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# Towards open object-oriented models of collaborative problem solving interaction

**A. Dimitracopoulou[1], N.M. Avouris[2], V. Komis[2], C. Fidas[2]**

[1]University of the Aegean, Rhodes, Greece

[2]University of Patras, Patras, Greece

adimitr@rhodes.aegean.gr, N.Avouris@ee.upatras.gr, komis@upatras.gr, fidas@ee.upatras.gr

## ABSTRACT

Usually analysis of collaborative problem solving situations is done through discourse analysis or interaction analysis, where in the centre of attention are the actors involved (students, tutors etc.). An alternative framework, called "Object-oriented Collaboration Analysis Framework (OCAF) is briefly presented here, according to which the objects of the collaboratively developed solution become the centre of attention and are studied as entities that carry their own history. This approach produces a view of the process, according to which the solution is made of structural components that are 'owned' by actors who have contributed in various degrees to their development. OCAF is based on both actions and dialogues of actors and allow deriving further qualitative as well as quantitative indicators of both solution quality and collaboration. Web-based tools supporting the OCAF approach are discussed. These tools are designed to be open in possible adaptations and able to be linked to various collaborative systems supporting diagrammatic problem solving.

### Keywords

Collaborative problem solving analysis, dialogue-action analysis, web-based analysis tools

## INTRODUCTION

The methodological issues of collaboration analysis are important to the effectiveness of the collaborative learning process, the designation of appropriate learning activities and settings, as well as the design of collaborative technology-based learning environments. A number of different approaches have been developed for the analysis of collaborative activities in different mediums and environments. Some of them are focused on problem solving strategies or on plan recognition (Hoppe & Ploetzner, 1999), others on the evaluation of partners' involvement (Simmof, 1999), or on the process of mutual understanding and the learning effects (Baker *et al*., 1999). There are approaches of analysis implemented after the interaction and others that are applicable during the evolution of the collaborative process, thus providing assistance tools that are able to evaluate personal contribution and visualise collaboration patterns (Simmof, 1999).

A framework of analysis is presented in this paper, according to which the objects of the solution, become the center of attention and are studied as entities that carry their own history and are acted upon by their owners. This perspective produces a new view of the process, according to which the solution is made up of structural components that are "owned" by actors who have contributed in various degrees to the produced solution. This view of the world, which is a reversed view of the one we usually build of the problem solving process, can be useful, as it reveals the contribution of the various actors in parts of the solution, and identifies areas of intense collaboration in relation to the final solution.

According to this view an operational framework of analysis and evaluation of collaborative problem solving has been defined called 'Object-oriented Collaboration Analysis Framework" (OCAF), also described in Avouris *et al.* (2001). OCAF's corresponding analytic model identifies patterns of interaction and relates them to objects of the shared solution. The model provides a new way of representing collaborative problem solving activity, taking into account both actions and dialogues of partners and supporting qualitative and quantitative representations that can be used as meta-analysis and evaluation tools. The framework has been used for the analysis of various kinds of collaborative problem solving environments based on jointly developed diagrammatic 'solutions', made of well distinguished objects, such as concept maps, entity-relationship diagrams, diagrams of specific modeling formalisms, architectural diagrams, etc. It has been shown that this approach can be applied both in synchronous distance-collaboration environments (dialogue via written messages) and in co-located group collaboration when a more oral-dialogue oriented collaboration occurs.

Moreover, the proposed analysis framework proposes a model that can be generated and further processed by adequate tools, attached to a collaboration support environment. These tools could be used not only by researchers but also by teachers managing on-line distance collaborative problem solving or by students, in an appropriate form, as a meta-cognitive or collaboration meta-analysis tool, helping them self-regulate their actions and their involvement.

