Socio-Cognitive Agents Fighting for Scarce Resources

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Abstract. It is conspicuous that within the research field of (social) conflicts there are only few contributions that make statements about the cognitive mechanisms underlying behavior in conflict situations. This especially holds for conflicts about natural resources. In this paper, we propose to use an agent-based approach, which naturally combines the perspective on the individual with models of social mechanisms of interaction. This allows us to examine social conflicts from both angles. We present an agent-based architecture in which agents have the ability to map social processes of interaction, and to incorporate them into their decision processes. On the basis of this architecture, we build a model, which serves as a platform for the examination of resource conflicts in game-like situations.

Keywords**:** social conflict, socio-cognitive agent model, cooperation, RePast

1 Introduction

Long ago, social sciences have adopted multi-agent systems (MAS) for the construction of simulations that shed light on social phenomena. The use of computer simulation in the field of agent-based social simulations entails advantages of different kinds: theoretical hypotheses can be tested directly, it is straightforward to produce vast bodies of data relative to artificial large-scale populations, and real-life social phenomena can be described and interpreted [1]. “Over the years, the notions of agent and agency have [even] occupied a major role in defining research in social and behavioral sciences” [2] (p. 3). This also holds for research on social conflicts and has led to various influential simulation models and results.

However, a significant problem of general nature has been identified for theories and architectures of (cognitive) agents: The question Castelfranci therefore poses is, “how to reconcile the ‘external’ teleology that orients the agent’s behaviour with the ‘internal’ teleology governing it” [3] (p. 1). It is this question which has guided our work on a socio-cognitive architecture and the corresponding model. The architecture allows for the creation of cognitive agents that have the ability to map social processes of interaction and to incorporate them into the agents’ decision processes. We take the term *architecture* to mean an approach that does not only try to model behavior, but also to capture structural properties of the modeled system. The related model, which in parts is realized as a RePast model already, is set up to examine specific problems surrounding conflicts over a scarce, regenerating and "natural" resource. Both will be described in this paper. Like others [2-4], we argue that an interdisciplinary view is able to reveal some solutions to the problem formulated by Castelfranci. Therefore, we adopted both, a cognitive-scientific and a social-scientific view.

2 Embedding of the Architecture and the Model

Within the SCAR (Socio-Cognitive Agents fighting for scarce Resources) project[1], a socio-cognitive agent model has been developed that is based on selected theories and concepts of the social sciences and cognitive science. Among these are the PSI-theory of Dörner [5], the model of escalation by Glasl [6] and social constructivism [7, 8]. In contrast to traditional models from the social science, a socio-cognitive agent model allows for an analysis of data within the scope of psychology and cognitive science. Moreover, such models can be interpreted on their micro level by considering behavioral descriptions as well as already validated concepts of cognitive science and psychology. Like Takadama et al. we are interested in "agents that can reproduce not only human-like behaviours externally but also human-like thinking internally." [9]

The SCAR project has the epistemological goal to enlighten the processes underlying social conflicts by implementing an agent-based system. This comprises both classes of processes: those involved in the emergence of conflicts, and those which result in their resolution. In order to get to such an understanding, a perspective relating to the individual (with a focus on decision processes) must be combined with a perspective relating to social mechanisms of interaction. Thereby, we do not only want to show under which conditions conflicts occur, but also, *how* conflicts develop and *how* they are processed. In this context, the influencing factors of the external as well as the internal "environment" of agents are considered and scrutinized. Besides external factors, internal factors like motives, needs and the depth of information processing play an important role. The SCAR project aims at investigating the influence of these factors on the decision process of the actors involved in combats over scarce, "natural" and abstract resources.

We decided to focus our investigation on problem structures that are known from the research area of commons dilemmas (cf. [10, 11]). It is our particular interest to observe how the application of different strategies influences the agent's satisfaction.

