Using schemata to model metacognitive social phenomena

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Abstract

This paper proposes the use of cognitive schemata to model metacognitive social phenomena, characterizing the reciprocity between micro and macro dimensions in an organization. The main idea that rationalizes this research is that explicit modeling of social cognitive constructs might improve the understanding of organizational culture and learning processes. In this sense, organizational actor's beliefs are represented in cognitive maps, allowing the identification of social cognitive patterns, composed by values and procedures, through schemata. A schema can be used by an agent according to its interpretation of social values and the level of convergence between an organizational actor and organizational culture.

Introduction

Human organizations character raise from mutual influences between individuals and organizational culture (Kunda, 2001). Organizational culture is defined by patterns of beliefs and behavior within a group. Those patterns are emerging outcomes of interconnected social structures such as conventions, rules, social institutions, systems of symbols, shared values, attitudes, skills, rituals, and so (Sun, 2001). The emergence of social phenomena, such as culture and organizational learning, is the result of interplaying individual cognitive constructs. This way, sociocultural dynamics can be studied through the representation of such emergent cognitive structures, considering both macroscopic and microscopic processes (Louçã, 2003b).

Nevertheless, nature and dynamics of emergent social phenomena are considered hard to identify (Axtell, 2000). An alternative to this kind of analysis is the socioculturalist approach, considering the diversity of individual situated participations in collective activity (Sawyer, 2003). One way of studying emergent social phenomena is to represent high-level cognitive models, emerging from situated interactions between social actors. Collective cognitive structures can be deduced from individual cognitive models, adopting a conception of society composed by successive flows of microsituations (Sallach, 2003).

The multi-agent paradigm, in which autonomous agents interact concurrently, is particularly well suited to support interactions in an organization (Louçã, 2000). Individual cognitive models can be represented in agents. On another hand, interactions characterize social patterns that influence organizational actors.

This paper contributes to a work in progress, oriented by the generic goal of studying emergent social phenomena through the explicit modeling of social cognitive structures in multi-agent systems. In (Louçã, 2000), a multi-agent model was proposed, where cognitive agents are linked to organizational actors and departments. Those artificial agents are composed by software tools and knowledge-based systems, supporting interactions between organizational actors. Cognitive mapping is used to represent actor beliefs (Louçã, 2003a). Following this line of research, (Louçã, 2003b) proposes to consider a socioculturalist approach, taking into account individual cognitive maps in collective activity. (Louçã, 2003c) develops this idea using the Social Impact Theory (Latané, 1981; Nowak and Latané, 1994) to deduct macro-social outcomes.

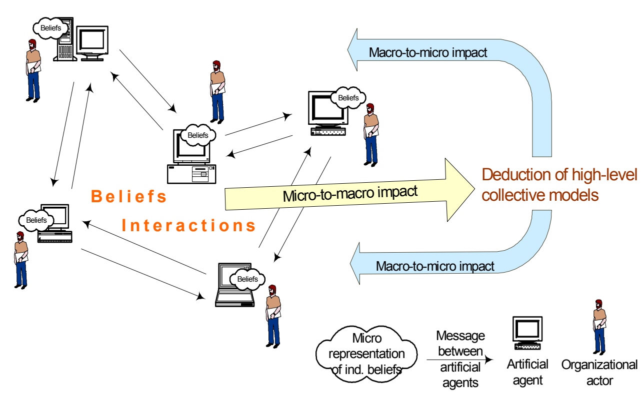

Figure 1
Reciprocity between micro and macro dimensions in an artificial society (Louçã, 2003c)

Figure 1 depicts this general idea, where some cognitive representation of collective values is deduced from interactions between actors. Collective representations are influenced by individual models, which are, by their turn, influenced by high-level cognitive models. This phenomena is known as the micro-macro link in social sciences (Schillo et al., 2000; Sawyer, 2003).

