DYNAMICS OF STATE-PROBLEMS AND DESIGN INTERMEDIATE OBJECTS IN DISTRIBUTED AND COLLABORATIVE DESIGN PROCESS

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The implementation of multi-agents systems aided collaborative and distributed design requires a deeper understanding of the real interactions between actors, inside multidisciplinary teams. In this view, the implementation of these systems requires to observe, to model and to analyze this process with finer granularities levels. This paper presents an approach of collaborative and distributed design process analysis based on the modeling of interactions between actors during this process. The approach consists in discerning, from the real interactions, the relationship between the state-problems and the dynamics of design intermediate objects (DIO) in the computer mediated collaborative and distributed design process. The analysis of state-problems, in a real design process experience shows that the dynamics of the state problems has the influence on dynamics of DIOs.

1. INTRODUCTION

The implementation of multi-agents systems aided collaborative and distributed design requires a deeper understanding of the real interactions between actors, inside multidisciplinary teams. In this view, the implementation of these systems requires to observe, to model and to analyze this process with finer granularities levels. Indeed, the collaborative and distributed design is a complex process (Chiu, 2002, Ostrosi, 2003 and Ostergaard, 2003). This complexity results from the conjugation of a great number of heterogeneous data (domains, actors, organizations, methods) that are interacting between them (Garro, 1995). Moreover, the variety of the points of view results in multiple goals to carry on during the design process. The interaction between the actors, during the collaborative and distributed design process, shows that this one is a key variable. In the majority of the cases, the results issued from the interactions must be consensual in order to be accepted. Under these conditions, the final solution of the design process can result only from the reached consensus on the different elements of this solution. The comprehension of convergence towards an acceptable solution, as a whole, requires a modelling of variables intervening for the period of the interactions between the different actors (Coiera, 2002), the aims and the relations which they maintain during the design process.

In this context, during design process, the designers spend most clearly of their time to create, to discuss, to interpret, to evaluate, to transform... etc the texts, the graphs, the computing results, the different product representations of the product (under the form of various diagrams, drawings or numerical models). These objects are called Design Intermediate Object (DIO) (Boujut, 2000, Mer, 1995, (Gregory, 1997 and Sanchis, 2001). According to *Jeantet and Al,* the ***intermediate objects*** are the produced or used objects, the traces and the supports of the action to be conceived (in relation to the tools, procedures and actors) during the design process. The concept of DIO corporate an effective means of reading of the activity of real design. We will thus be interested in the analysis of a process of collaborative design remotely through of DIOs.

If designers spend, on the one hand, 80% of the time generating and retrieving their data (Baya, 1995), and on the other hand, 93% of the time assessing information on a non-quantitative level of abstraction, then information tools should offer external memory aids to retrieve these data (Dong, 1997). Inside the design teams, as the designers must communicate their thoughts between them, the verbal communication offers a fairly direct path to the state of the design process and its related problem, which we call ***state-problem***.

In this paper, we propose an approach that, beginning with the real interactions and the concepts emergence, consists, on the one hand, in discerning the different state-problems and their dynamics characterizing the collaborative and distributed design process, and on the other hand, in searching the history of DIOs and the causes of the dynamics of DIOs.

In the second section, we present the dynamics of state-problems**.** Here, their identification and evolutions in time permits deepened understanding of the dynamics of the problems that occur during the collaborative and distributed design process. The developed approach is demonstrated by a distributed and collaborative design experience of the GRACC group (***GRACC : G****roupe de* ***R****echerche sur l'****A****ctivité de* ***C****onception* ***C****oopérative*). In the third section, we propose a data analysis between the design intermediate objects and the emerged state-problems during their emergences as a public (in synchronous and shared representations). Finally, we summarize the important results of our approach.