Most of the existing collaboration systems present limitations when used by young students in real school settings. Some of the limitations are attributed to the fact that the teacher who is in charge of several students, fails to interpret the enormous number of complex interactions that can take place simultaneously. Additionally, there is a lack of tools analyzing collaborative activity and providing participants with appropriate information in order to self-regulate this activity. Acknowledging these limitations, during the last years, researchers have started to work on addressing this problem. Systems that aggregate the interaction data of logfiles into a set of high-level indicators and present them to the participants or the teacher have been proposed. From these systems, we could distinguish three main categories: (a) Systems that present or visualize indicators concerning exchanged patterns in a discussion. The system proposed by Simmof (1999) visualizes in an innovative way discussion threads with nested boxes exploiting quantitative information on participation rates in exchanged messages. In MarCo, a dialogue oriented system (Tedesco & Self 2000), a mechanism detects disagreements and conflicts between users' beliefs or intentions, on the basis of selected dialogue acts. (b) Tools based on qualitative analysis of members actions, deriving higher order descriptions of group activities, such as the CardDalis system (Muehlenbrock & Hoppe 1999) were applied in the low level conceptual task of puzzle resolution. FACT (More & Moriyon 2001) is another framework that produces tree-like histories, related to actions. (c) Systems that analyses messages and actions such as the system under development by Jermann et al. (2001) that is intended to display separate indicators of participation rates on messages and others on actions. Other systems, such as EPSILON (Soller & Lesgold, 2000) and COLER (Constantino-Consalez & Suthers, 2001), analyse data from actions and messages and monitor directly group members by appropriate messages, without presenting the derived information to users (students or teachers).

In order to develop effective analysis frameworks and tools for collaborative problem solving analysis, we need to investigate some key questions:

- How to coordinate the analysis of actions and dialogues?
- What are the most significant data to be logged and coded?
- How to inter-relate collaboration features with problem solving content and process and what abstraction methods we need to construct a computational model?
- How to provide a rich variety of analysis output, to assist facilitators or experienced learners?
- How to develop open and flexible tools, able to be easily adapted and used in various systems of a same category?

This paper makes an attempt to explore some of the above issues. The OCAF framework and its model in textual and diagrammatic form are presented. The supported analysis dimensions are discussed in view of OCAF applicability and usefulness in research and teaching issues.

## THE OCAF FRAMEWORK

The proposed framework is based on two basic considerations, one related to the *object oriented view* of collaborating actors' roles and contributions and the other to the *unified analysis of dialogues and actions on objects*.

a) The diagrammatic solution of the problem is a representation of the shared effort of the involved partners as well as of their shared memory. In OCAF we shift the center of attention on these objects of the solution. That implies that these objects, constitutive of the solution, are studied as entities that carry their own history and are acted upon by their owners (the actors involved in their conception, creation, modification and inter-relation in the specific diagrammatic solution built by them). This perspective produces a view of the process, according to which the solution is made up from structural components that are "owned" by actors who have contributed in various degrees to the produced solution.

b) Previous research has shown (Baker *et al*., 1999) that mutual understanding among the collaborative agents takes place via a combination of perception of graphical action and communication. Furthermore, depending on the provided tools facilitating dialogue, the collaboration mode can vary from a more action-dominant mode to a more discussion-based mode. For these reasons, it is argued that there is a need to apply a unified analysis and interpretation of both dialogue and actions related to the solution objects, in order to analyze and evaluate collaborative activities in diagrammatic problem solution.

From the resulting framework of analysis, a model M of the solution is defined, conceived in this context, as a formal model, that can be used to reconstruct or analyze certain aspects of both actions and dialogues occurring in the problem-solving group. This model of ownership of the solution is based on the notion of ownership of the components of the diagrammatic solution. Such a diagram in many cases is made of objects (entities) that are shown in the diagram in abstract or pictorial form. These can be related through relationships often shown or implied in the solution. The entities have attributes or properties that are associated to them. The entity/relationship/attribute constructs could be one set of the basic objects that make a diagrammatic solution. The proposed model according to OCAF has been formalized in textual and diagrammatic form as follows:

Let a given Solution S of a problem X be: $S(X) = \{ E_i , R_j, A_m,\}$ , Where E represent the node entities of the solution, ( i=1, …, k) R the relationships connecting them (j=1,…,l) and A the attributes of the entities (m=1, …, n) that participate in the solution.

