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Human-Centered Decision Aid: Activity Theory, Individual and Collective Decision

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HUMAN-CENTERED DECISION AID: ACTIVITY THEORY, INDIVIDUAL AND COLLECTIVE DECISION

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Abstract

This paper proposes to consider decision support systems (DSS) under the activity theory and human-centered design perspectives. We suggest to embed in the decision support system part of the decision maker(s) decision schemes and mutual influences in order to transform the DSS artifact into an instrument that will allow its users to adapt their own cognitive models of the task. Examples are presented in the individual and collective decision processes, explaining the way the users can interact with the system. This leads to propose to orient future DSS research towards supporting decision makers themselves, thus possibly defining a concept of decision making support system to be in agreement with human-centered design main principles.

Keywords

Decision support systems, activity theory, cognitive processes and models

Introduction

Being related to concepts such as free will, responsibility, knowledge or rationality, decision making is often considered as the most “human” of human cognitive processes. But on the other hand, it seems that the major trends in designing decision support systems have emphasized the rationality only, and that they did not take into account major characteristics of users as human and social beings. Neither was systematically analyzed nor justified the role and the place of the decision support system in the global framework of human activity. On the opposite, this paper supports another approach that is based upon human-centered design, activity theory and cognitive psychology and that allows to reinforce and to better support the human part of decision making process.

The paper is structured as follows: in a first part, we recall briefly the main principles and features of activity theory and human-centered design, that both encourage re-considering the human and machine roles in human activity. In a second part, we present some examples of cognitive models for individual and collective decision modeling, and the way these models were used to design human-centered decision support systems. In a third and last part, we discuss about these examples from the activity theory point of view, and draw future research perspectives in this direction.

Human–centered design and activity theory

Human-centered design

The questions related to the place of human beings in workplaces and to the objectives and modalities of task automation have become more and more challenging as technologies and information processing were spreading all over industrial processes, or even personal activities. After decades of systems developments centered and driven by technology, it was however stated that thinking about the human operator as a kind of "residual element" within a set of machines could lead to errors and great difficulties in controlling the system. These difficulties may be "limited" to the level of performances in companies (Landauer 1986), but may also reveal to be extremely dangerous in the case of critical systems (Reason 1990). The idea of human-centered design was therefore proposed (Hoffman *et al.* 2001) as a new way of thinking about systems, while taking into account more explicitly human characteristics of users, and re-integrating them into the control chain of the system.

What is human-centered design? Referring to (Rabardel 1995), human-centered design (or analysis) focuses on the user's point(s) of view on his/her activity, while classical technology-driven approaches only focus on the technical part of it. This means that human-centered design has to focus upon the system's user and to consider him/her as a *psychological* being, provided with motivation, goals, cognition and memory. The user is no longer see as some kind of neutral automata in charge of part of the tasking, evaluated in terms of performance only. Human-centered design therefore needs to rely on a better understanding of the cognitive processes involved in activities, as well as of the sociological aspects when dealing with group activity. But focusing on human cognitive psychology is not enough if the activity is embedded into and supported by a technical and organizational framework that cannot be ignored. There is therefore a need for extending the analysis to the interactions between cognitive processes and this framework. This is especially the purpose of activity theory that we present briefly here below.

Activity theory, concept of instrument

Activity theory was proposed by Vygotsky and his colleagues Luria and Leontiev (Vygotsky 1978) at the beginning of 20th century as an innovative way of thinking about human work and action. Activity theory is based upon the idea of having the action relying on an artifact that mediates subject (the user) and object (the environment). Human action is therefore a three-fold structure as represented on Figure 1(left).

