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Shared representations: dyadic and triadic perspectives in work and training

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Abstract. The use of modeling, simulation and visualization techniques in scientific and technical domains has lead to the co-existence of large diversity of external representations that, when deployed in collaborative work settings, can be designated by the term "shared representations". This contribution will focus on dyadic cognitive and triadic semiotic perspectives on the issue of interpretation and construction of shared representations. Illustrations will be given from a collaborative design game situation and implications for the design of cooperative systems will be formulated.

1 Introduction

The use of modeling, simulation and visualization techniques in scientific and technical domains has lead to the development of a large diversity of external representations which, when deployed in collaborative work settings, can be designated by the term "shared representations". The main aim of this contribution is to call into question the prevalent intuition of the relative easiness with which representations may be shared. The counter intuition would be the suspicion that the proliferation of computer-based representations might just as well lead to a "confusion of tongues" such as during the construction of the Tower of Babel. We build a theoretical frame founded on both cognitive and semiotic perspectives illustrated by examples from a training situation in engineering design. Implications for the design of cooperative systems include the construction of a typology of shared representations presented in the final section.

2 Shared representations in collaborative design

The design process, as a technical as well as a scientific endeavour, heavily relies on shared representations of the problem, the product, and all its intermediary states. For example, in a context of globalization and multidisciplinarity, design processes involve many numerical representations through Product Lifecycle Management (PLM) systems. In this section, we present a training situation in engineering design that subsequently will be used to exemplify a preliminary definition of shared representations and their functionalities.

The Delta Design Game (Bucciarelli, 1991) is a serious game used in engineering education as a reliable and robust simulation of a collaborative design setting. The game engenders situations that show the importance of argumentation, conflict management, inter-relational aspects and intermediary objects (Boujut & Blanco, 2003). The game involves role-playing in which a team of co-workers enlist to design a house in a fictitious world according to a list of specifications concerning cost, internal surface, building time, etc. The design activity relies on the placement of red and blue equilateral triangles on a cardboard (Figure 1).

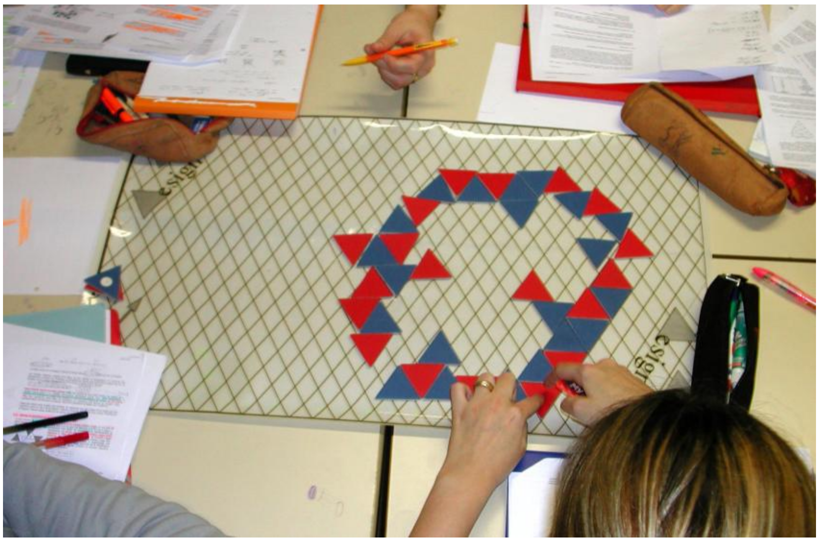

Figure 1. The Delta Design Game situation

During the game, each expert learns a job through a specific set of definitions and rules for a particular domain of expertise. For example, the tasks of thermal engineers and of structural engineers necessitate intensive calculus to evaluate design proposals. The rules of the different jobs are antagonistic enough to ensure that compromises are needed to find a solution that satisfies all team members. We exploit the game for exemplification because it is an artificial situation which, for training purposes, overemphasizes crucial aspects of collaborative design.

