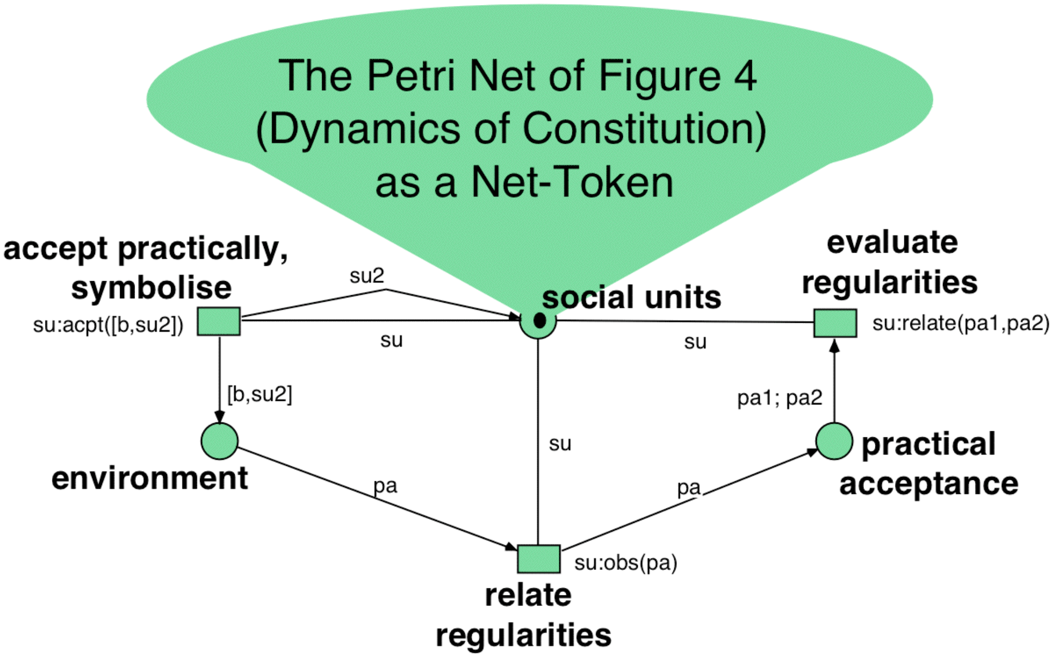

Figure 5: The Dynamics of Social Structuring Modelled with Reference Nets

3.19

This *dealing with* in the TSSO is called *Auseinandersetzung*, which roughly can be translated as *quarrel*, but means a mix of quarrel, debate, treatment, handling and even struggle. Quarrels (not only conflicts) are understood as the motor of social change, development, and decline.

3.20

Any occurring quarrel unavoidably runs through a specific dynamics of structuration. Whilst the constitutional dynamics predominantly originates and reproduces social units, the structurational dynamics rocks the boat: depending on what shape it takes, it provides all kinds of social changes, from imperceptible modifications to revolutions, from stabilisation, conformation and encouragement to distraction, dissolution and destruction. The dynamics of social structuration consists of six, in order to the course of the proceeding quarrel, chronologically arranged factors. And these factors are nothing else than specific constellations of the topical problem and the constitutional dynamics of all those social units that are involved in or related to the quarrel – or more precisely, of the factors of their constitutional dynamics. The six factors are:

1. Expectations on the effects of the quarrel
2. Practical (non-symbolic) of the issue of the quarrel
3. The relation between new symbols the units produce during the quarrel
4. The relations between the elements of the constitution dynamics the involved units reproduce themselves with
5. The mutual ascription of structural capabilities
6. The relation between practice and symbolism in this quarrel

3.21

Every factor can switch between either leading the quarrel to have no effects on the institutional capability structure the quarrel takes place in, or to have such effects (which is self-structuration). In the following example one typical result of iterated quarrels will be shown, where almost all factors are switched to the latter case.