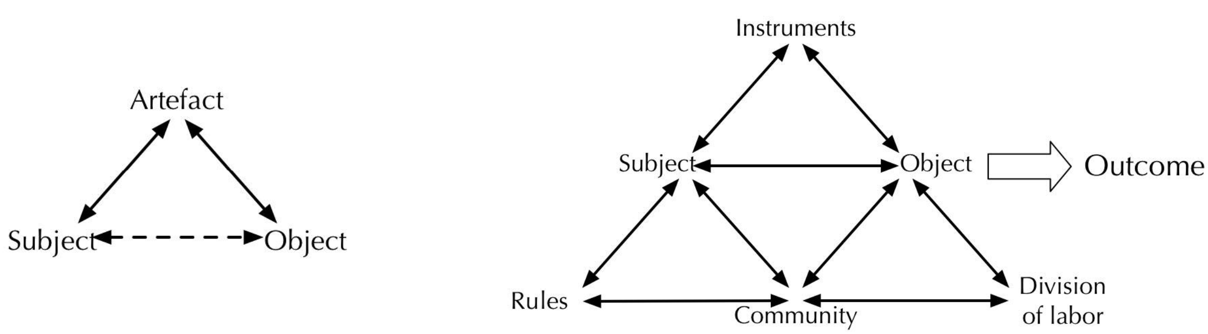

Figure 1. Activity theory (initial version: left, extended version from (Engeström 1987): right).

Instead of focusing on cognitive psychology and on an "isolated" individual, activity theory proposes to focus on *activity*, that can be observed in professional and stable frameworks. The *subject* is a user or a group of users involved in an activity. An *object* (also to be understood as an objective) motivates the subject and orients his/her actions. The mediation, supported by the artifact, may involve several kinds of tools, which could be material (in the classical sense of the term) or symbolic (such as culture, language or way of thinking). Vygotsky especially studied the way language was first used by children as an external mean of communication with adults, and then internalized in order to become a structuring tool for thought (Vygotsky 1978, Vygostsky 1981).

An extension of Vygotsky's first version of activity theory allowed to take into account the social aspects of activity (Leontiev 1981). In this second version (see Figure 1 (right)), the initial triad is extended to task sharing, community and rules: task sharing represents the way work is split amongst individuals, and the hierarchical aspects of organization; community represents the group of individuals involved in the activity; rules concern norms and regulations within the community.

Rabardel proposes to refine Vygotsky's triadic structure in defining *instruments* instead of simple artifacts. According to his point of view, many theories that focused on the artifact as a separated universe by itself (some artificial intelligence approaches were and still are in this line) led to forget about the user once more, or at least to set new barriers between the three poles of the structures. On the opposite, Rabardel (1995) proposes to define an instrument as a hybrid entity composed of an artifact and of the utilization schemes of the user (individual schemes) or group of users (praxis). In oversimplified words, the instrument is the association of an (material or symbolic) artifact and of a "part of the user" related to his/her know-how and expertise. It seems to us that this approach is especially relevant when one considers the computer as an artifact, because the inscription and memorization of the user's contribution to the instrument is easily supported by symbolic data.

Most of the concepts that were presented here above were however primarily developed for material artifacts, and most often for sensori-motor schemes. We propose to extend these notions to decision making, as explained in the following paragraph.

Decision as an activity

Considering decision under the activity theory point of view need to make some clarifications.

First, we have to think about the triadic representation. We shall assume here that even if not explicitly mentioned in the analyses, the decision making process is not supposed to be epistemic, and that there is an object to be modified after a decision (settings of an industrial process are actually modified according to a control decision, auctions are sold or bought after a trading decision, etc.).

Second, we have to make clear that we focus on decision making as a professional task, in other words that we are concerned with decision makers (DM). In decision theories (more generally in cognitively based modeling), several types of decision makers are usually considered: naive, novice, expert and professional of decision making (i.e. statistician and/or operation researcher…). We shall focus here on experts, whose daily (or weekly) actions take the form of decisions. An expert DM is familiar with the tasks he/she has to perform. He/she knows how to structure what a naive subject would consider as amorphous. An expert is someone who can make sense out of chaos (Shanteau 1988). All these features make decision making fully compatible with the concept of activity. But an expert is also able to convince his/her colleagues as well as his/her hierarchy, as all of them agree to acknowledge his/her great experience. The expert level of decision making is therefore also compatible with the extended version of activity theory and social considerations.

Last but not least, there needs to be an artifact. We shall consider that the decision support system plays this role, assuming that one unique computer-based system allows simultaneously to effectuate the decision (transform it into an order) and to assist the decision maker in his/her decision task (in a way that we shall make more precise in the coming paragraphs).