3 Socio-Cognitive Architecture

A cognitive architecture can be understood as a blueprint for agents. It provides "a set of principles for constructing cognitive models, rather than a set of hypotheses to be empirically tested." [12] (p. 124). As such, a cognitive architecture specifies the infrastructure which determines the way knowledge is represented and stored. Moreover, it describes the processes which are needed to utilize and acquire the knowledge (cf.

[1] The SCAR project is a dissertation project carried out at the CESR, University of Kassel.

e.g. [13, 14]). In this section we present the architecture developed in the SCAR project. However, first, we would like to introduce important definitions and present a selection of theoretical considerations that were central for its development.

3.1 Preliminary Theoretical Considerations

A "real need for new complex cognitive models that take into account social factors in cognition" has been identified [4] (p. 2). To be more precise, complex models and architectures are needed which set their focus on high level cognitive representations like goals and beliefs. Various authors have already pointed out that the term "conflict" stresses the antagonism between the parties' goals and interests, respectively. Kriesberg [15] (p. 17), for example, observes: "Social conflict is a relationship between two or more parties who […] believe they have incompatible goals." Similarly, the resolution of conflicts often seems to comprise a shift of goals that resolves this perceived incompatibility. These views support our approach of focusing on the topic of goals and try to understand how they are processed. The agent's goals and its processing can then be related to the prevailing (external) structures. For this reason, the agents that we examine are goal-based agents cf. [16]. We consider agents that are able to set their own sub-goals and moreover to take the social factors of cognition into account. Additionally, the considered agents are black-box agents. That means that their internal state cannot be fully observed from the outside, but rather has to be derived from their "utterances" and actions. In order for the agent to interact successfully, this incomplete knowledge has therefore to be compensated by intelligent information processing and by social abilities.

Among the social abilities are the capabilities to exhibit social behavior, to interpret and exchange signs with other actors. Although models of agent-based social simulations address the questions of coordination, cooperation and negotiation, they focus on social structures only. Thereby, they do not capture processes that describe how these structures emerge, stabilize and disappear [4]. By contrast, social constructivism considers that (stable) social behavior requires the creation of shared knowledge and the social construction of reality cf. [17]. Social constructivism examines resources such as signs and social constructs that refer to social structures, institutions and habits of action [4]. The consideration of social constructs is the core concept which expands our cognitive architecture to a socio-cognitive architecture.

3.2 Basic Principles for the Information Processing

This section provides basic principles for the agent's information processing. These principles are important building blocks for the subsequent architecture and the corresponding SCAR model.

Social Constructs

In order to capture social phenomena within an agent-based system, and to be able to relate them to the cognitive processes of the agent, it is essential to represent those phenomena explicitly. *Social constructs* serve as such representations. Within the context of agent-based modeling, they have already been applied, for example, by Helmhout [4, 18]. Social constructs are, as representations of the agent, in the mind of the agent. However, beyond this, they also exist as artifacts in the external world cf. [4] (p. 65). These artifacts can be documents like agreements or contracts.

We take the concept *social constructs* to comprise both: a format for representation and a process. This process aims at supporting “cooperation, coordination and socially accepted behavior” [18]. Social constructs emerge as the result of social communication and consensus achieved by a group. Such a consensus is achieved when “things” are treated in the same way or at least in an expected way (i.e. following the same rules) by the agents involved [19]. The following definition combines the main aspects of a *social construct*: “A *social construct* or *social affordance* is a relatively persistent socially shared unit of knowledge, reinforced in its existence by its daily use.” [18] (p. 3).

Figure 1 shows how this process is realized in SCAR: Each agent has a commitment to its own goals, but also a commitment to social constructs. The influence of a social construct on the decision process of the agent is the higher the more often it has been reinforced by positive social signals. The influence is low if it has not been reinforced, or has even been decreased by the dispatch of negative social signals.