2. DYNAMICS OF STATE-PROBLEMS IN DISTRIBUTED AND COLLABORATIVE DESIGN PROCESS

Modeling of interactions. During the collaborative and distributed design process, each domain is represented by an actor, which has specific responsibilities in the design process. Thus, each actor is authorized to be an expert on certain fields of knowledge called *registers of reference*. We note q the number of actors and A_k ($k=1\dots q$) the actor k corresponding to the register of reference k. During the design process, the actors interact. For example, an actor A_k proposes, at the moment t, a conjecture related to a problem. It is about a potential solution, candidate to become an entire solution. An actor A_l representing the domain l, reacts to this proposition. He advances, for example, a criterion of evaluation of the proposed conjecture. We note Int_i , $i=1..., n,$ the i^{th} interaction, with n the number of interactions. In the most elementary form, an interaction Int_i of an actor A_k , at the moment t, is characterized by one or several transmitted messages. Thus, we consider a message as being a form of representation of *the knowledge domain.* It can be characterized by a *syntactic element* (for example, verb or noun), with a *specific semantic* to a knowledge domain. We call these elements, ***entities of analysis*** and we note e_j , where $j=1,..., m$.

Then, for analyzing the collaborative and distributed design process, each interaction is filtered with the aide of the entities of analysis. The filtered interaction Int_i is called *enriched interaction*. It is noted Int'_i. Then, the relationship between the enriched interactions Int'_i and the entities of analysis e_j is given by the matrix $C[c_{ij}]$, where $i=1..., n$; $j=1...,m$. If the enriched interaction Int'_i, contains the entities of analysis e_j, then $C_{ij}=1$, otherwise $C_{ij}=0$.

For example, a collaborative and distributed design is done within the GRACC. Four research laboratories (CRAN-Nancy, IRCCyN-Nantes, M3M-Belfort and 3S-Grenoble) have participated in this experience. The problem is the design of a children's trailer. A group of work with four actors was constituted with a *project manager*, a *form designer*, a *frame designer* and a *link designer*. The design experiences that we have carried out are mainly *remote design experiences* which implement computer means and software of the market (CAD, MS-Office, video conference, sharing of applications...). There were four meetings overall. The total duration of each synchronous meeting is two hours and their corresponding corpus contains approximately 750 interventions. We analyzed the first synchronous meeting of the experience of collaborative design (*GRACC*). For this design experience, the matrix $C[c_{ij}]$ (see Figure 1), corresponding to an extract of the corpus, represents the relation between the enriched interactions Int'_i and the entities of analysis e_j.

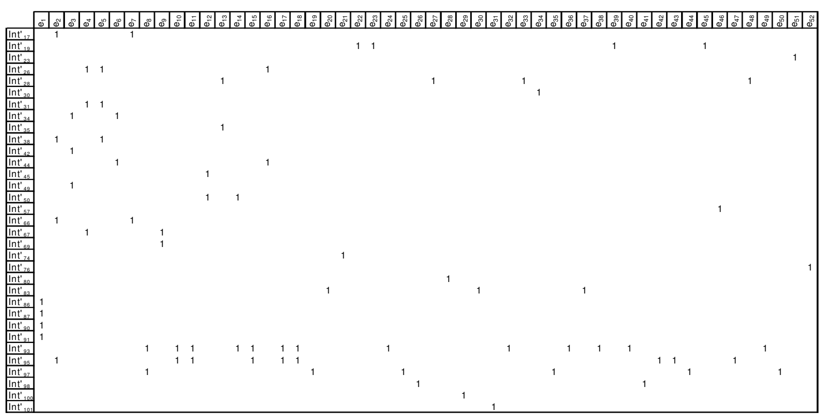


Figure 1 – Matrix C[c_{ij}]