In order to follow the line of the definition of a decision support instrument, we have to make explicit "which part of the user" to attach to the artifact, and which form this part could take: in other words, we have to define what the concept of scheme of action (Richard 1990) becomes when transposed into a decisional domain.

Cognitive models for individual decision making

Decision making involves two main types of tasks: choice and judgment. In a choice task, the alternatives are compared, the ones to the others, in a judgmental task a label has to be attached to each alternative. A choice task needs, at least, two alternatives. Only one suffices to perform a judgmental task.

A major key point of cognitive approaches of decision modeling is that decision making can be viewed as the outcome of an information process (Lindsay and Norman 1980). Several kinds of processes have been studied, such as heuristics (like representativity or availability (Kahneman *et al.* 1982)), articulation of elementary strategies (Svenson 1989, Montgomery and Svenson 1976), decision making as problem solving (Huber 1986) and as a search for a dominance structure (Montgomery 1986). We shall focus here on a computational model of the latter, namely the Moving Basis Heuristics (MBH), proposed by Barthélemy and Mullet (1986) (for more extensive analysis and references, please refer to (Barthélemy *et al.* 2006)).

Let us suppose that a judgmental decision task attached to an expert consists in selecting or rejecting products that can be described along 10 attributes a_1 ...a_{10}. For the sake of simplicity, let us imagine as well that each attribute has only 5 possible values, 1 being the best valuation, and 5 the worst. Writing a_i^j the attribution of value j to attribute i, a product - dedicated to be either selected or rejected - will then be described by a vector of aspects[1] such as [a_1^3, a_2^4, ..., a_{10}^2]. If we suppose the attributes scales to be ordinal, the space of products will be equivalent to the direct product of ten ordered dimensions

[1] An aspect is to be understood as a couple (attribute, value or interval of values), as defined in most of decision theories.

corresponding to each of the attributes dimensions. Following the dominance search and MBH approaches, we assume that the expert's decision will always rely on a limited set of special references (or anchors), defined by *limited* subsets of aspects. These references might be considered as some kind of representations of cognitive prototypes (Rosh and Mervis 1975), used by the DM to infer decisions. A major property of these reference sets is therefore that are mutually incomparable (they form what is called an antichain in the total space). In other words, the MBH approach assume that (i) a reference only applies when a certain dominance condition is respected[2], and that (ii) for an expert DM, one and only one reference can apply for a given decision task (otherwise, it could lead to indecisive situations, which is uncharacteristic of an expert). From now, we'll call these special reference the dominance structures of the expert DM.

Thus, in our example, one could imagine that a combination such as a_3^3, a_5^2 (attribute a_3 with value 3, and attribute a_5 with value 2) could allow to decide (*i.e.* select or reject) for all alternatives that will be at least at these levels for attributes a_3 and a_5, whatever could be the values of the other attributes. SD1=$\{a_3^3, a_5^2\}$ is then one of the dominance structures of the expert decision maker. $\{a_2^4, a_4^3\}$ or $\{a_3^1, a_7^2, a_9^4\}$ could be other possible dominance structures, but $\{a_3^4, a_5^2\}$ could not, as it is dominated by SD1 on attribute a_3.

In analyzing the decisions taken by an expert DM under interactive questioning, it has been demonstrated that it is possible to extract his/her set of dominance structures (the minimal set of configurations allowing to "cover" the whole space while remaining mutually incomparable, in order to respect the dominance principle), and to know which parts of an alternative to be selected are meaningful to the decision maker (Barthélemy *et al.* 1995). Of course, the complete exploration of the combinatorial space is generally not possible: the size of the problem may be too large, or, even if the problem was limited in terms of combinatorics, an expert DM would not accept to spend too much time to answer this kind of questions. Efficient solutions may be however proposed with some light supplementary hypotheses (Lenca 1995).

From this model, there is no great difficulties to trace back to the activity theory: the most important part of the decisional behavior of an expert decision maker is defined through his/her dominance structures, that can be directly translated into a set of production rules[3], that is to say *decisional schemes*. Moreover, in agreement with Rabardel's point of view (1995), several schemes – here several dominance structures – may be associated to a situation depending on the context and on the user's point of view at decision time.