This paper goes further in representing high-level cognitive models. In particular, the notion of schema presented in (Rumelhart, 1980) and developed in (Turner, 2001) is used to represent social patterns of cognitive values and procedures.

The paper is organized as follows. The next section presents the theoretical foundations, on which this research is based, including the domain of cognitive mapping, multi-agent systems and the general theory of schemata. The third section presents previous research, a conceptual framework to represent emergent social phenomena, based on the reciprocity between micro and macro dimensions in a multi-agent model. The fourth section concerns the main proposition of the paper, the identification of social patterns of cognitive values and procedures through schemata. The document concludes with the discussion of those ideas and some research perspectives in the domain.

Theoretical foundations

This research stands on multidisciplinary theoretical foundations, namely on multiagent systems to model organizations and interactions between organizational actors, on cognitive mapping to represent agent's beliefs and on schemata to model high-level cognitive structures.

Multiagent Systems

Systems of artificial agents are characterized by being distributed, with no central control. Agents are autonomous and pro-active, interacting with each other concurrently[1]. Agents can represent societies where the global behavior of the system is composed by agent's autonomous actions. Multiagent systems are adequate to model dynamic interactions because the macro-level of collective values can be explained in terms of the micro-level artificial agents. Those characteristics allow the study of what Coleman referred to as the foundations of sociology: the micro-macro relations underlying social dynamics (Sawyer, 2003).

By drawing on cognitive science, artificial agents allow to support heterogeneous organizational actors through a wide range of knowledge representation and reasoning techniques, based on logic, rules, frames, semantic nets or others (Davis et al., 1993; Luck et al., 2003). Cognitive mapping is a knowledge representation technique that has been recently proposed, associating agency to individual subjectivity and interpretation (Louçã, 2000 and 2003a).

Cognitive mapping

Recent research in multiagent systems has searched for new knowledge representation technologies, simple but operational enough to be accepted in organizations. On another hand, those technologies should be powerful and adapted to ill-structured organizational domains. According to this need, cognitive maps have been proposed to model cognitive agent's beliefs in multiagent environments, as reported in (Chaib-draa, 2002; Louçã, 2003a).

A cognitive map is a graphical representation of the behavior of an individual or a group of individuals, concerning a particular domain. Cognitive maps can be employed at a micro level, to represent individual cognitive models, and at an institutional level, to represent collective cognitive models. Psychologists mainly use cognitive maps as causal structures linking different notions or ideas. Generally, cognitive maps facilitate communication inside a group, supporting discussion and negotiation when people sustain different points of view. Several software systems are proposed to represent organizational discourse into cognitive maps, describing mental models in artificial agents (Chaib-draa, 2002; Louçã, 2000 and 2003a) or allowing the use of network analysis techniques (Lewis et al., 2003).

A cognitive map is composed by *concepts* (representing things, attitudes, actions or ideas) and *links* between concepts. Those links can represent different kinds of connections between concepts, such as causality or influence links.

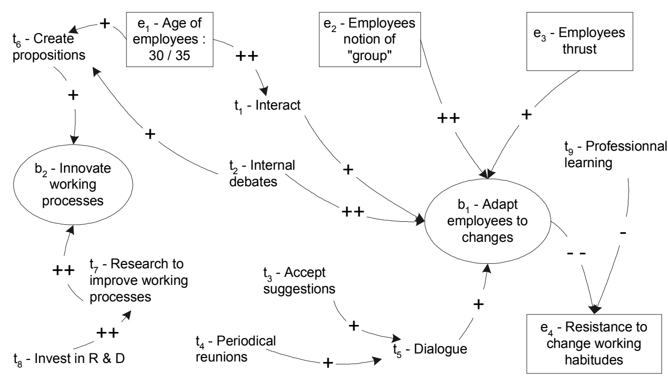

Figure 2
Example of a cognitive map (Louçã, 2000)

<u>Example 1 – cognitive map</u>:

Figure 2 exemplifies a cognitive map where there are three kinds of concepts: "t" – tasks; "b" – goals and "e" – states of the world. Links between those concepts can represent very positive influences (++), positive influences (+), negative influences (-), or very negative influences (--). In this example, the link between task t8 – "Invest in R&D" and task t7 – "Research to improve working processes" is (++), meaning that t8 has a very positive influence on t7. On another hand, t7 influences very positively the achievement of the goal b2 – "Innovate working processes". b2 is directly influenced by t7 and indirectly influenced by t8.