Identification of state-problems and their dynamics. In the case when a family of enriched interactions corresponds to a family of entities of analysis, the matrix $C[c_{ij}]$, $i=1...,n$; $j=1...,m$ takes a particular form. Here, the partition of the set of the enriched interactions and the partition of the set of the entities of analysis are carried out so that each part of the enriched interactions corresponds to a part of the entities of analysis. Ideally, the search of these correspondences allows the decomposition of the matrix $C[c_{ij}]$, in sub-matrix C(Diagonal) and C(Out-Diagonal) where sub–matrices C(Diagonal) are filled only with "1", and sub-matrix C(Out-Diagonal) are filled with "0". In practice, it is not always the case. During the interaction, it is necessary to have confrontation and the negotiation in order to reach to finally a consensus. Mathematically, the search of the families of enriched interactions and the families of entities of analysis is a search problem of simultaneous partitions in the two sets, the *enriched interactions* and the *entities of analysis*, in correspondences or quasi-correspondences, class of partition to class of partition. Then, the basic idea consists in carrying out permutations of lines and columns of the matrix $\boldsymbol{C[c_{ij}]}$ such as to find the structure of the correspondence on the crossing of these two sets (Marcotorchino, 1987).

The structure of the matrix $\boldsymbol{C[c_{ij}]}$ makes possible to identify the families of entities of analysis. The sequence of these *entities of analysis* in a family is called *concept* (Movahed-Khah, 2005). Emergence here means that a concept, as a group of entities of analysis, was not previously represented, but can be represented because it has been constructed now (Gero, 1998). Moreover, the correspondences per block permit to characterize a family of interventions by the corresponding concepts. Each concept offers a fairly idea to a state of the design process and the related design problem, which we called state-problem. Thus, a family of enriched interactions allows identifying the *state-problem* of the collaborative and distributed design process.

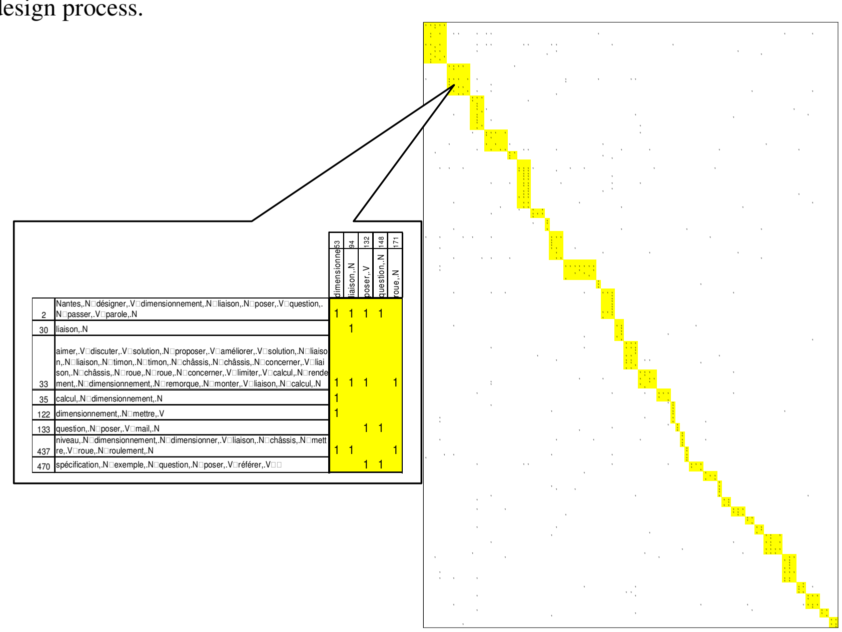


Figure 2 - Partition of matrix C[c_{ij}] for a meeting

For example, the "Figure 2" shows the partition of enriched interactions-entities of analysis matrix $\boldsymbol{C[c_{ij}]}$ for the considered design experience. It shows the identification of the 33 families of entities of analysis corresponding to 33 *state-problems.*

The relationship between the interventions and state-problems permit to note their continue evolution. Then, the design process, as a dynamics system, is represented as a change of qualitative states. A state can be considered as attractor in a dynamics system. It is represented then, as a state which drew up the other neighbors states. The representation of the state-problems in time allows to note the dynamics of the problems in relation to the design process organization, as well as in relation to the evolution and/or the emergence of the solutions. For example, the dynamics of 33 state-problems in "Figure 2" is represented in "Figure 3" for a synchronous meeting of 500 interventions (two hours). The analysis of these state-problems shows that this dynamics is characterized rather by many irregular leaps. These leaps, probably unforeseeable, show that the design process, on a micro scale, is far from being harmonious. In fact, these leaps depend strongly as much on the structural causes, such as the auto-organization (or self-organizing) inside of the team (Stempfle, 2002), the human action, such as the creative characteristic of the design (Movahed-Khah, 2006 and Movahed-Khah, 2004).