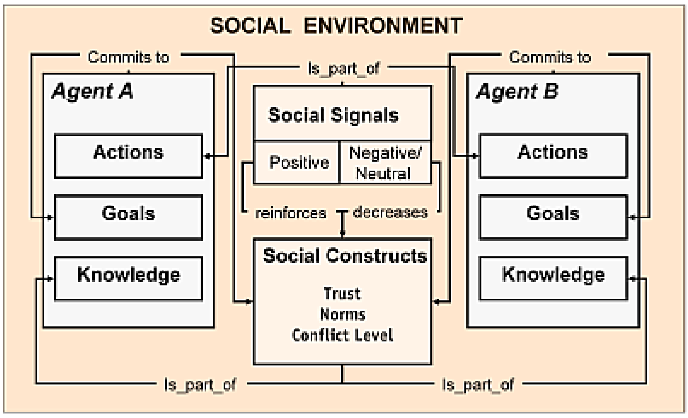

Fig. 1. Two agents living in their social environment and the emergence of social constructs.

Whereas the traditional AI perspective on agents regards them as a means of classical problem solving, some authors are beginning to stress the importance of agents that are able to create social goals and moreover are physically, socially and culturally situated as well [20, 21]. Boella and colleagues argue “that, in noncooperative situations, social goals provide agents with the motivation for committing to other agents' communicated goals” [21]. Such social goals can be formed by social constructs.

Expectancy-Value Principle

In psychology, the *Expectancy-value* principle is a well-known model of motivation. It postulates a multiplicative interrelation between subjective expectations and incentives to determine the utility of an action. This yields the following equation: utility = expectancy * value.

We adopted this principle for our architecture as one mechanism for the processing of an agent's goals. We assume that there are *basal goals*, which have to be incorporated by any agent in order for the agent to "survive" in its environment. These basal goals are considered as fixed, at least during the agent's life span. Within the scope of systems theory, this thought is accommodated in the orientation theory by Bossel, for example, whereas the "[o]rientors are value orientations emerging in the evolutionary adaptation of systems to their specific environments." [22] (p. 1). In psychology, the idea of such basal goals is often realized by the concept of fundamental human needs. Regardless of whether we apply orientation theory or the assumption of basal needs during the agent's lifespan, those basal goals can vary in their importance. The *value* that such a basal goal adopts indicates to which degree the goal is fulfilled and depends on the current situation.

Now that we have clarified the *value* part of the *Expectancy-value* equation, we turn to the *expectancy*. The size of the *expectancy* depends on the agent's experiences with the fulfillment of its goals. If the agent has already developed good strategies to fulfill a specific goal, the expectancy value for this very goal will be high. Though, if the agent has no experience at all concerning that goal, the expectancy value for this goal will be low. After the multiplication of each *expectancy* value for each specific goal by its *value*, the highest result yields the agent's intention (cf. figure 2).

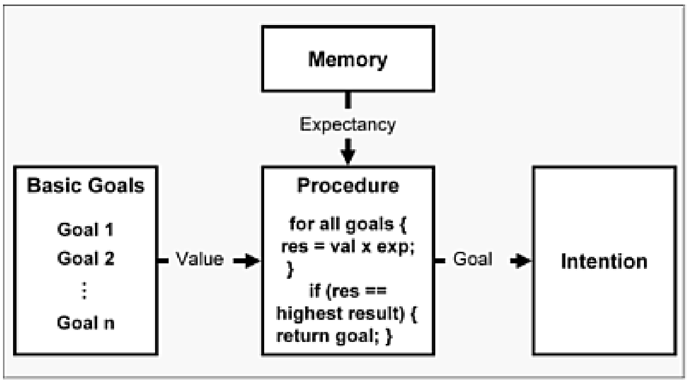

Fig. 2. Calculation of the agent's intention: As per description in pseudo code, that goal becomes an intention whose value multiplied by the expectancy yields the highest result.