The Hierarchy-Increasing Dynamics

3.22

The hierarchy-increasing dynamics is subjected to the following conditions. A steep hierarchy is already established. This is easily seen by the extremely unequal distribution of two sorts of structural capabilities: formal-legal capital and political capital. There exist deep gaps between, e.g., on the one hand the amount and degree of actualisability of the capital a ministry of science disposes of, and, on the other hand, the amount and actualisability of the same sorts of capital owned by universities. Another such gap can be found between chairmanship and faculties, or between professors and students etc. Now as formal-legal capital and political capital are used to prevail in quarrels and to organise social structures, the respectively formal highest positions and politically most versed actors, which are the same, do have hands over university structures and capabilities. Moreover, they receive practical and symbolic acceptance for influencing, altering, preserving and attending those structures and capabilities – which raises the amount of their capital and makes it worthwhile.

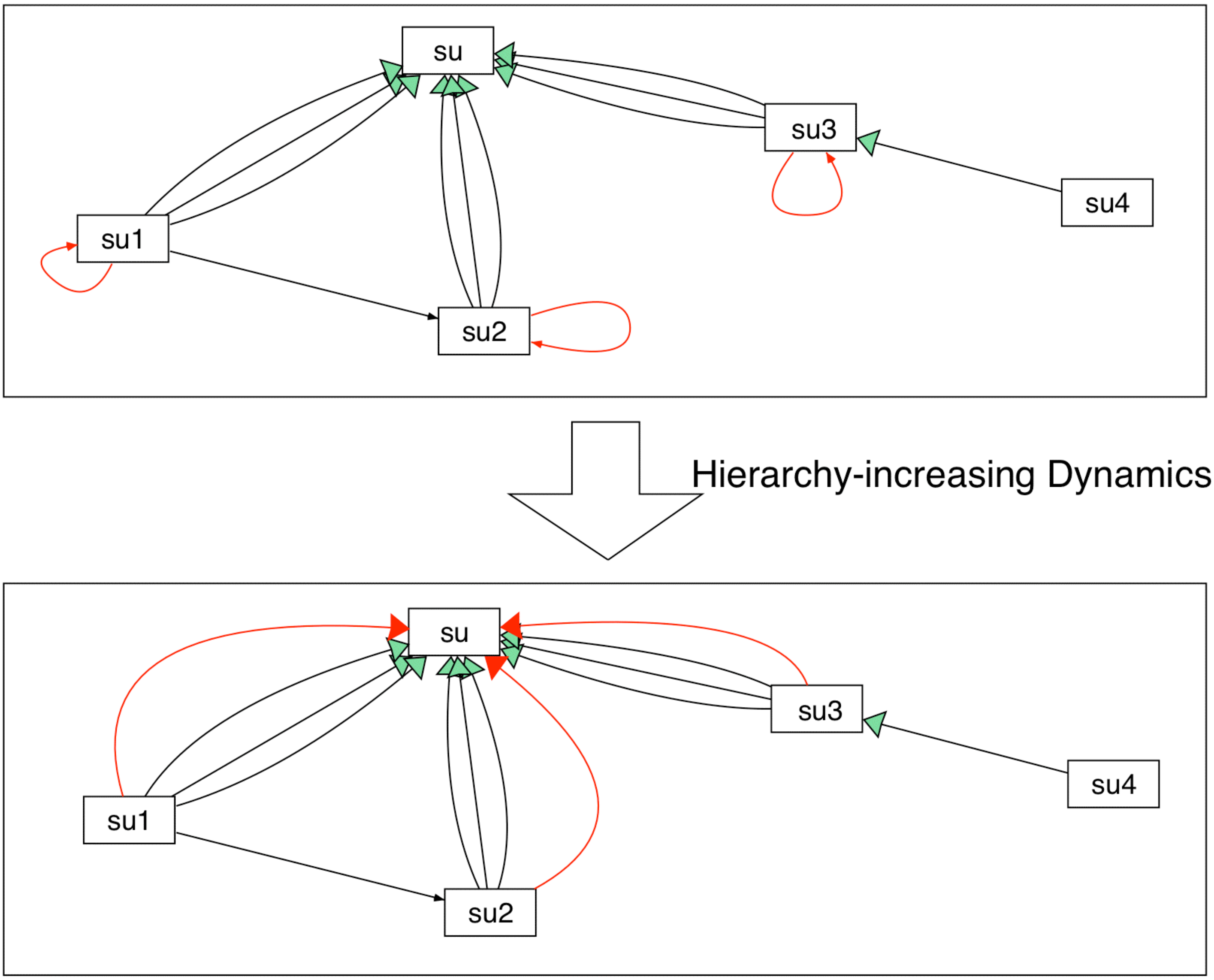

Figure 6: Changes in the Capability Structure through a Hierarchy - increasing Dynamics

3.23

Figure 6 is a visualisation of a transition between two states during a Renew-simulation of the Petri net system given in Figure 4 and 5. "Normal" professors or students (named su_1, su_2, and su_3 in Figure 6 where arrows indicate the capability structure) contrarily deny disposing of capabilities which are relevant for self-administration, hardly receive practical or symbolic acceptance for self-administration work, and so they tend to dislike it while considering it being totally separated from or even obstructing scientific work - and therefore quite useless (depicted as self-loops in Figure 6 - the small arrow tips indicate minor relevance of this capability). As a result, they abandon as much (self) administrative work as possible to leading positions (named *su* in Figure 6). *And with the administrative work they leave their administrative capability up to the top positions, too, while administrative capability is a mixture of formal-legal capital and political capital.* Thankful for "good dictators" most of the time, scientific university workers provide the actors on the formal top positions regularly with capabilities up to an extent, which legally neither is envisioned nor tiled.

3.24

In accordance with the Petri net model in Figure 4 and 5, the hierarchy-increasing dynamics transforms the capability structure in the way Figure 6 sketches it. The structural capabilities relevant for self-administration purposes are transformed into capabilities for the leading position.