2.1 Defining shared representations

First of all, shared representations are necessarily *external*, i.e. outside the head, as opposed to postulated *internal* representations inside the head. A clear distinction between internal and external representations and their integration into a comprehensive framework (Norman & Zhang, 1994; Zhang, 1997) is essential to understanding shared representations. Shared representations designate structures in the external environment which allow one to interact with the objects, relations and phenomena relevant to the solving of a problem. Such external representations most often consist of configurations of inscriptions using a two-dimensional plane (paper, screen), but they might also be three-dimensional physical objects (mock-up, beads of an abacus, pieces of a game), or a combination of the two (virtual objects, 3d model, digital mock-up in an augmented reality context). Shared representations in the Delta Design Game include the triangles on the cardboard, but also the written rules of the game, and the individual external representations (texts, sketches, calculations) that the players might choose to share with their team members.

2.2 Functions of shared representations

Shared representations inherit much of the functionality of the broader class of external representations. We describe three functions based on Duval (1995).

- *Objectification*. External representations allow making some abstract idea perceivable by the senses, i.e. becoming aware of something through expression for oneself. If this is true for an individual, it also happens in collaborative design settings. In design processes, the construction and the representation of a solution go hand in hand. Shared representations also satisfy the need for recording information about the process and facilitate the emergence of design rationale.
- *Communication*. External representations ensure communication between agents. In design, shared representations allow exchanging information between team members that have expertise in different domains, regarding the economical, functional, esthetical, structural, and thermal aspects of a solution in the Delta Design Game.
- *Computation*. External representations allow computations that would be too cumbersome internally. For example, in order to calculate the mechanical equilibrium of a solid, a graphical representation can be visually exploited to identify geometrical parameters and missing

values. Alternatively, the same goal can be attained by using an algebraic representation to mobilize mathematical solving methods that are usually too complex for mental calculation.

All three functions are highly relevant in professional and educational design settings. For example, Gero and Kannengieser (2004), in their situated FBS framework, show that production of new concept is a cyclic process (named "reformulation"), going alternatively through the internal world (both interpreted and expected) and the external world both individually and collectively. The three functions of shared representations, objectification, communication, and computation, may vary in importance as a design process unfolds.

3 An epistemological stand

Many claims about computer tools call attention to their so called representational affordances: cooperative systems are thought to be semiotic tools for meaning making by co-workers. The word "semiotics" refers to the tendency of humans to make sense out of signs and symbols; the word "affordance" refers to the activities that the computer tool allows. The notion of the mediating role of shared representations essentially hinges on the same line of reasoning. In this section, we examine some existing literature in order to find support for the two opposing intuitions stated in the introduction: shared representations might be an aid or, on the contrary, a hindrance in cooperative work and training situations.

3.1 The cognitive dyadic perspective

Within cognitive science, representation is essentially viewed as a dyadic or two-term relation: something that stands for something else. Both internal mental representations and external ones are defined as one-to-one relations between representing and represented entities (Palmer, 1978). For example, the nodes and links in a semantic network, whether postulated in the mind or simulated on the computer, stand for objects and relations in the real world. In the Delta Design Game, the shared representations consists of colored triangles, termed *deltas*, that represent the bricks of a wall, and a flat plane that stands for a 2D planet (on a cardboard such as in Figure 1 or on a computer screen such as in Figure 2). The spatial configuration of triangles represents the physical structure of a house.