We recall that one of the most important characteristics we claim to be attached to the dominant structures is that they can be extracted from the observation of the decision makers' behaviors. Therefore we propose to use these accessible data structures as the relevant "part of the user" to be integrated into the instrument in the spirit of activity theory, as we mentioned previously. This is what was done in the case of industrial process control, in the COMAPS project (Cognitive Management of Anthropocentric Production System) that we present in the following section.

Example of application: cognitive management of industrial process control

COMAPS project[4] aimed at the reinforcement of the role of expert decision makers in the control of complex and flexible industrial processes. COMAPS approach was based on the non-intrusive extraction of DM's decision strategies whose support was actually the expert's dominance structures. In this case, the extraction of decisional schemes was not based upon the ordinal structuring of the decision space, but instead on statistical modeling of behaviors (see Figure 2). This modeling was still aiming at the dominance effects analysis, as well as at taking into account the cognitive limitations of users' rationality (mining data resulting from history of user's decisions respected the principle of low number of dimensions that were to attach to dominance structures (Lesaux *et al.* 1999)).

As the analysis needed to be based upon empirical observations of decision along time, the mining algorithms were not supposed – as it is usual in machine learning approaches – to compute decision strategies once from a fixed set of data, but they were designed to allow the continuous updating of the dominance structures according to the sequences of user's decisional behaviors (Lesaux 2000).

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[2] This dominance condition is to be understood in the usual decision theories sense: one alternative is dominant over another one if it is not worst on all attributes, and better on at least one.

[3] We recall that decisions are not to be considered as only epistemic, and that we consider here the effect of decision on the object to be implicitly embedded in the user's choices or judgments.

[4] COMAPS research project was funded by the European Commission in the 4th Framework Program (BRITE EURAM III).

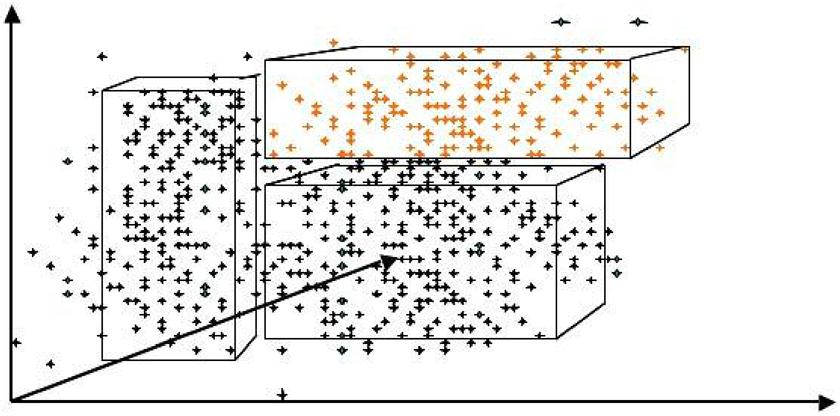

Figure 2. COMAPS statistical clustering decision observations (dots) into dominance structures (blocks).

The resulting decision support system was based on the following principles:

- First, the operator remains in control of the control decision, and the assisting tool only provides some feedback, advices and possible extra-information about the control situation and the previously related decision. More precisely, based upon a "check-as-you-decide" principle, each control situation is displayed at the operator with a color (called "decoration") indicating its status in the machine. As it can be seen on Figure 3, three different colors may be used: if the color is red, the decision to be taken by the operator is inconsistent with the previous cases and the related decision strategy. If the color is blue, the case seems not to have been encountered in the past. If the color is green, the case is compatible with the current understanding of operator's strategies.
- Second, the operator may on demand access to the underlying rules and cases databases that underlie the decoration. Figure 4 represents the way decision schemes (i.e. association rules) are represented in a separate window.
- Third, as the operator remains in control of the final decision to be applied, each of his/her choices is sent back to the mining algorithm that updates accordingly the evaluation of dominance structures.