3.25

This hierarchy-increasing tendency is tightened by the fact that the lower scientific actors stand in the formal hierarchy, the more isolated they are - which means, they do not dispose of a meta-capability-structure consisting of *solidarising skills* like abilities to organise, communicate or cooperate. But high-positioned actors do dispose of it: it is identical with their structural capabilities (= capital), which confer them with rareness, a clear and steep internal hierarchy, and a huge supremacy, that means close boundaries, to the legally subordinated positions and actors. And this makes them highly capable of organising themselves and of using *divide et impera*-strategies.

Empirical Research

4.1

Beside theory integration and modelling, a further root for developing a theory of social self-organisation was empirical research about self-organisation and decision making in universities. For an early inspection cf. (v. Lüde et al. 2003), concluding results are published in (Langer 2005b). Merely unknown underlying informal mechanisms of self-administration and self-organisation were discovered, e.g. (a) a conservation dynamics that keeps in balance top down initiatives with symbolic protests, business competition, rivalry, and trust building; (b) an intrinsic hierarchy-increasing dynamics (which can show that the formal strengthening of leading positions in german universities is not very innovative); and finally (c) two different dynamics of making invisible and of paralysing all the knowledge and power that specifically could be applied for using self-organisation mechanisms reflexively to achieve volitional structural efforts.

4.2

The results of the university study (and, additionally, the results of an investigation about institutional reorganisation by implementing feedback procedures in schools, see (Bastian et al. 2005)) were integrated with the outline of a general theory of social self-organisation (see Section 2.1 above) by analysing them on similarities. In this way, the general theory got empirically grounded, differentiated, and corrected, and the empirical results were theoretically rearranged and explained. The outcome of this procedure is a middle range theory of self-organisation in institutions of education (published in Langer 2005a).

Agent Systems Following the TSSO Approach

5.1

In this section we describe how the social concepts of the TSSO are transferred to a socionic MAS architecture called Sonar that uses and enhances the design of our former architecture Mulan. The main feature of Sonar is the uniform treatment of social concepts as proposed by the TSSO.