The goals' values can be used for other kinds of calculations, too. The sum of all values provides information about the agent's overall success (related to its goals) in the current situation, for example. If the agent's aggregated success is below a certain threshold, this influences the way how its processing of information is carried out. We discuss this mechanism in more detail below, when the SCAR-model is described.

3.3 The Socio-Cognitive Architecture

Figure 3 shows how information from the outer world enters through the agent's perceptual apparatus. These perceptions comprise changes in the world, including actions of other agents. However, the perception is not always perfect. Through modulation that we define as the process of varying the frequency in which information processing is carried out, we are able to realize imperfect perception. In our architecture, this is put into practice by the modulators *arousal* and *level of resolution*. Modulators are devices or processes that perform modulation. We use them basically, to influence the frequency in which information is perceived. This mechanism is based on the pressure that the agent's goals exert, and as such is adapted from Dörner's PSI-theory (cf. [5]).

The agent can achieve its goals partially, which is indicated by the *degree* to which each goal has been achieved. If the sum of all goal achievements falls below a specific threshold, the agent's *arousal* will be high. The outcome of this is a low *resolution level* which causes the information processing to be carried out imprecisely. If the sum of all goal achievements results in a transgression of this threshold, the agent's *arousal* becomes low, resulting in a high *resolution level* with accurate perceptions. Agents carry out their decisions on the basis of their perceptions. The perception yields important information about the success concerning the fulfillment of the agent's sub-goals.

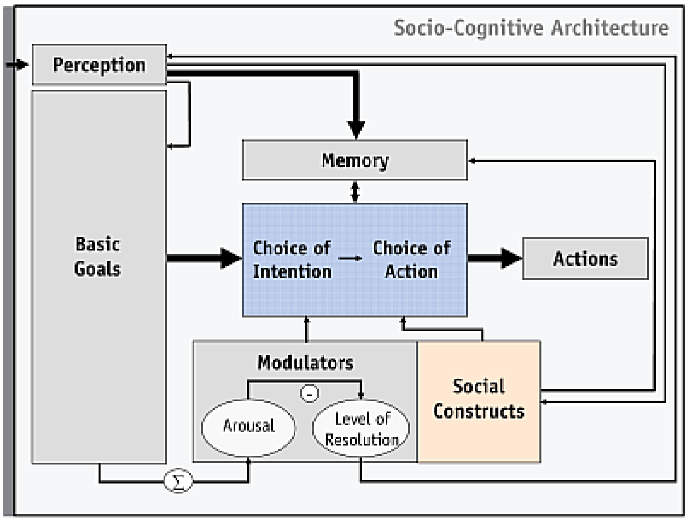

Fig. 3. Socio-Cognitive Architecture of a single agent.

The SCAR architecture also considers social constructs as representations created by the interaction between members of a social group or the interaction between groups [4]. This allows for the construction of high-level social goals. In Section 3.2 we have already explained how social constructs are built and preserved, and how intentions are chosen according to the *Expectancy-value* principle.

Social constructs influence the frequency with which the agent considers its intentions anew. Let us suppose that after the application of the Expectancy-value principle (Section 3.2) there are two very close results. If no social interaction has taken place, the basic goal with the higher result would become the next intention. However, if an agent "senses" a strong commitment to a social construct, such as a norm or a contract, it would choose in favor for an intention aiming at cooperation even if its result has been slightly lower. The reverse case occurs if the agent has no commitment to its social constructs. In this case it would prefer non-cooperative intentions, even if the expectancy-value principle resulted in a slight advantage for the cooperative intention.

The agent's memory stores the history of interaction between the agents, declarative knowledge (which in SCAR is "innate" knowledge only) as well as procedural knowledge. The agent's possible actions are twofold: it can manipulate its environment directly by e.g. taking a specific amount of resources; but it is also capable to send messages (signals) to other agents.