In dyadic view, external representations serve to unambiguously identify objects, relations and phenomena, and to communicate about them. As in other scientific domains, definitions of symbolisms are fixed by *convention* (see Quine, 1976). For example, Arabic numerals are used for manipulating numbers, while taking for granted the *choice* of symbolism as a particular mapping of inscriptions to numbers (i.e. Arabic versus Roman). The same is true for logical diagrams, such as those of Venn, Euler, and Peirce, and for graphical representations, such as line graphs, pie-charts, and histograms. Each of them is a notational system to discuss its content and postpone the foundations of the representational system itself. According to Lewis (1969), a convention is the regularity observed in a recurring situation, because it is true that, and it is common knowledge that, everyone conforms to it, everyone expects everyone else to conform to it, even if an individual would prefer one of the other possible codes, he prefers to conform to whichever one everyone else conforms to. An example of such a convention is the color of the deltas in the game which represent the ability to produce heat (red) or to conduct heat passively (blue). So according to Lewis' definition, everybody likewise interprets the color of the triangles according to the regular code of red for heat and blue for cold, because you expect others do it the same way, even you would have preferred it the other way around. A convention boils down to sharing the arbitrary (de Vries, 2010). A legend or key is not neededb because, as Stenning and Oberlander (1995) put it: A legend or key specifies that part of the mapping from representation to world which has to be made explicit to users of the representation because they do not carry it as part of their general knowledge.

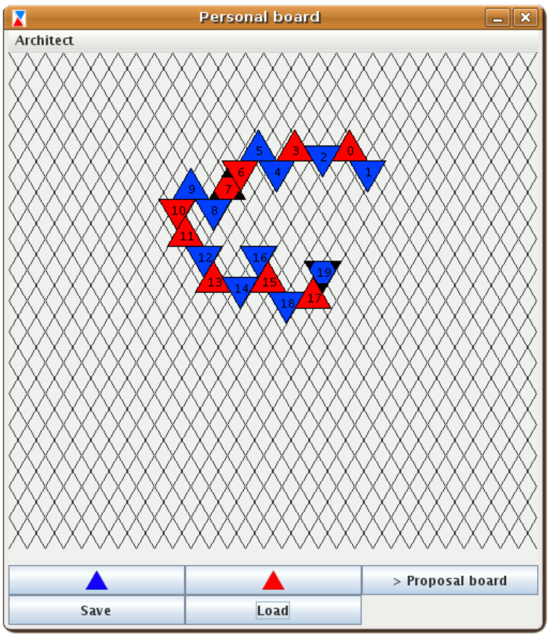

Figure 2. An example of representation as a two-term relation

Norman and Zhang (1994) and Zhang (1997) describe *isomorphic* external representations of an identical logical structure of objects and rules (of tic-tac-toe, of the Tower of Hanoi). For example, the design game can also be played at a distance using a collaborative system (Masclet, 2009). In this version, the triangles of the traditional game are numbered in order to facilitate their identification. Game players, without questioning the meaning of the numbers, use the triangles in the intended way. Some others functionalities, such as the annotation of chatting, were introduced to allow material utterance as defined in (Dearden, 2006). Isomorphic representations vary in degree to which they materialize the rules of a game. So for example, the computer game version does not allow superposing triangles, whereas the physical version requires the players to deliberately respect this rule.

In the beginning of the Delta Design Game, the external representations are genuinely shared. All players attribute the same significations to objects and attributes, even if thermal aspects (color) are irrelevant for some tasks. A unique shared representation (triangles in a plane) has advantages. It gives access to the same geometrical configuration for all players, and can used by all of them for proposing alternative configurations. It constitutes the common ground; players do not need to know the specific external representational systems of each other's jobs. In a certain way, it allows collective objectification. Like in science, shared representations are also crucial for their operational meaning. The rules for manipulating them are described exhaustively, much in the same vain as in a formal system consisting of rules and axioms. It is not allowed to invent rules for manipulation, even if some plausible interpretation seems to allow it (Hofstadter, 1979). For example, in the Delta Design Game, players should not invent purple triangles to represent moderate radiation capacity.

So in summarizing the first viewpoint, the particular way of representing in shared representations does not matter at all, the crux is that the allow to reason about the represented world. However, as Quine (1976) argued, external representations introduced by definition are formally arbitrary but must conform to a traditional usage or else one could express anything through the use of any random symbolism. Of course, the symbolisms in cooperative systems are not randomly chosen. In the Delta Design Game, blue for cold and red for hot is an arbitrary choice with regard to their role in the game, but it conforms to the cultural expectations of the participants.