5.1 Multi-Agent Systems

5.2

Today, agents and multi-agent systems (MAS) are one of the most important structuring concepts for complex software systems (cf. Jennings 2000). By including attributes like autonomy, cooperation, adaptability, and mobility, agents go well beyond the concept of objects and object-oriented software development.

5.3

One of the aims of our project is to develop executable models (i.e. programs) of agents and multi-agent systems that directly incorporate the ideas of the selected social theories. In order to reach this aim it is necessary to avoid a bias on which agent architecture is well suited or which agent development style should be used. We chose to delay this decision as long as possible. This is done by a seamless further development (refinement, composition and coloration, i.e. the attachment of algebraic annotations to the net elements that specify the net's behaviour) of the Petri net models gained by modelling the theory. The further development is seamless because the modelling paradigm is not changed as it would be the case when using ad-hoc graphics or a software modelling language like the UML. The objective of the modelling process is twofold: first, to identify the *agents*, i.e. the active elements of the theory models and second, a collection of (interaction) processes that describe the interdependencies of the active elements.

5.4

A common, but misleading procedure might have been to only identify actors as agents and to attach other (on first glance passive) social entities like norms (to recall a popular example) as mere attributes to the actors. As our research has shown - and as it will be exemplified in the paper - there is no justification to constrain the set of agents to actors. A widened scope leads to simple and elegant models of society that, nevertheless, offer adequate explanational power.

The Multi-agent System Mulan

5.5

The multi-agent system architecture Mulan (Köhler et al. 2001;, Duvigneau et al. 2003) is based on the *nets-within-nets* paradigm, which is used to describe the natural hierarchies in an agent system. Mulan is implemented as a reference net system using Renew. Mulan is compatible to the FIPA specifications (Foundation for Intelligent Physical Agents 2005) and thus an open system that can be connected with any other FIPA compliant agent system.

5.6

The overall structure of Mulan consists of four levels:

1. The organisational level defines the communication and mobility channels in the system (cf. Köhler et al. 2003).
2. The platform level hosting the agents and providing an AMS (agent management system) and a DF (directory facilitator) - details can be found in (Duvigneau et al. 2003).
3. The agent level describes the internal message processing. An agent must be able to receive messages, possibly process them and generate messages of its own. The agent may exchange messages with other agents via the platform. The central point of activity of a such an agent is the selection of protocols and therewith the commencement of conversations. The protocol selection can basically be performed pro-actively (the agent itself starts a conversation) or reactively (protocol selection based on a conversation activated by another agent). Both kinds of a conversation are influenced by the knowledge of an agent. In simple cases the knowledge base can be a database, or - more advanced - an inference engine (cf. Köhler et al. 2001).
4. The interaction level is defined by interaction protocols. The variety of protocols ranges from simple linear step-by-step plans to complex dynamic workflows (cf. Cabac et al. 2003).

Sonar - Agents as Social Units

5.7
There is a conceptual problem in Mulan as in almost every MAS architecture. The central problem of any ordinary MAS is, that the agent is the dominant category. To see why this is problematic consider the process of coordination. Coordination of a group of agents generates joint intentions/commitments. The problem here is that joint intentions/commitments are not a part of any of the group's agents. They are a (macro) concept beyond agents, i.e. beyond the micro level (cf. also the discussion of Castelfranchi and Conte 1995). Such an additional macro concept does not fit to an actor oriented approach and complicates the design.

5.8
The TSSO helps us to overcome this problem. The proposed solution is our Sonar MAS architecture, that enhances Mulan. For the Sonar architecture we adopt the TSSO view. The fundamental concept of the TSSO, *practical order*, may denote any socially relevant concept, e.g. a structure, a process, an actor, a society, an institution, a property and so on. We claim that it is necessary to directly translate this concept to first order objects of agent systems, thus to map it to the agent concept.

5.9
This approach differs radically from the usual way of only mapping actors to agents. In Sonar, actors (agents in the classical sense) are not chosen as the primary architectural entity because this might have the consequence that any kind of social structure is a second-order concept. Instead the Sonar architecture is designed along the first-order concepts of *social practice*, *structural capabilities*, and *symbolic reflection* which are related in the dynamics of constitution.