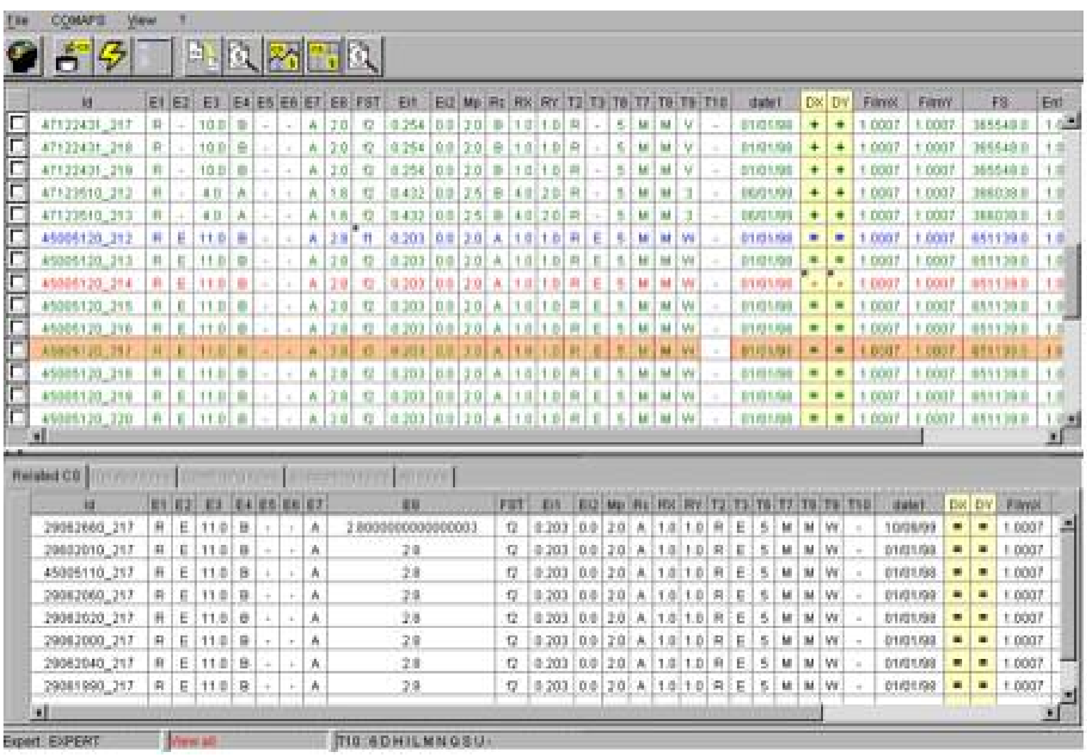

Figure 3. COMAPS main screen: each line of the upper part of the window corresponds to a control situation to be processed. Decisions are displayed in the two yellow columns and the color of each line follows the "check-as-you-decide" code. The lower part of the windows point at control situations that are retrieved as close to the current one in the control history.

Role of the assistance system in COMAPS

COMAPS system is dedicated to a better understanding of the expert decision maker's strategies, but mostly in a reflexive way: its main goal can be finally described as providing the operator with external "long-term memory" of his/her own strategies, i.e. some kind of extra "food for thought" in order to further improve process understanding and control.

A second function (called novice mode) is oriented towards group and organization, while authorizing a novice operator to control the process while being constrained by (and learning from) the embedded expert decision makers strategies.