4 The SCAR Model

We now describe an agent-based model that is set on the top of our architecture, with the goal to examine conflicts over scarce and abstract resources. The core components of the architecture described above are realized already as a computer model written in Java. With such a computer model, we provide a platform for the observation of how conflicts develop, and how they are processed. We are geared to game like situations in order to shed light into these processes and started with two-agent situations, where both agents have to fight for a scarce, abstract and regenerating resource.

4.1 Basic Assumptions for the Creation of the Model

Classical decision theory neglected the fact that one's own decisions can be foiled by opponents and that the information about the opponent's preferences are incomplete. While traditional game theory finally took the decisions of others into account (however, thereby disregarding their underlying processes) it also assumed a state of complete information. Within the SCAR model, the following facts are considered: first, partners almost never act independently from the other and second, information is incomplete. Moreover, benefit values and even the rules often change during the game.

4.2 Environment

The demand that benefit values change during the game is met by the properties of the agent's environment. The environment consists of (at least) one other agent and an abstract, finite resource. The agents are interdependent. This interdependence is due to the growth function of the resource, but also due to social dependencies. Each agent can communicate threats and "promises" which both can be understood as commitments.

The chosen properties of the resource lead to interdependence on the long run. The growth function is chosen similarly to the one in Ernst et al. [23], and is shown in figure 4. Only if both agents cooperate, they can reach the area, where the propagation is optimal. If the resource level falls below this range, a temporary relinquishment of the resource exploitation could be necessary.

In a broader sense, norms can be understood as properties of the environment, too. Norms can be implemented in simulation as built-in constraints or as built-in obligations cf. [20]. Though, they can also emerge within a process of frequent use. This kind of process was discussed earlier, when social constructs were elucidated. For now, as a first approximation, we decided to introduce norms, which are supposed to support the regulation of the harvesting of resources, as built-in constraints. These norms are bound to the actual size of the stock: It is allowed to harvest little, if the stock is low and more, if it is high. Violations of norms have potential to fan conflicts.

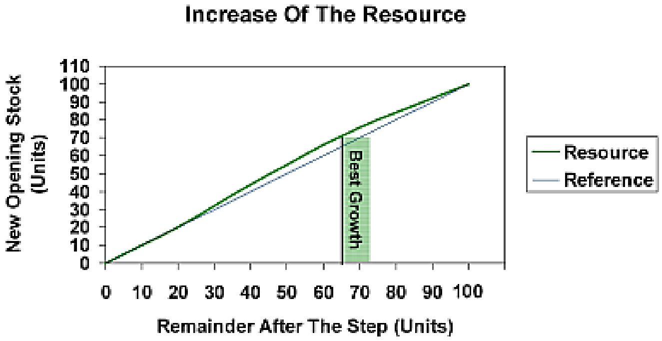

Fig. 4. Resource growth per step: x-axis shows stock before propagation, y-axis shows stock after propagation. The optimal growth is in the area around 65 units remainder.

4.3 The Agents

In section 3. we have already provided the basic constituents of the agents incorporated by our architecture. We have clarified that they are goal based agents with incomplete knowledge and we have described the core mechanisms for their information processing. We would now like to deliver more detailed information.

Needs

The core driving forces of our agents are their needs. They are the most obvious source of motivation and as such form the basic goals of the agent. The stronger a need the stronger is the value assigned to it for the current situation. Since the agent does not always know the effects of its actions relating to its needs, the result of its actions is afflicted with a good portion of uncertainty. This is due to the agent's incomplete knowledge and its bounded rationality. This fact is, at least partially, accommodated in the Expectancy-value principle, described in section 3.2., where the expectancy, is determined by the experiences of the agent, stored in its memory.

On the left side of figure 5 the needs are illustrated as tanks. Satisfying events cause the tanks to be filled; dissatisfying events cause them to be emptied. In addition, the tanks have a leak, which causes a certain, constant decay each time step. If the content of such a tank falls below a specific level, the agent most probably strives for its satisfaction. Thus, needs indicate set-point deviations of significant variables. The needs each agent possesses are the acceptance, resource and competence needs. We chose these needs according to the research project (that is the analysis of resource conflicts) and the demands the environment makes on the agent:

Acceptance need: In order for the agent to have the ability to establish cooperation, it should be equipped with a social need. Therefore we provided the agents with the acceptance need. Each time, an agent receives a positive signal from another agent this will cause the tank to be filled. If an agent receives a negative signal this leads to a clearance of the acceptance tank.