[1] A good roadmap for the next generation of agent-based computing can be found in the recent 2003 report of AgentLink II, a network of researchers concerned with agent-based computing (Luck et al., 2003).

This particular type of cognitive map (also known as influence map) is mainly used to represent strategic thought in organizations, as reported in (Louçã, 2000).

The main interest of cognitive maps is their reflexive character, allowing people to become conscious of implicit knowledge, through the visualization of direct and indirect links between concepts. We each construct our private *versions of reality* and deal only with those constructions, which may or may not correspond to some real world (Louçã, 2000). On another hand, organizations can be seen, at some abstraction level, as systems of construction and interpretation of reality (Weick, 1995; Lissack and Gunz, 1999). Cognitive maps can also be employed to model collective systems of values. The main advantage of collective cognitive maps is to take in account shared concepts, representing some interpretation of organizational culture.

Figure 3 illustrates the bi-directional process of influence between individual and collective cognitive maps: firstly individuals negotiate collective values through concept matching, composing a collective cognitive map; then, social cognitive values influence individual models. This way, a collective cognitive map can be regarded as a way of depicting social outcomes, such as shared values and cognitive structures.

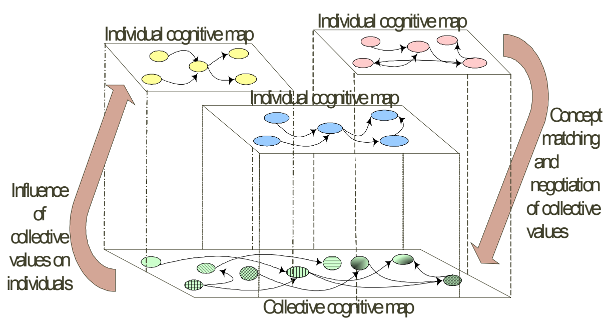

Figure 3
Collective cognitive map bi-directional influence
(Louçã, 2003a)

Nevertheless, one limitation of this approach is the representation of social outcomes only at a discrete moment of time, without dynamically monitoring the system throughout interactions. For this reason, the notion of cognitive schema will be introduced, aiming to represent the emergence of organizational shared values.

Cognitive schemata theory

Marshall distinguishes three main types of knowledge: (1) *declarative*, corresponding to static concepts, (2) *procedural*, composed by rules representing skills and techniques, and (3) *schematic*, that combines procedural and declarative knowledge (Marshall, 1995). Research in knowledge representation has been studying ways of combining declarative and procedural knowledge, composing some kind of sophisticated cognitive structures. Cognitive schema theory responds to this ambition proposing the use of schemata, representing patterns of associations between concepts and causal rules. Schemata are psychological constructs representing human generic knowledge (Turner, 2001).

From an historical perspective of cognitive science, the notion of schema has been introduced by the philosopher Kant and developed by the psychologist Piaget. To the last one, a schema or schematic representation is a heuristic device to problem solving (Piaget, 1970). Also in psychology, Bartlett has used schemata to classify memory errors, distinguishing unconscious mental structures that represent generic knowledge (Bartlett, 1958).

Schema constructs have been reintroduced in cognitive science by Minsky in the 70's with the notion of script, e.g., stereotyped sequences of actions (Minsky, 1975), followed by Schank with the notion of script (Schank, 1975), both inspired by Bartlett. Representing some kind of structured phenomena (events, procedures, and others), schemata can be seen as opposed to other forms of knowledge representation, such as logical propositions or semantic networks (Sowa, 2001).