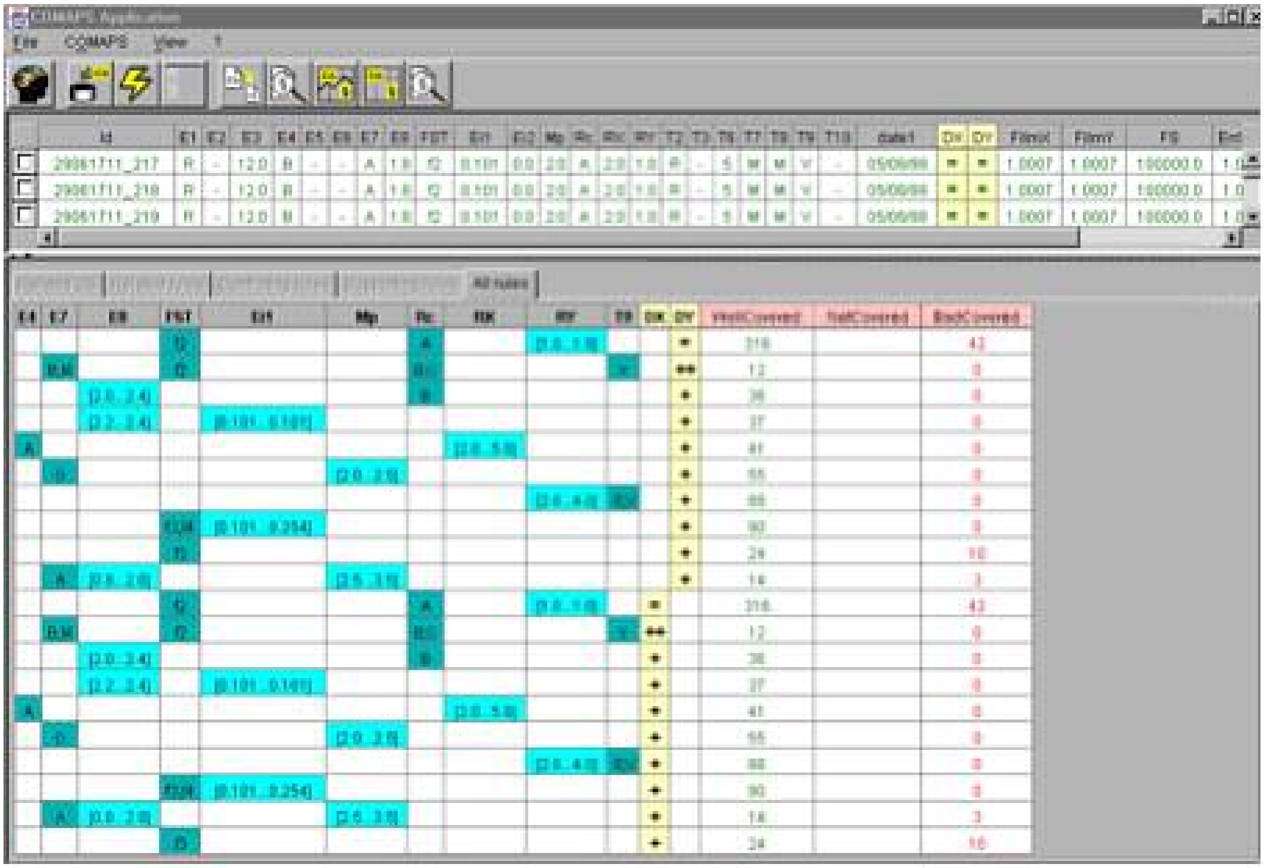

Figure 4. Accessing decision schemes in COMAPS. The lower part of the window displays the current set of production rules computed from the history of cases: blue parts of each line indicate the aspects evaluated in the rule, and the corresponding control decision is underlined in yellow. The mined dominance structures respect the principle of a low number of aspects.

COMAPS and activity theory

COMAPS is a first step towards activity-theory oriented (or human-centered) design of decision support systems: it allows to embed, in the artifact, part of the decision maker's expert schemes, transforming the neutral computer-based control system into what was defined to be an *instrument*. The regular updating of decision schemes from the empirical observations is also very close to the evolution if the instrument according to activity theory and Rabardel. Furthermore, the approach is supporting the idea of personalizing and individualizing the decision support system itself: while being equipped with one particular expert decision maker's scheme, the system cannot be used indifferently by other decision makers[5] and is adapted to a given decision style.

Several functionalities and research points are however still missing. A first one is that the dynamics of evolution of the schemes was not studied in depth, and especially the way these decision schemes could aggregate or disappear for new ones. If these functions are present in the mining algorithm (in order to guarantee an efficient updating of the model from empirical data), there was no analysis conducted at operator's level on validated decision schemes. A second major point concerns the

[5] In expert mode, of course: in the case of the novice mode, on the contrary, the tool is used as a mediator between an inexperienced user and the collected expert strategies.

evolution of the artifact: according to activity theory, the decision maker should be able to create dedicated commands within the artifact in order to make operant the observed strategies so that the evolutions of artifact and user could be joint. At last, the artifact was only considered according to individual version of activity theory and did not take into account the organizational context. The following example proposes a first answer to this question.