5.10
To put it in a nutshell: A Sonar agent is not defined as a goal directed entity. Instead, any system of rules generating social acts (here: structural capabilities) is considered as a Sonar agent. This has the consequence that not only actors are agents, but also role models and the results of coordination processes (the joint commitments etc.) are agents in Sonar.

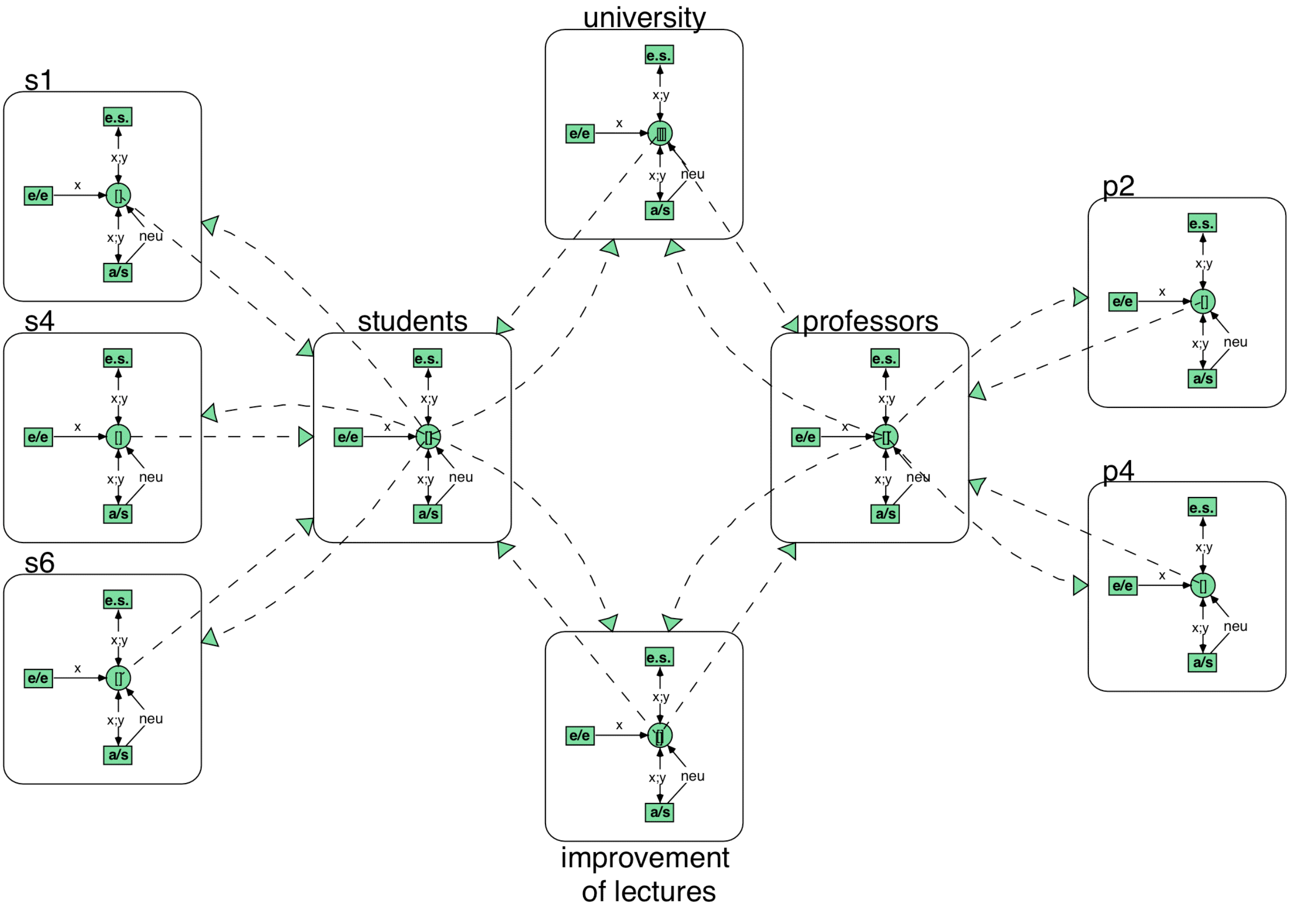

Figure 7: System of Sonar-Agents

5.11
As an example cf. the multi-agent system of Figure 7 taken from (Köhler et al. 2005). Each boxed net is the abstract representation of one Sonar-agent. In Figure 7 e/e denotes *evaluate* and *expect*; e.s. denotes *estimate stability*; a/s denotes *accept*, *ascribe* and *symbolise* which are the main activities of a social unit in the TSSO. The dashed arrows illustrate the ascribed regularity expectations of the TSSO. The Sonar-agents accept practically that the agent p_4 is involved in the process *improvement of lectures*. This acceptance is stable and has generated a structural capability, also named *improvement of lectures*, a next step in might be that the structural capability is symbolised resulting in a new entity, say: *assistant dean for lecture quality*.

Technical requirements

5.12
The agent systems need to be adaptive at run-time to a high degree. This and the use of the same concept - agent -

at all levels of the system leads to further requirements:

- Creation and Adaptability of agents at run-time - this entails the adaptability of the entire agent system at run-time
- Agent system adaptability also means adaptability of hierarchies and nestings in the agent system
- Use of identical concepts and mechanisms inside and outside of the agents - more precisely, the discrimination between *inside* and *outside* becomes blurred (because the same concepts are used)

5.13
As stated before, platforms in a full featured Sonar system may act like agents and encapsulate the hosted agents. It is therefore no problem to implement e.g. a holonic MAS using Sonar agents. The logical consequence of this approach is to exclusively use these *platform agents* as agents in the MAS. Following this idea leads to a dynamically reconfigurable MAS structure, i.e. a new hierarchy level may be introduced at run-time simply by creating a new (platform) agent and migrating other agents into it.

5.14
Since the inherent complexity of dynamic architectures demands for formal analysis, the choice of Petri nets seems appropriate not only as the modelling but also as the implementation language (like in Sonar). An application of formal techniques to the analysis of an dynamic architecture in the context of mobile agents can be found in (Köhler and Rölke 2005).