Influenced by the work in cognitive science, the psychologist Rumelhart and his colleagues have proposed a psychological theory of schemata (Rumelhart and Ortony, 1977; Rumelhart, 1980). According to this theory, schemata have a network structure; it represents knowledge at different levels of abstraction (schemata can be embedded); schemata have variables and constants (schemata can be instantiated) and schemata are recognition devices used to fit and evaluate data (Marshall, 1995). Those characteristics are founded in an essential notion: to understand something means to assimilate it into an appropriate schema. This interpretive dimension is the main advantage of using schemata in multiagent knowledge representation. As pointed out by David Sallach,

> (…) the interpretive process, and the complexity that arises there from, can be seen as a crucible of social emergence. Accordingly, interpretive agent models are likely to be a prerequisite of the effective simulation of social emergence, models that generate complexity while, at the same time, escaping reductionism (Sallach, 2003).

Following this line of thought, present research proposes the use of schemata to represent emergent collective cognitive constructs. The interpretation of schemata will allow agents to interpret and evaluate collective cognitive values. Let's focus for now on previous research, a framework to characterize the emergence of collective values.

Previous research – the emergence of collective values

Previous research proposed a multiagent model based on multi-dimensional reasoning processes (Louçã, 2000). Individual beliefs are used to compose a collective solution to a goal through a distributed and incremental process, based on agent's interactions. Cognitive maps represent beliefs of organizational actors. Maps are composed, on one hand, by concepts and by causal links between those concepts, in a *strictu senso* way (Weik, 1995), and on the other hand by the cognitive context of concepts (Louçã, 2003a).

In this model, the emergence of collective values is dynamically represented throughout interactions between agents. Messages exchanged during multiagent interaction can be used to match common concepts and to compose a sort of sub-cognitive maps, called *socio-cognitive models*. Those maps regard specific social domains, such as power relationships in the organization (legal, moral, and others). Generally, socio-cognitive models identify patterns of social life and collective values influencing interactions between social actors. Socio-cognitive models are interactively composed by agents, influencing by their turn agent's beliefs and behavior. This general idea is depicted in Figure 4.

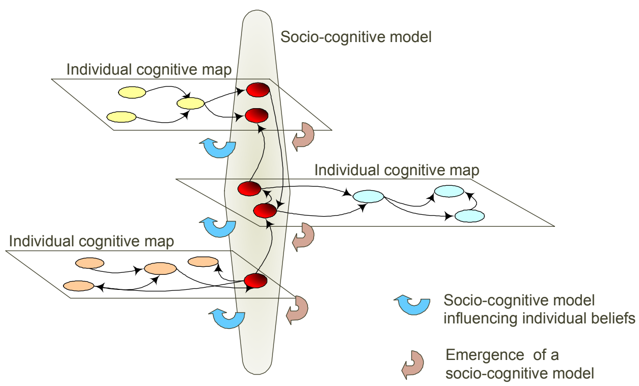

Figure 4
Emergence of a socio-cognitive model

A socio-cognitive models is conceived dynamically, allowing the identification of collective cognitive structures and representing remarkable aspects of organizational culture. An interesting issue of socio-cognitive models is their capability to explicitly represent links between common concepts and individual cognitive maps, taking into account the social context of each individual socio-cognitive model. This idea is according to the socioculturalist approach previously referenced, in which the study of the social context allows the adoption of a situated cognitive perspective about individuals. Latané's well known Social Impact Theory (SIT) identifies factors that characterize social context. The main factors of SIT's *principle of social forces* are considered: *strength S* (how important the agent is to the group that contributes to the socio-cognitive model – status and authority can influence strength), *immediacy I* (how close the agent is to the group), and *number N* (how many agents participate in the socio-cognitive model) (Latané, 1981). This way, both impact of individual beliefs on socio-cognitive models (micro-to-macro), and impact of socio-cognitive models on agent's cognitive maps (macro-to-micro) are characterized – see Figure 4. This micro-to-macro impact can be analytically represented according to the following formulas:

$$Imp_{x,\S} = f(S_{x,\S}, I_{x,\S}, N_{\S}) \quad (1)$$

$$y_{[a,b],\S} = \bigcup_{n}^{i=1} (y_{[a,b],i}, Imp_{x,\S}) \quad (2)$$

where $Imp_{x,\S}$ represents the impact of the agent x on the socio-cognitive model $\S$ – a function of strength $S_{x,\S}$, immediacy $I_{x,\S}$ and number $N_{\S}$. Therefore, the link $y_{[a,b],\S}$ between concepts a and b in $\S$ is a n-tuple including both *1, …, n* agents' opinions concerning $y_{[a,b]}$ and each agent's impact $Imp_{x,\S}$. Similarly, the macro-to-micro impact can be analytically represented by the formulas:

$$Imp_{\S,x} = f(S_{\S,x}, I_{\S,x}, N_{\S}) \quad (3)$$

$$y_{[a,b],x} = \bigcup_{n}^{i=1} (y_{[a,b],i}, Imp_{\S,i}) \quad (4)$$

where the measure of impact concerns the influence of *1, …, n* socio-cognitive models on agent x individual beliefs.

Next section goes deeper on studying the socio-cognitive model and social vs. agent's cognitive constructs.

Using schemata to model metacognitive social phenomena

The general idea now being proposed is that a schemalike representation of the socio-cognitive model will improve the ability to represent organizational culture. The identification of generic social patterns of association between concepts will allow connecting social cognitive constructs (i.e., culture) to agent's cognitive maps. Improving the ability to represent organizational culture is important to understand the organization, to manage internal conflicts or to evaluate organizational learning processes. These are some advantages of representing both micro-to-macro and macro-to-micro phenomena.

In this model, shared cognitive values and procedures are associated within generic schemata. Shared values and procedures are known and accepted by the most of organizational actors. Generic schemata, representing organizational culture, compose the socio-cognitive model. Like some cognitive map, a generic schema (also called a *social schema*) is composed by a set of linked concepts. When an agent needs to use a given social schema throughout its reasoning process, the schema is interpreted according to the agent's point of view.

These notions can be presented through the following definitions.

Definition 1 (*cognitive map*).
A *cognitive map* CM = (C , f_{CM}) is characterized by a set of concepts C and a function $f_{CM}(c_i, c_j, l_{i,j})$, with $c_i, c_j \in C$, $l_{i,j} \in$ {--, -, +, ++} and i, j, k $\in$ N. $l_{i,j}$ represents the link between c_i and c_j . f_{CM} associates concepts, identifying the quality of influence links (very negative, negative, positive or very positive).

The notion of cognitive map is quite general and corresponds to a set of concepts and links between those concepts. Figure 2, in previous section, is an example of cognitive map. On another hand, the notion of schema corresponds to a particular kind of cognitive map. A schema is exclusively composed by directly or indirectly linked concepts. The definition of schema is subsidiary to those of sub-cognitive map and transitive completeness.

Definition 2 (*sub-cognitive map*).
CM_1 = (C_1 , f_{CM_1}) and CM_2 = (C_2 , f_{CM_2}) are cognitive maps. CM_1 is a *sub-cognitive map* of CM_2 (CM_1 is included in CM_2, represented by $CM_1 \subseteq CM_2$) if and only if $C_1 \subseteq C_2$.

According to Definition 2, the set of concepts included in CM_1 is a sub-set of those included in CM_2. This way, a sub-cognitive map is a cognitive map included into another one.