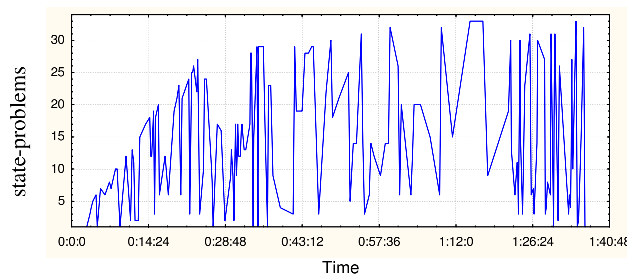


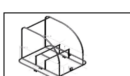
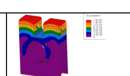
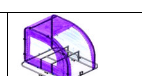
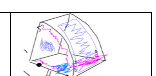
Figure 3 – Dynamics of state-problems in a synchronous meeting

3. RELATIONSHIP BETWEEN DIOs AND STATE-PROBLEMS

The relationship between Design Intermediate objects (DIOs) and State-Problems (SPs) can be represented by a matrix which consists in crossing a set of DIOs with of a set of state-problems and to look what occurs in the cells from crossing. We note $\boldsymbol{v}$ number of DIOs and $\boldsymbol{O_K}$, $k=1...,v$, the $\boldsymbol{k^{th}}$ emerged DIO at the moment $\boldsymbol{t}$. During the design process, the actors interact while discussing on DIOs. For example, an actor puts, at the moment $\boldsymbol{t}$, the $\boldsymbol{O_K}$ in public (shared space in synchronous situation). This emergence of $\boldsymbol{O_K}$ in public gives the opportunities of a discussion on this object and influence the exchanges (interactions) between the actors.

Table 1 shows some emerged DIOs in design process experience.

Table 1- Represented DIOs in a meeting of distributed and collaborative design

					
Software	SolidWork 2001	MS-Excel 2000	Ansys	MS-Photo Editor	NetMeeting
Object	3D model	Table sheet	FEM result	Image	Sketch

These interactions are marked by the various acts which are transcribed, initially in the corpus, and afterwards by our means of analysis, in the form of concepts emergence (which are related to the state-problems). We note $\boldsymbol{P_l(t)}$, $l=1...,w$ with $\boldsymbol{w}$ the total number of the state-problems, the emerged state-problem $\boldsymbol{l}$, at the moment $\boldsymbol{t}$. Then, the relation between the state-problem $\boldsymbol{P_l(t)}$ and the DIO $\boldsymbol{O_k}$ is given by the matrix $\boldsymbol{Y[y_{kl}(t)]}$, $k=1...,v$ $l=1...,w$. If the emerged DIO in public $\boldsymbol{O_k}$ is simultaneous with the emerged state-problems $\boldsymbol{P_l(t)}$ then we have $\boldsymbol{y_{kl}(t)=1}$, otherwise $\boldsymbol{y_{kl}(t)=0}$. The matrix $\boldsymbol{Y[y_{kl}(t)]}$ represents the relation between DIOs (rows) and the state-problems according to time (columns) (see Figure 4).

For representation the number of occurrences $\boldsymbol{x_{kl}}$ of the $\boldsymbol{O_k}$ in the state-problem $\boldsymbol{P_l}$, we transform the first matrix $\boldsymbol{Y[y_{kl}(t)]}$ into a quantitative matrix $\boldsymbol{X[x_{kl}]}$, $k=1...,q$ $l=1...,n$ (see Figure 5).

