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Supporting document augmentation to leverage representations in knowledge work

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Abstract The paper deals with the issue of representations as support of collaboration in knowledge work. On the basis of previous studies in different domains, the paper focuses on two aspects that led to the design of two complementary technologies: first, *underspecification* as a means to make the communication easier between professionals of different disciplines; second, the enrichment of documents by means of several kinds of annotations that convey individual and group experiential knowledge. Since annotations can be incrementally shared in collaboration and can contribute in building a shared cognitive context, they facilitate collaborative problem solving without requiring a posteriori (re)constructions of a consensual representation of either the ongoing discussion or partial solutions. The two resulting technologies are shortly described and a scenario where their envisioned integration could be profitable is illustrated by taking inspiration from one of the field studies discussed.

1 Introduction

Collaborative problem solving is a knowledge based activity. Often, this activity is conducted by sharing some representations that are linked to the problem at hand

and more generally to the domain(s) where the problem makes sense. Thus, speaking of representations as supportive means of collaborative problem solving implies to consider the relations between these representations and the knowledge involved in this process. A better understanding of these relations is a prerequisite for the design of a technology supporting collaborative problem solving.

In this position paper, we want to discuss the findings of our research in collaboration and knowledge management and the technological solutions that we derived from the observation in different settings of collaborative activities that encompass problem solving as an input for the conception of a more comprehensive support of collaborative problem solving.

2 Knowledge and representations

When knowledge workers and their collaborative activities are considered, sooner or later people end up by speaking of "knowledge sharing". This expression can be obviously considered as a shorthand for a more complex phenomenon, but in the long run such an expression and similar ones can all contribute almost surreptitiously in considering knowledge as a sort of object (if not a commodity, a valuable asset) that can be produced, and then shared (and transmitted) among actors. In this view, representations are seen as means to *carry* what is often called "explicit knowledge": since they can be shared and transmitted very easily, the same could indeed happen for the knowledge they codify and represent. Far from being a pure terminological matter, this way to speak of knowledge is dangerous for the consequences that these metaphors have on the conception of a supportive technology (McLoughlin, 1999). In fact, almost all knowledge-based technologies are (more or less consciously) based on the above assumption of "shareability". On the other hand, according to a constructivist approach, our position is that knowledge intrinsically belongs to individuals and cannot be shared or transmitted; rather it is socially constructed through social practices and interactions (Winograd & Flores, 1986, page 78). Consequently, representations are not about explicit knowledge, but rather *linguistic means* that are able to evoke (tacit) knowledge in the mind of the participants of a collaborative effort. As such, these representations are necessarily an under-specification of what is needed to exhibit a knowledgeable and effective behavior. Under-specification concerns not only a partial view of the reality of interest (representations must be bounded) but it also concerns the intrinsic impossibility of drawing complete/accurate/ unambiguous descriptions of even small parts of that reality. In other words, we argue that representations cannot deal with two kinds of infinity, like an interval of rational numbers do in relation to real numbers.

In our view, this "limit", far from being a real limit, explains why representations are so an effective way to support collaborative problem solving: in their intrinsic under-specification, and therefore in the room representations leave to human interpretation and to the human capability of "connecting the dots", lies the power of representations. On one hand, under-specification allows collaboration among actors that do not have a mutual acquaintance or do not share the same level of competence in the respective domains: in fact, such actors do not need to understand and reconcile all the (missing) details of an underspecified notation, simply because these are not reported in that notation: moreover, underspecified representations, while they are effectively usable by who knows their hidden details, do not overwhelm the cognitive capability of who ignores those details, but rather motivate them in acquiring the necessary meanings and conventions to participate in the discussion proficiently. On the other hand, under-specification makes collaboration time-saving and cost-effective for actors that are members of a community of practice: in fact, they can agree on efficient (since minimal) representations and fill in the gaps by means of conventions and informal practices that are derived from common experience. In so doing, they can keep their working representations at the right level of abstraction to develop the discussion in an effective and proficient manner. These claims and especially the latter one are based on our experience in two knowledge management projects where users constructed representations to play exactly these two roles within and across communities of practices in their collaboration for the design of complex products: hiding unnecessary complexities and fostering mutual alignment around conventional agreements (Bandini et al., 2003; Bandini & Simone 2006).