Cognitive models for collective decision making

We present briefly here a prospective example dedicated to the collective dimension of decision (for a more detailed presentation, see (Coppin *et al.* 2007)). The second version of activity theory allowed extending the analysis to the norms, the community and the division of labor. We especially consider here the community level, and the ways conflicts – that are at the origin of activity evolution – could be solved or at least made explicit in order to reach a more appropriate consensus.

As it was already stated for technology-driven developments and for classical decision support systems at individual level, most of classical approaches dealing with expert decisions aggregation and consensus only work on the decision outputs of the individual decision makers amongst the team. They generally try to combine and harmonize these individual decision outputs into an optimal common strategy, but do not take into account the activity level of decision makers.

Though these traditional approaches may find very solid formal and mathematical background, they may fall under the same critic as classical utility models for individual decision: they are neither taking into account the cognitive processes of individual DM, nor the mutual influences amongst these processes (Ruta and Gabrys 2000). As a first step, we would like to extend and adapt the cognitive individual models presented in the previous sections to the collective level, while integrating the influences and effects that other decision makers – currently working on the same questions and problems – have on individual dominance structures. As for the individual case, we suppose decision makers under study to be experts, and to share a common set of output alternatives related to the case to be processed, even if their points of view may differ. Especially, they may share only a small subset of variables describing the situation, and may even have different measurement or interval values for a shared variable, and/or possess distinct fields of expertise.

At collective level, we propose that the "part of the users" to be described – and further to be used for transforming the artifact into an instrument – should include the sets of dominance structures of each individual DM, and a complement of description on the mutual influences and inter-individual past conflicts and past congruencies. In terms of information processing, this means that when facing a situation of decision, each expert decision maker may be represented by a set of candidate dominance structures as represented on Figure 5.

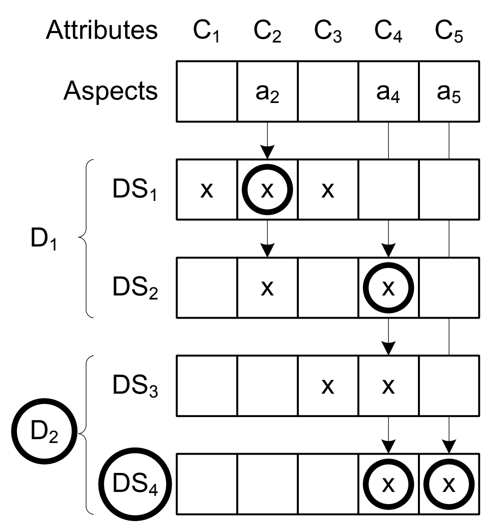

Figure 5. Activation of dominance structure for an expert DM. DS_1 and DS_2 are two dominance structures leading to decision D_1, DS_3 and DS_4 two other structures leading to D_2. Here, from aspects representation of the situation, dominance structures are totally or partially "activated", and lead to decision D_2.

From this description and a representation of the network of influences amongst the organization, the mutual influences of cognitive processes amongst the team may be described through a reinforcement effect (acting on a dominance structures thanks to the attributes validated by other DM) or by abduction (acting on a dominance structures and its attributes when it may lead to a conclusion that is related to other DMs' ones) (see Figure 6).

From this kind of modeling, we may better understand the dynamics of conflicts and decision making amongst a team of experts. Especially, we expect to understand the inner mechanisms that may lead to phenomena such as extreme consensus or active minorities (Moscovici 1986).

Example of application: assisting consensus amongst a team of experts

We applied this approach to the field of airborne surveillance, where multiple expert decision makers have to cross their local decisions and conclusions about targets identification to reach a consolidated consensus. Simulating the sequence of intermediary decisions amongst the team, it was made possible to understand the reason for some preferences reversal along time (Coppin *et al.* 2007).