$$Y[y_{kl}(t)]=\begin{array}{c|cccccc|} & P_a(t_I) & P_b(t_{II}) & P_c(t_{III}) & P_d(t_{IV}) & \dots & P_w(t_t) \\ O_1 & y_{1a}(t_I) & y_{1b}(t_{II}) & y_{1c}(t_{III}) & y_{1d}(t_{IV}) & \dots & y_{1w}(t_t) \\ O_2 & y_{2a}(t_I) & y_{2b}(t_{II}) & y_{2c}(t_{III}) & y_{2d}(t_{IV}) & \dots & y_{2w}(t_t) \\ O_3 & y_{3a}(t_I) & y_{3b}(t_{II}) & y_{3c}(t_{III}) & y_{3d}(t_{IV}) & \dots & y_{3w}(t_t) \\ O_4 & y_{4a}(t_I) & y_{4b}(t_{II}) & y_{4c}(t_{III}) & y_{4d}(t_{IV}) & \dots & y_{4w}(t_t) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ O_v & y_{va}(t_I) & y_{vb}(t_{II}) & y_{vc}(t_{III}) & y_{vd}(t_{IV}) & \dots & y_{vw}(t_t) \end{array}$$

Figure 4- Crossed matrice $\boldsymbol{Y[y_{kl}(t)]}$

$$X\left[x_{kl}\right]=\begin{array}{c|cccccc|} & P_a & P_b & P_c & P_d & \dots & P_w \\ O_1 & x_{1a} & x_{1b} & x_{1c} & x_{1d} & \dots & x_{1w} \\ O_2 & x_{2a} & x_{2b} & x_{2c} & x_{2d} & \dots & x_{2w} \\ O_3 & x_{3a} & x_{3b} & x_{3c} & x_{3d} & \dots & x_{3w} \\ O_4 & x_{4a} & x_{4b} & x_{4c} & x_{4d} & \dots & x_{4w} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ O_v & x_{va} & x_{vb} & x_{vc} & x_{vd} & \dots & x_{vw} \end{array}$$

Figure 5- Quantitative matrix $X[x_{kl}]$

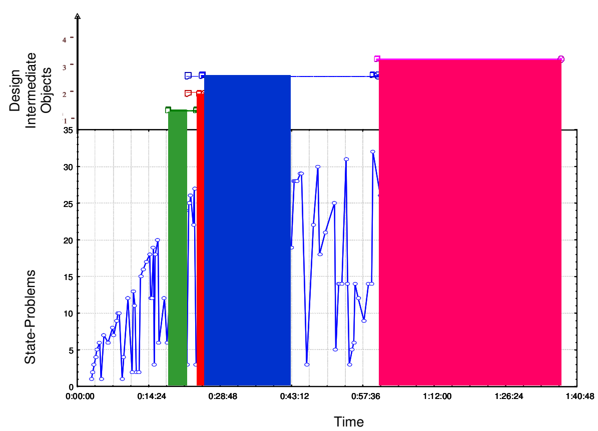


Figure 6- Overlapping of state-problems and DIOs

Structuring of the matrix $\boldsymbol{X[x_{kl}]}$ permits to identify the families of the emerged state-problems during emergence of the families of $\boldsymbol{O_k}$. If a family of DIOs corresponds to a family of state-problems, then sub-matrices corresponding to the diagonal blocs of the matrix $\boldsymbol{X[x_{kl}]}$ represent the strong relationship between DIOs and SPs. For example, the matrix $\boldsymbol{X[x_{kl}]}$ (see Figure 7) represents the relation between the four DIOs and the 33 emerged state-problems in an experience meeting (see the example of overlapping represented by different colours in “Figure 6”). “Figure 8” presents the structuring of matrix $X[x_{kl}]$**.** The result of structuring helps us to identify the emerged state-problems in family of SPs in relation with each family of DIO.