Example 2 – sub-cognitive map:
Considering the cognitive map presented in Example 1, a sub-cognitive map is depicted in dotted line:

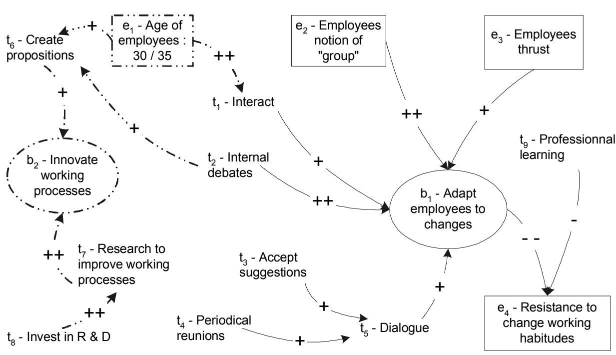

Figure 5
Sub-cognitive map

The notion of transitive completeness allows a particular kind of sub-cognitive map.

Definition 3 (*transitive completeness concerning a concept*).
CM_1 = (C_1 , f_{CM1}) and CM_2 = (C_2 , f_{CM2}) are cognitive maps. CM_1 is *transitively complete* in CM_2 concerning c_i, if and only if $CM_1 \subseteq CM_2$ and CM_1 contains at least all concepts directly or indirectly linked to c_i , with $c_i \in C_1, C_2$.

Example 3 – transitive completeness:
This sub-cognitive map is transitively complete in the cognitive map illustrated in the first example, concerning the goal b_1 , since it includes all concepts directly or indirectly linked to b_1 .

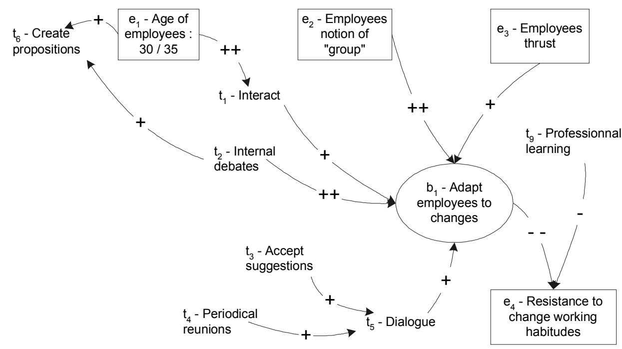

Figure 6
Transitive completeness

A schema is a particular type of sub-cognitive map completely included into another cognitive map.

Definition 4 (*schema*).
CM = (C , f_{CM}) is a cognitive map. A *schema* of c_i in CM is the smallest sub-cognitive map transitively complete in CM, concerning c_i , with $c_i \in$ C.

This definition means that the schema of a given concept contains all and only the concepts directly or indirectly linked to that concept, i.e. concepts being influenced and influencing the given concept[1].

Example 4 – schema:
The schema concerning b_1 is the following sub-cognitive map:

[1] This notion of schema is different from the idea of *transitive closure* from Graph Theory (Faure, 1968). In cognitive mapping terms, transitive closure would result only on those concepts directly or indirectly influenced by a given concept. Inversely, the notion of schema allows considering also those influencing that concept (representing all the ways *arriving to* and *going from* that concept).

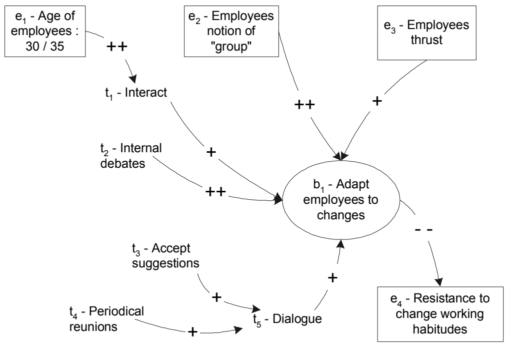

Figure 7
Schema

A social schema is a schema recognized by a group of individuals, representing shared cognitive values and procedures, i.e., concepts and links known and accepted by the most of them. On another hand, a social schema is generic, meaning that links indicate simple influence associations, with no qualitative evaluation such as --, -, + or ++.