Outlook and Perspectives

6.1
In this paper we presented our recursive research that interrelates computer and social scientists' perspectives on artificial societies. The social scientists' perspective is the theory of social self-organisation (TSSO). The TSSO as an empirically grounded theory of the middle range for social self-organisation expressed and validated using a high-level formalism, namely Petri nets. The presented Petri net model formalises the computer scientists' perspective.

6.2
The formal model of the TSSO allows, on the one hand, for the analysis of the inner logical structure of the theory, and on the other hand, for the derivation of the dynamics of social structuring from the dynamics of constitution.

6.3
But as the core of the TSSO is a general theory of self-organisation, it can be applied to natural and artificial societies as well. In the context of real societies the TSSO helps to understand the processes in institutions and contributes to the attempt to manage them. Current work of the ASKO project applies the TSSO to the empirical field of universities. Additionally, we will extend the TSSO to a general theory of social processes. In the context of artificial societies the Petri net description of the TSSO provides an integrated formal model in a mathematically exact and coherent way. By means of these attributes the model helps to improve the system architecture since it avoids an eclectic approach where new concepts of *sociality* are introduced without any coherence.

6.4
Furthermore, for the design of a MAS architecture named Sonar the development of the Petri net model avoids the bias that is unavoidable if some concrete architecture elements or even the programming language is chosen in an early design phase. In Sonar agents are not chosen as the primary architectural entity because this might have the consequence that any kind of social structure is a second-order concept. Instead the Sonar architecture is designed along the first-order concepts of *social practice*, *structural capabilities*, and *symbolic reflection* the dependencies of which are related in the dynamics of constitution.

6.5
Note that the basic concepts of the TSSO model are not restricted to multi-agent systems - they can be applied to any kind of self-organising or -modifying system architecture (cf. Cabac et al. 2005).

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