Resource need: Since our goal is to investigate how resource conflicts emerge and how the underlying cognitive processes look like in such conditions, we have to consider the resource as a driving force. Consequently, we introduced the resource need.

Competence need: The need for competence is the need of having the ability to actively influence the future by doing something or in some cases do nothing. The need for competence is satisfied if the own actions result in visible consequences and is lowered if either nothing can be done or even more if the agent's own actions do not seem to have any desired consequence. As such it provides an incentive for learning.

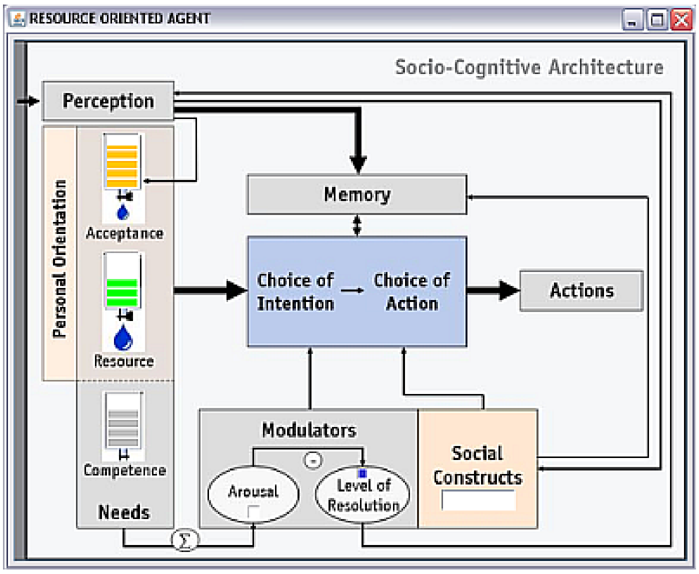

Fig. 5. Screenshot of an agent with a relative stronger resource need.

Personal Orientation

As discussed before, needs are persistent, cannot be modified deliberately and should be the same for all agents. However, the strength of the influence a need exerts on an agent can vary. Furthermore, it is assumed that this variation is independent from the current situation. In this manner, differences in personality can be implemented. We put this into practice by initializing the agents with different decays with respect to their need "tanks". In figure 5, the strength of the decays is indicated by drop size.

Actions

The agent has the option to take up to four resource units per time step. Moreover it can decide not to take any resource at all. Expressive moves can be understood as simple forms of communication. A sequence of action, in which a pattern is observable, shows the agent's ranking of its values to others. Another form of possible action is the transmission of social signals. The agent can choose what kind of signal it wants to send: a strong or weak acceptance signal, no signal or a threat.

Which action will be carried out is dependent of the agent's motives. Whereas the needs form the basic goals of an agent, motives are the concatenation of an intention with an imagination of how this intention could be achieved cf. [5]. In other words: when speaking of motives, the result of the *Expectancy-value* equation is associated with a plan. According to this plan, the accordant action will be chosen.

4.4 Measurement of the Conflict Level

Because of its multi-facetted nature, conflict is quite often defined in exceedingly vague terms. However, Glasl [6] provides clear conflict criteria. Rather than seeking causes purely in the individuals, he emphasizes the internal logic to conflict relationships, stemming from the failure of "benign" ways of handling contradictory interests and standpoints. This logic yields to Glasl's nine-stage model of escalation, which is based on the principle of incompatibility. According to this idea, Glasl defines conflict as "an interaction between agents (individuals, groups or organizations) whereas at least one agent perceives incompatibilities between his/her thinking/ideas/perceptions/and/or feelings and/or will and that of the other agent (or agents) and feels restricted by the other's action" [6] (p. 17).