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}	P_{19}	P_{20}	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	P_{26}	P_{27}	P_{28}	P_{29}	P_{30}	P_{31}	P_{32}	P_{33}
O_1	0	1	1	0	0	1	0	0	0	0	0	3	0	0	1	1	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
O_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
O_3	4	2	2	0	0	2	0	1	4	1	1	4	3	1	1	2	6	0	1	0	2	2	3	3	2	1	1	2	5	0	0	0	0
O_4	4	2	5	2	0	6	1	1	2	2	1	2	2	4	4	0	0	0	1	4	0	0	2	0	0	2	2	0	0	3	3	3	3

Figure 7- Quantitative matrix X[x_{kl}]

		A										B	C												D									
		P_5	P_7	P_8	P_{11}	P_{19}	P_{28}	P_{29}	P_{31}	P_{32}	P_{33}	P_{18}	P_1	P_2	P_9	P_{12}	P_{13}	P_{16}	P_{17}	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	P_3	P_4	P_6	P_{10}	P_{14}	P_{15}	P_{20}	P_{26}	P_{27}	P_{30}
A	O_2																																	
B	O_1											1				1																		
C	O_3												1	1	1	1	1	1	1	1	1	1	1	1	1		1							
D	O_4												1	1	1	1	1					1			1	1	1	1	1	1	1	1	1	1

Figure 8- Partition of matrix X[x_{kl}] (threshold >= 33%)

Initially, the chaining of (the set of) these state-problems enables us to describe the concepts relating to the contents of DIOs. For example, $\boldsymbol{O_3}$ and $\boldsymbol{O_4}$ (see Figure 9) are respectively related with the family of SPs $\{P_1,P_2,P_3,P_6,P_9,P_{12},P_{13},P_{16},P_1,P_{21},P_{22},P_{23},P_{24},P_{25}\}$ and the family of SPs $\{P_1,P_2,P_9,P_{12},P_{13},P_{23},P_3,P_4,P_6,P_{10},P_{14},P_{15},P_{20},P_{26},P_{27},P_{30}\}$.

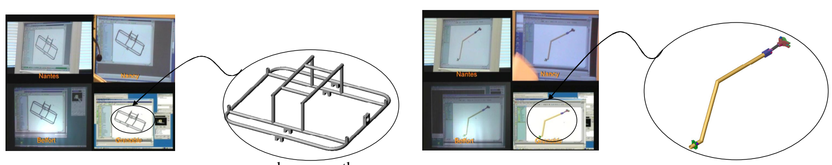


Figure 9- The 3rd and 4th DIOs in synchronous representation

The search for the entities of analysis relating to SPs, permit to understand and describe the simultaneous emergence of the corresponding of the DIOs. For example, some entities of analysis in the family of state-problems corresponding to the simultaneous emergence of the ***3rd*** DIO, are the following:

> P_2= {**dimensionnement, .N** ; **liaison, .N** ; poser, .V ; question, .N ; **roue,.N**} ;
> P_3= {attendre, .V ; **châssis, .N** ; commencer, .V } ;
> P_{12}= {homme, .N ; **main, .N**, humain, .N} ;
> P_{24}= {accrocher, .V ; dessous, .N} ;
> P_{25}= {regarder, .V ; **dimension, .N**, dessus, .N} ;

The interpretation of these relative data concerning the $\boldsymbol{O_3}$ enables us to enter to the implicit contents of DIO via the verbalization of the thoughts. Hence, we note that the interactions of the actors in the presence of $\boldsymbol{O_3}$ are focused on the problems of configuration (orientation) of the product components, the computing from mechanics of materials (strength of materials) and the ergonomic aspect.

4. CONCLUSION

The implementation of collaborative and distributed multi-agent systems requires to observe, to model and to analyze the design process with finer granularities levels. In this paper, a framework for understanding the relationship between state-problems and simultaneous emergence of DIOs in the collaborative and distributed design is proposed. The interaction between actors in the presence of DIOs and during this design process shows that the dynamics of DIOs is an influential variable on the management of the meetings. The analysis of the state–problems and their relationship with DIOs, in a real experience of distributed and collaborative design, shows that theirs dynamics is the result of the interactions of actors with DIOs in the public space (shared space). Moreover, these dynamics, apparently instantaneous, show that this process strongly depends on the relationship between the emergence of DIOs and the state-problems. Based on the proposed approach, we are currently working on the development of a multi-agents systems for discovering the influence of the DIOs on the state-problems in the computer mediated distributed and collaborative design process.

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