3 Under-specification at work

The first project was about supporting the problem solving needed in the design of truck tires (Bandini et al. 2003). A truck tire is a chemical device made up of chemical components and other elements: in particular, a truck tire is composed of rubber compounds (the chemical part), which is responsible for all the thermal-mechanical characteristics of the tire, and metallic reinforcement, which provides the tire with the necessary rigidity. The task of compound designers can be described as follows: they start a new project either to meet the requests of marketing, or to change one or more performance indicators of an existing product; then to this aim they produce a list of possible recipes and choose one of these after an evaluation of benefits (i.e. they evaluate if all the requirements have been satisfied) and drawbacks (i.e. what kind of costs and side-effects have been generated). During the field study, we realized that cooperative problem solving happens "in the wild", i.e., outside planned formal meetings and that it is based on mechanisms that are invisible and self-organized. The concrete aspects that emerged during the study were: a jargon owned by the designers to speak of rubber compounds properties and a set of paper-based media to record their (positive and negative) experiences in constructing new compounds basically as a modification of previous "recipes" (cf. continuous innovation). These two "tools" were seamlessly and continuously put to work during their discussions. They served as individual memory that was increasingly accumulated and "shared" by adding on previous individual contents: the jargon identified basic pieces of information; the paper sheets organized these pieces in order to make the way modifications of the recipes yielded to rubber (and hence tires) properties explicit. These individual supports showed marginal differences that were naturally reconciled in a comprehensive structure called "T-Matrix" that was based on the following information (see Table 1). Blends of rubber compounds are described by a set of Blend Features (BFs), such as tensile strength or hardness, while tires are described by means of Tire Performances (TPs), such as wet handling and mileage. BFs and TPs could be expressed in either qualitative terms (i.e. as textual descriptions or comments given by the experts) or quantitative terms (i.e. test results). In addition, a set of interventions on the recipe (RIs) can be performed to modify its composition. The very important knowledge about chemical compounding for truck tire stands in two relationships, called Compounding Relation and Design Relation. The first relation binds RIs and BFs, while the latter describes the correlation existing between BFs and TPs.

The structure of the T-Matrix was the basis of a very simple technology whose aim was to let all kinds of designers collect the conventional information that progressively stratified their design experiences. Interestingly, there was no need to define any sort of explicit structure for the access rights: a distributed social control guaranteed that each update was reliable since performed by (or on behalf of) a "reliable person".

TP 1	⊙↓	○↑	⊙↑	○↑
TP 2	▲↑	⊙↓	⊠	▲↑
TP 3	⊙↓	○↑	⊙↓	○↓
	BF 1	BF 2	BF 3	BF 4
RI 1	⊠	○↑	⊙↓	▲↓
RI 2	▲↓	⊠	○↑	⊠
RI 3	▲↑	○↑	⊙↓	○↓
RI 4	○↓	⊙↓	▲↓	⊙↑

	Symbols	Meaning
Correlation	⊙	Strong
	○	Good
	▲	Weak
	⊠	No
Proportionality	↑	Direct
	↓	Inverse

Table 1 A uninterpreted example of T-Matrix and the meaning of the symbols describing correlations and proportionality of the relevant features

Some time later, the T-Matrix was also made available to the responsible roles of the production lines, although in read-only mode only, when they had to solve problems depending on contingent situations (e.g., an ingredient with not standard properties or the unavailability of a specialized machine) with the goal to preserve the same properties of the ongoing production. As a consequence, the jargon became a resource shared by additional people: this contributed to expand the role of this sort of "common language" and to the development of collaborative behaviors between design and production people, which historically constitute two communities not always permeable. Interestingly enough, a subsequent effort to build a much richer computational model of the technical content involved in design was not used to this purpose, but rather to support the self-education of newcomer engineers and to facilitate them in understanding the pragmatics of the communicative interactions supporting the design of rubber compounds.

Although in a fully different domain, i.e. software integration, the second project showed similar characteristics: underspecified and socially controlled representations of software architectures and non-functional requirements were the means to support distributed problem solving involving costumers too (Bandini & Simone 2006).

4 Enriching Flexible Representations

From our subsequent studies in the healthcare domain (Cabitza et. 2007, Cabitza et al. 2009, Cabitza & Simone 2009), it emerged that the role of technology has also to deal with the capability to enhance the *evoking power* of representations. Since knowledge belongs to individuals, this capability cannot do without the direct intervention of actors themselves. The technology can be used to allow actors define local and very specific "rules" that enrich and augment the available representation with visual cues that are able to support this evocation either explicitly or implicitly (e.g., by reminding them of an apt use of the representation itself, or of the represented entity) . To this aim, we designed and developed two kinds of technologies.

The former one is WEDYM: this is a text editor for web documents that is integrated with an annotation system that allows for the use-friendly and in-line insertion of two types of annotation: classic textual side notes (i.e., marginalia) that users can anchor to any element of the content of a document and that the system puts in the margin of the document in a visual manner that was strongly inspired by traditionally typographical conventions; and semantic annotations (depicted in terms of particular underlinings) that users can create by associating a part of the content with items that they can select from either user-defined tag lists (e.g., folksonomies) or standard reference taxonomies (like MeSH[1] in the medical domain)[2].