Definition 5 (*social schema*).
The schema S_{soc} = (C , f_{Ssoc}) is a *social schema* if and only if its concepts and the links are known and accepted by the majority of the agents, and links are not qualitatively evaluated.

Example 5 – social schema:
Let's consider a universe of 10 agents. A social schema is composed by concepts and links existing in the majority of agents' cognitive maps, i.e. represented in at least 6 of them. This way, the social schema concerning goal b_1 can be illustrated as following:

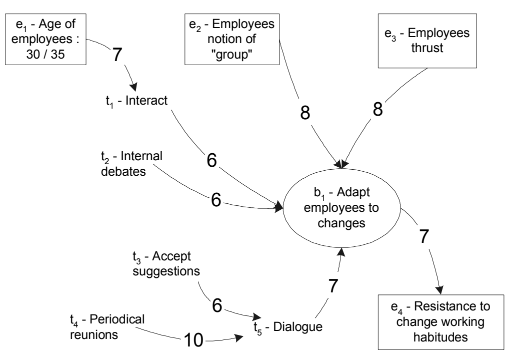

Figure 8
Social schema

Each link has referenced the number of individual cognitive maps where this link is represented. However, links are not qualitatively evaluated. Agents can have different points of view concerning a given link, but nevertheless accept that some influence exists between those two concepts.

Agents use social schemas to interpret collective cognition, as follows. When an agent wants to achieve a goal, it interprets the social schema of this goal - links are qualitatively evaluated according to the agent point of view, i.e. according to its cognitive map or requesting its social actor opinion. This way, links can be evaluated very positively (++), positively (+), negatively (-), or very negatively (--).

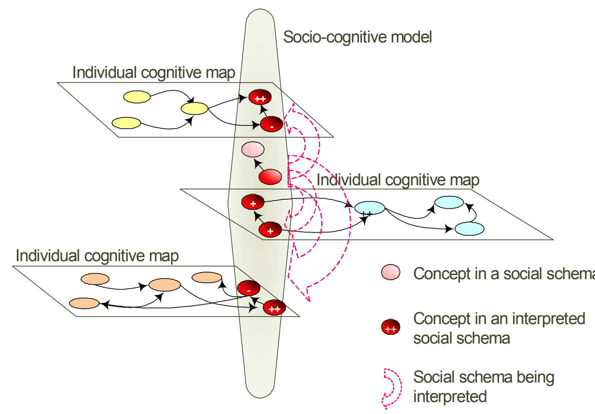

Figure 9
Schema interpretation

Figure 9 illustrates the conceptualization above. A social schema composed by two concepts is being interpreted by several agents. Dotted arrows depict distinct interpretations (qualitative evaluations) concerning links within the social schema.

Micro-macro convergence

The propositions above mean to explicitly describe organizational culture in the multi-agent model depicted in Figure 1, allowing to better understanding and managing an organization. These ideas could improve a distributed support system where organizational actors report their cognitive maps and compare them with the socio-cognitive model, presented in last section. In this sense, *convergence* and *divergence* to collective values are relevant issues.

Social schemas are social cognitive constructs interpreted by agents. The interpretation of a schema depends on the level of convergence (or divergence) between the agent and organizational culture. The socio-cognitive model is composed by social schemas. Recalling the micro-to-macro analytical expressions (1) and (2), these can be reformulated in such a way that the impact of the agent x over the socio-cognitive model includes ε_x, representing the degree of convergence of agent x with organizational culture.

$$Imp_{x,\S} = f(S_{x,\S} , I_{x,\S} , N_{\S} , \varepsilon_x) \qquad (5)$$

Similarly, the convergence factor ε_x could be applied to the macro-to-micro impact. Macro-to-micro impact $Imp_{\S,x}$ leads the agent to match his beliefs with a socially accepted, existing schema. Cognitive convergence has been studied in literature (Lawless and Grayson, 2003).