3.2 The semiotic triadic perspective

Semiotics embraces a triadic view on representation as a three-term relation. Or, in other words, in citing Peirce: "Something which stands to somebody for something in some respect or capacity". A number of terms are used for the three entities (see Eco, 1988, for an overview). The first entity is the material form of the representation: a mark of ink, a configuration of pixels, a sound, the color or texture of a physical object. The second entity is the referent or the object in the world which is represented. The third entity is the idea or the thought that is evoked in someone's mind, the *interpretant* in Peircean terms. In a semiotic perspective, representation always implies a point of view. Even in natural language, a letter sequence, i.e. /hier/, only represents something from the point of view of a particular language, in this case "yesterday" for a French or "here" for a Dutch interpreter. Thus, understanding an external representation requires interpretation and heavily depends on prior knowledge of and experience with similar representational systems. As a consequence, any collaborative work situation that involves coworkers with different backgrounds is particularly interesting.

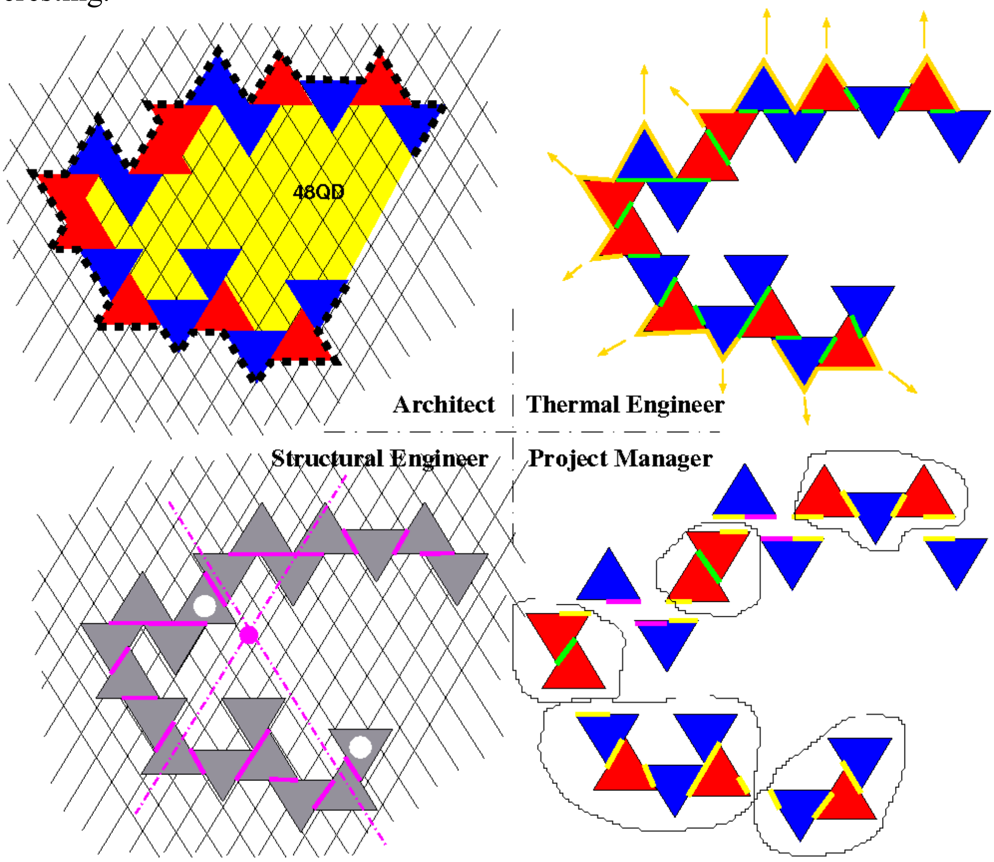

Figure 3. Task-dependent interpretations of a shared representation

In the Delta Design Game, as players gain expertise on their job, they start concentrating on different aspects. Figure 3 shows possible interpretations that are likely to occur for the different tasks.