The latter application is ProDoc, a web-based application developed according to the WOAD framework (Cabitza & Gesso, 2010), that allows users to create, fill in and retrieve complex sets of forms, charts and documents. ProDoc organizes

[1] MeSH is a standard controlled vocabulary to index documents and their content in the medical domain. http://www.ncbi.nlm.nih.gov/mesh

[2] WEDYM has been developed by Michele Bologna, who described its architecture and functionalities in his Master Thesis. The thesis is made available at the following URL: http://www.gl-iss.org/downloads/BolognaMScThesis.pdf

electronic documents according to a strictly paper-like document metaphor, i.e., as if each document and data mask were a single sheet from a multilayered virtual folder. In addition, ProDoc is able to enrich forms and documents by means of additional (mostly graphical) cues (e.g., underlinings, icons) according to the documents' content and interaction with the user: the conveyance of these cues (which we called Knowledge Evoking Information, or KEI in Cabitza & Simone 2009) is associated to the occurrence of particular conditions that characterize a specific situation by means of if-then constructs, called mechanisms. Within the WOAD framework, we also developed a simplified notation for the computable expression of mechanisms (Cabitza & Simone 2009b) and built a prototypical editor to allow users and communities define them participatorily according to their local conventions. Both WEDYM and ProDoc have been tested in different contexts: WEDYM was used as a support of team work and collaborative note taking at a university class on knowledge management; ProDoc was evaluated by a group of doctors and by a group of archaeologists to check its main functionalities (Cabitza et al. 2009b, Locatelli et al. 2010). In both cases, the outcomes were encouraging.

5 Towards an integrated scenario

Apart from the technical details, these two applications allow each single actor to augment either personal or common documents by means of what she usually deals with to interpret the representations that these documents contain (e.g., annotations, dictionaries, references). For the time being, these systems work on textual documents only, but their basic idea can be implemented for other kinds of representations (graphics, pictures, 3D renderings and the like). Moreover they are not yet integrated in a single application: this is part of our future work.

Irrespectively of these limitations, it is possible to imagine a scenario where their joint functionalities can be put to work to support collaborative problem solving, on the basis of the experiences reported in the previous sections. For instance, let us revisit the case of compound designers and describe a scenario where their activities, as we observed them years ago, could be supported by this fancied "integrated technology".

Compound designers work partially alone and partially in groups when the requirements of a customer have to be met. In the first case, they use their local representation of the basic concepts representing the recipes' composition and how this impacts the features of the tires that include that compound. During their individual work, designers can use all the annotations/affordances that the integrated technology makes available: for example, they can add annotations containing an indication of what customer a past solution was identified for, or rules establishing that some combinations of ingredients are critical for rubber production, and the like. When they meet in order to compare their individual proposals and reach a consensus on the best possible solution fulfilling all customer's requirements, their individual representations are uploaded to the T-Matrix (i.e., to an agreed shared representation) as potential solutions. This upload is made possible because the structure of the T-Matrix is derived from local representations through appropriate mappings. In so doing, designer have at their disposal a local space where their annotations and rule-based mechanisms hold and support their reasoning (like a personal information space described in Tang & Carpendale 2007); and they also have a shared space where alternative solutions are contained (Bannon & Bodker 1997, Hertzum, 1999). During the discussion, the latter ones can be collectively annotated (e.g., by the meeting facilitator, or in turn by the designers themselves) or annotated by transferring local annotations to the corresponding pieces of information in the shared space. Each annotation carries the information about its author and a time-stamp. The same can be done for local mechanisms that might be considered as useful to support the decision process, for instance by highlighting passages or relationhips to be further discussed because recognized as partially inconsistent with respect to elements imported from other authors. At the end of the meeting, the contents of the T-Matrix are transferred back as an update of the local representations, together with the annotations and the new shared mechanisms. At this point, each designer can discard the information she deems as not worth of being recorded in a persistent manner. In a subsequent meeting, the recorded information serves as a sort of self-managed minutes of the previous meeting and supports each designer in the next stage of the discussion.

This scenario mimics what we have discussed with the designers in terms of management of information during their meetings: a continuous and flexible transfer of contents from/to local and shared meaningful representations. This case is particularly favorable since the above mentioned mappings are the product of the mutual learning process that occurs in this particular community of practice. Of course, this is not always the case and the transfer of information from/to local and shared spaces would require a greater human intervention, until the mutual learning process occurring during the meetings partially reproduces the more favorable situation.

This approach contrasts the idea that problem solving is made easier by a top-down and rationalistic 'a-priori' construction of a common background and view of the state of affairs (i.e., a model), or by an 'a posteriori' reconstruction (if not a reconciliation) of the possibly divergent argumentations emerged during the discussion. Rather, we envision a technological support that enables the participants to embark upon discussions where they can co-construct their local and extemporaneous background 'on-the-go', i.e., by sharing content and meta-content (i.e., annotations and convention-based rules) in and out of their respective personal information spaces. To this extent, our approach differs from the one usually called "design rational" and it is more in the line of the "action-reflection" approach proposed by Fisher & Torbert (1995).

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