We adopt Glasl's definition and use his model of escalation as a diagnostic tool. By the application of his nine-stage model (however slightly modified), it is possible to reconstruct the conflict process. Stage one is achieved, for example, if there are differences over some issue or frustration in a relationship. In our model, these differences are expressed by the dispatch of negative signals. Note: Even though, not even a violation of norms or the like has to take place, the conflict nonetheless already starts, due to merely perceived impairments. The stronger these impairments get, the higher the conflict stage: Conflict stage three will be reached if agents act in the border area of norms, stage six if signals of threat have been received repeatedly, stage seven, if norms are exceeded, and so on.

4.5 Investigation of Conflicts over Scarce Resources Using Games

It is now the task to investigate different parameter settings in order to find out, when a conflict arises, and which conditions have to prevail to resolve a conflict. These conditions, of course are dependent on the conflict level. Whereas a conflict on a low level can be resolved by the dispatch of friendly signals, this might not be the right instrument to be used in advanced stages of conflicts.

It is generally assumed that a disadvantageous situational structure promotes the arising of conflicts. A low initial amount of resources in the environment and a low attachment to social constructs might often be sufficient to induce conflicts; but also rather good environmental conditions might lead to conflicts, if there are perceived incompatibilities.

We assume that under the described conditions there need not be a best solution in the sense of an optimum to be found. The performance measurement of the agents takes place by the observation of the agent's satisfaction over time. With respect to this we like to scrutinize how sustainable the agent's strategies are and how different strategies affect the satisfaction of single actors over time.

5 Summary and Outlook

In this paper, we have described a socio-cognitive architecture and an agent-based platform to investigate conflicts over scarce resources. Within this description we took those aspects of the individual into account that cause the agent to behave socially. Furthermore, we have shown how social behavior influences the decision process of agents. In this way we have brought together the cognitive scientific and social scientific perspectives. In order to model a socio-cognitive agent, we considered two types of knowledge: One type stemming from individual and the other from social sources. Whereas the individual sources are based on basic goals (needs), the social sources can be seen as conventions formed in broader contexts. The latter form the high-level social goals of the agents. On the basis of the architecture we built a model that represents simple game-like situations with the aim of examining social conflicts.

The work presented here is the basis for several future research directions. Our next step will be to support hypotheses like the following: 1) permanent inner conflicts sooner or later cause objective perceivable conflicts. 2) The more uneven the distribution of the resource is, the higher is the amount of the individual frustration. The higher the frustration in turn, the more intense are subsequent conflicts. 3) De-escalating measures are dependent on the prevailing conflict level. Hence, it is important when to intervene. 4) If the amount of resources is above a certain threshold, the conflict escalates more slowly than if the resource is endangered. Up to now, the first hypothesis could not be tested satisfactorily, because of a lack of data. Predominantly, statements can be found in the research area of social conflicts, which are rather related to political or social structures in general. It proves to be difficult to relate the collected data within this research field to the individual. The remaining hypotheses (2-4) have already been discussed in the literature but could not be tested suitably, because to our knowledge, there is no agent-based model which allows for the examination of conflicts in this granularity.

Looking beyond such concrete hypotheses, the following research questions will guide our work in the near future: Which influence do social structures have on the conflict process? And, how do shifts of conflict contents emerge? Our main question is, however, based on a phenomenon that is well known in psychology: In spite of better knowledge, people often prefer an immediate reward directly, instead of a higher (and persistent) reward later on. We suspect that this phenomenon is crucially responsible for conflicts to occur. Following Dörner [5], we call this phenomenon, ”cognitive short sightedness”. We are interested in how cognitive short sightedness emerges and how it influences conflicts over scarce resources. We assume that the influence, the modulators and the strength of the sensed commitment to specific social constructs play an important role in this context.

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