Related work

This research can be compared with other propositions, mainly concerning some specific aspects of the framework, such as knowledge representation and cognitive mapping in multiagent systems. The use of cognitive maps to represent knowledge can be put side by side with semantic networks and conceptual graphs. Like cognitive maps, semantic networks represent knowledge through nodes connected by arcs. Nevertheless, in those networks, nodes are hierarchically typed, with derivation, according to the generality level of the nodes (Sowa, 2001). Conceptual graphs are systems of logic based on SOWA's semantic networks, with a direct mapping to natural language. Conceptual graphs are useful, for instance, to translate computer-oriented formalisms to and from natural languages. Cognitive mapping concerns much less restraint notions, not needing particular typing – it is a general methodology, and one of its strengths is the adaptability to a large variety of domains. This same argument can be used when comparing cognitive maps with bayesian networks. Cognitive maps and Bayesian networks have already been associated in qualitative probabilistic networks (Wellman, 1994), a sort of cognitive mapping with causal probabilistic links, allowing bayesian reasoning in cognitive maps. However, the use of the original cognitive maps has the advantage of simplicity – cognitive maps can represent a larger domain of situations, it is a tool really used by psychologists and allows qualitative reasoning.

The POOL2 system, proposed by (Zhang, 1990), composes collective maps through the aggregation of individual cognitive maps. POOL2 doesn't incorporate the notion of interaction between artificial agents. In A-POOL – Agent-Oriented Open System Shell (Zhang et al., 1994), cognitive maps are used to represent artificial agents knowledge. The communication is done through the exchange of partial cognitive maps and the purpose of interactions is to compose an organizational map. The most recent evolution of this system includes the propagation of numerical values (Zhang et al., 1994). However, the use of quantitative inference is far from the qualitative spirit of cognitive mapping. In the line of thought of A-POOL, (Chaib-draa, 2002) proposes a method of causal reasoning adapted to multiagent negotiation. Chaib-draa introduces the notion of interaction matrix to represent different points of view. Nevertheless, the conflict detection is not dynamic throughout interactions, it's done at a given moment – this model isn't adapted to artificial agents that dynamically and continuously adjust their knowledge to a changing environment.

Conclusion and research perspectives

This research proposes to explicitly represent social cognitive constructs, while modeling the micro-macro link. Its main goal is to propose some operational representation of collective values, even if this approach assumes strong simplifying hypotheses. The first one concerns the use of a cognitive mapping-like representation to model a complex cognitive reality, such as human interaction in organizations. Another simplification concerns the existence of social schemata equally known by all agents. In reality, each organizational actor has its own degree of access to information within the organization. Finally, cognition is internal to actors and not to organizations – social cognitive patterns emerge from interactions, but they don't really exist besides actors reasoning about their own interpretations. This means that organizational cognitive representations, such as the socio-cognitive model here proposed, are simplifications aiming to allow the explicit use of collective values in multiagent systems.

The main advantage of this approach is to represent the integration of collective vs. individual perspectives, i.e., organizational culture vs. actor's interpretations. From this point, several lines of research are opened regarding emergence of social values. One of them concerns the explanation of organizational learning using schemata. According to (Rumelhart, 1980) and (Turner, 2001), three types of learning can be distinguished: (1) *accretion*, in which schemata are instantiated but not generated; (2) *tuning*, where existing schemata are tuned to better fit the data; and (3) *restructuring*, to create new schemata. This last kind of learning can be (3.1) *pattern generation*, to change an old schema (change variables into constants and vice-versa), also known as learning by analogy or (3.2) *schema induction*, where an organized combination of schemata becomes an identifiable schema, also known as contiguity learning. The use of schemata to model metacognitive social phenomena can contribute to the study of these different kinds of learning. Social and individual perspectives can be put together to explain and improve organizational learning.

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