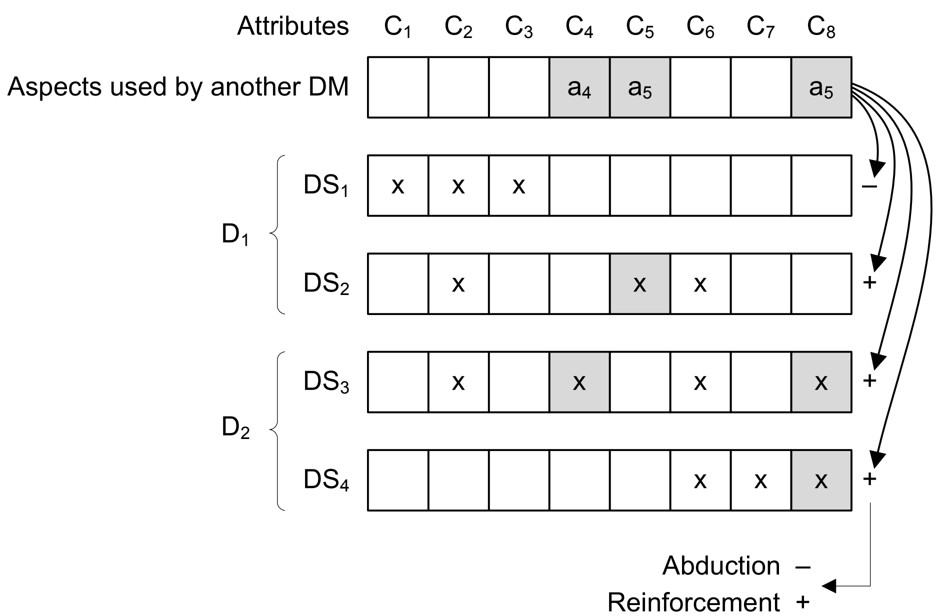

Figure 6. Influence of "external" information of the activation of dominance structures. Here, DS_1 is weakened while DS_2, DS_3 and DS_4 are reinforced, since they are consistent with the aspects representation of another DM.

Role of the assistance system in collective decision cases

The roles of the assistance system in the collective case that can be planned from these bases could be among the following when dealing with global system performance:

- Analyzing and making explicit coalitions within the decision teams, and studying their effect upon the consensus;
- Highlighting dropped or un-explored dimensions of alternatives that have a potential value for decision consensus;
- Stimulating and filtering the communications between decision makers according to context and requirements (to avoid "oscillations" in decisions or to reach a minimal level of coverage and of decision justification).

Generally speaking, the assisting tool has the capability of memorizing past combinations of individual decisions, and to make explicit the inter-relations between decision makers amongst the team.

Links with activity theory

At the collective level, activity theory especially emphasizes the notion of conflicts within the team, and the way these conflicts may lead to individual schemes and artifact evolution. The approach we propose in this case, even if still prospective, aims at answering these questions: identifying and making explicit the origins of conflicts between decision makers, as well as highlighting decision makers' social schemes (such as coalitions or active minorities), which allows the inscription in the artifact of part of users psychological motives and behavioral schemes.

Conclusion: Rethinking about decision aid approach

Decision maker(s) support systems

As a conclusion, let us come back to the notions of human-centered design of information systems and activity theory. Decision support systems, considered through the prism of these approaches, will evolve from simple artifacts to instruments. Still according to Rabardel (1995) and Vygotsky (1978, 1980), one can even distinguish between material instruments (allowing to act directly on the objects), psychological instruments (allowing the decision maker to manage his/her own activity) and semiotic instruments (allowing to interact with other decision makers). Structuring decision support systems from individual and collective decision schemes allows to address properly this three-fold requirement: (i) extracting and mirroring individual dominance structures gives decision makers a way to self-manage their activity, (ii) communicating these structures to others allows to address the semiotic level, and (iii) integrating these structures in the artifact allows to enhance efficiently the actions upon the objects. Therefore in the line of human-centered approach (Barthélemy *et al.* 2002) we promote the concept of decision maker(s) assistance instead of decision making assistance (Coppin *et al.* 2007).

Perspectives

The first results we got on individual and collective decision support system must of course be consolidated, especially at the collective level. It should be also interesting to analyze, in a more longitudinal study, the way the activity generates successive stable generations of instrument and know-how. This notion, close to Piaget’s stages of children cognitive development, could lead in the case of decision makers to a renewed definition of levels of expertise associated to the levels of maturation of the instrument itself.

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