- The architect examines the internal surface of the house, the exterior and interior shape, and percentage and spreading of blue deltas.
- The structural engineer focuses on positioning of the deltas and the length of the joints. He also pays attention to anchor points (the white dots) because they allow him to compute the resistance and strength of the structure.
- The project manager ignores positioning of the deltas and only analyses the type of joints between the different types of deltas. They give the essential parameters for calculating construction costs depending on the length and type of cement needed. Furthermore, the number of horizontal joints (viewed from the earth) also influences the overall cost through the need of special prefab blocks.

- The thermal engineer concentrates on red deltas (heat sources), length of joints (conductive mechanism), and length of outer angles (whatever their color) for regulation of the mean temperature.

The players produce critical information and create new external representations for themselves or for the team members, such as drawings or writings on the plastic game board (Figure 4). Players also often switch from a vehicular language (the deltas) to a more appropriate vernacular language (dots, joints...). In addition, Figure 4 shows pencils placed on the cardboard for indicating the direction of gravity or the « symmetry axes » of the house. The drawings and annotations express information produced by different team members. Thus, group members start from an imposed common language, then, depending on their task, associate new meanings to the objects of the game, and finally may enrich the existing shared representations by producing new representational elements. They introduce new elements of communication to enrich the basic set of representations. This might be seen as divergence from the shared representations, but players also often go back to the initial representations. A next step in the process could, in principle, involve designers deciding together upon improvements of the shared representations, e.g. their individual internal representations could be externalized which would allow each expert to speed up the operations. In sum, the triadic perspective embraces the possibility, in principle, that different members of a team associate different meanings to a common external configuration in the environment. In other words, sharing the observable or the tangible does not imply sharing the interpretation.

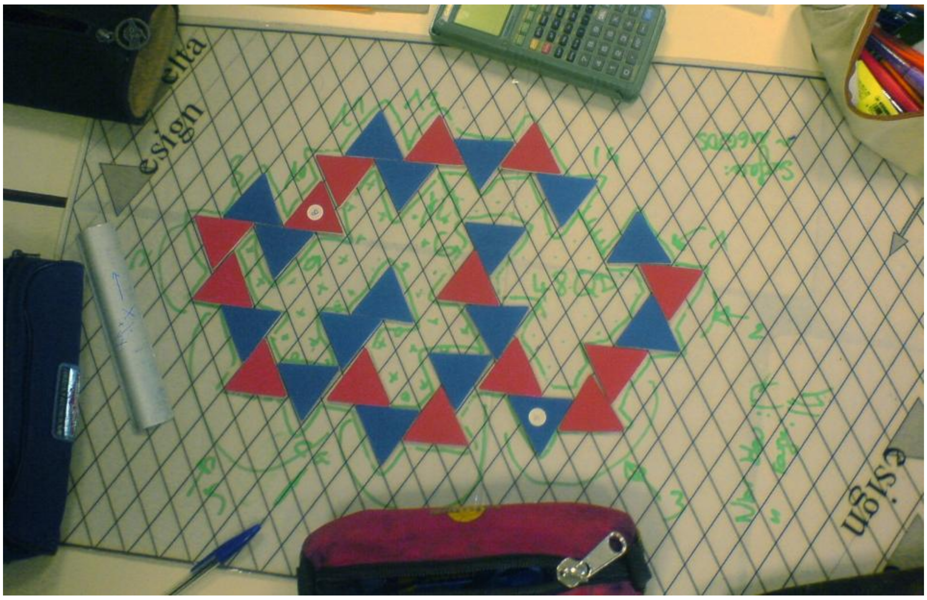

Figure 4. Mixed individual and shared representations

4 Implications for cooperative system design

The theoretical perspectives and the Delta Design Game reveal dynamic interactions between phases and activities in collaborative design and their associated shared representations. Different types of shared representations are appropriate at different times of individual and collective processes as a function of the tasks and activities at hand. Cooperative systems could capitalize on digital processing to dynamically adapt external representations to ongoing tasks, participants, and activities, not only in design, but also in other work settings. The dyadic-triadic distinction and the shared-individual distinction form a useful foundation for the identification of different types of shared representations. We define a typology of shared representations with a view to formulating implications for the design of cooperative systems.

Table 1. Typologie of shared representations

	Attribution of signification to inscriptions	
Application area	**Polysemic Multiple meanings**	**Monosemic Unique meaning**
Generic	Text, freehand drawing, photograph	Line graph, histogram, pie-chart, flowchart
Context-specific	Freehand diagram or schema	“On the fly” visualizations, (virtual) objects in a game
Domain-specific	Architectural sketch, floor plan, organizational chart	Molecular structure and electrical circuit diagrams

We focus on two dimensions: the way in which signification is attributed to inscriptions and the area of application (see Table 1). The first dimension roughly corresponds to the dyadic-triadic distinction and revives Bertin (1967) notions of monosemy (one-to-one meaning) and polysemy (one-to-many meanings). In polysemic representations, a particular configuration in the environment can have multiple meanings. In fact, the signification of an inscription has to be *inferred* from the configuration of inscriptions. Polysemic representations are often used in fuzzy contexts, where one needs to express the possibilities one has in mind, which are not certainties. The early phases of design, for example, are the privileged circumstances for such external representations that support creativity (Tversky et al., 2003). In monosemic representations, each configuration in the environment has only one accepted meaning. In other words, the attribution of the signification of an inscription *precedes* observation of the configuration of inscriptions. Such monosemic representations aim to reduce misunderstandings and are required (or even imposed) during negotiation and contracting.

The second dimension concerns the generality of the representational system. On the extremities, systems can be generic, that is known by the people of the same cultural background and taught at school. Or, on the contrary, representational systems can be specific to an application area and cautioned by domain experts (diSessa, 2004). These formats satisfy the need for recording information, processing information and communicating information between experts. The widespread use of new visualization techniques calls for a third category, context-specific representational systems, because some external representations only have local meaning attached to the particular context of emergence. The Delta Design Game falls in this category both because of the invented representations of objects that belong to the setting (e.g. triangles for bricks), but also because of the emergent representations during play, such as the pencil for indicating gravity, or the freehand drawings and calculation results. The frontiers between categories are not strict and playing the game involves traversing the categories of the typology in an on-going mediation of different types of representations for different purposes in different phases. Real work situations also involve differentiated use of different types of shared representations. Some phases of a process necessitate polysemy for creativity, others require monosemy for precision. Some problems involve cautioned domain representations, for some others, generic representations suffice, and some others still provoke the invention of new representations. In particular, in innovative design process, traditional representations may be too limited to express new concepts and knowledge.

The proposed typology should help system designers to characterize shared representations used in collaborative situations in a variety of work settings. Dependent on ongoing activities, subtle equilibriums between the various types of shared representations need to be found. Coworkers may be forced to navigate between polysemic and monosemic systems in order to get understood, many interdisciplinary collaborative processes involve such a dynamic interplay. However, shared representations are rarely identified as belonging to a particular category, i.e. they are not labeled. Moreover, non verbal representations do not communicate *about* their representational format (Wittgenstein, 1922), so users of shared representations may mistakenly attribute a particular representation to a particular type. This coins an old philosophical question whether the recognition of the type precedes understanding of the content of the representation or the other way around (see also Hofstadter, 1979). Study of the verbal interactions between team members, both in face-to-face and in distance, should provide data on the consequences of incorrect categorizations.

Further work should investigate mechanisms for allowing coworkers to propose their own external representations or to translate from one type to another. This may facilitate objectification, boost creativity and ease communication.

Finally, shared representations, according to the triadic view, may lead to multiple possibly inconsistent interpretations.

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