The model of the solution can be:

$$M\ (S) = \{ E_i\ *\ \tau i\ /P_i f_j,\ P_k f_l\ ,\ \ldots\ R_j\ *\ \tau i\ /\ P_i f_j,\ P_k f_l\ ,\ \ldots\ ,\ A_m\ *\ \tau i\ /\ P_i f_j,\ P_k f_l\ ,\ \ldots\ ;$$

$$-E_i\ *\ \tau i\ /\ P_i f_j,\ P_k f_l\ ,\ \ldots\ ,\ -R_j\ *\ \tau i\ /\ P_i f_j,\ P_k f_l\ ,\ \ldots\ ,\ -A_m\ *\ \tau i\ /\ P_i f_j,\ P_k f_l\ ,\ \ldots\ \}$$

Where: E, R, A, are the entities, relations and attributes that are part of the final solution, while with –E, -R, -A the items discussed during the problem solving process, but not appearing in the final solution, are shown. $\tau_i$ is an index of the item, as implied by its initial action of insertion or by its discussion in the timeline of the problem solving process.

To each item a sequence of $P_i\ f_j$ is associated. Each $P_i\ f_j$ represents the human agent Pi (e.g. a student, a teacher or facilitator) participating in a direct or indirect way in the problem solving process and his/her functional role $f_j$ related to the particular part of the solution.

The different functional roles f used in OCAF are described in Table 1. It should be noticed that two functional roles concern the initial proposition to insert the item (by action (I) or by dialogue (P)), while the others express the discussion on each item. Also testing of the proposed solution is done through argumentation (A) in the case of static-diagrammatic solutions, while testing can involve use of alternative representations and provided testing tools in case of development of dynamic models of the solution (T).

So for example: $[E\ (CLOCK)]=A_P\ B_M\ A_I]$ indicates that the entity 'Clock' has been produced from interaction of Agents A and B. Agent A made the initial proposal ($A_P$), which was modified subsequently by Agent B ($B_M$), finally Agent A inserted the object in the shared Activity space ($A_I$), accepting the modification.

In our context, a functional role reports the purpose of a 'communicative act', from the point of view of its 'actor' or 'interlocutor', thus constituting an interpretation of the actors/interlocutors intention in communication It is to be noted that, the term of communicative act refers not only on messages (written dialogues during collaboration by distance), but also on actions of collaborative agents.

| **ID** | **Functional Role** | **Derived from :** | **Example** |
|---|---|---|---|
| I = | Insertion of the item in the shared space | *action analysis* | *Action:* 'Insertion' of Entity "Velo" |
| P= | Proposal of an item or proposal of a state of an item | *dialogue analysis* | *Message:* "I believe that one entity is the firm 'ABC'" or "let us put the value of entity flow to state *locked*" |
| C= | Contestation of the proposal | *dialogue analysis* | *Message: I think that this should be linked to the entity B by the "analogue to" relation* |
| R= | Rejection / refutation of the proposal | *action and/or dialogue analysis* | *Message:* "What their attributes will be ? I don't agree". Or<br>*Action:* 'Delete' Entity "Velo" |
| X= | Acknowledgement/ acceptance of the proposal | *Action and / or dialogue analysis* | *Message:* "That's right" *or*<br>*Action: Insertion of* a proposed enitity |
| M= | Modification of the initial proposal | *action & dialogue analyses* | *Message:* I suggest we put the state to "unlock"<br>*Action:* "Modify" |
| A= | Argumentation on proposal | *dialogue analysis* | *Message:* "I believe that I am right because this is …" |
| T= | Test/Verify using tools or other means of an object or a construct (model) | *actions & dialogue analyses* | *Message:* Let us run this model to observe this part of the model behavior<br>*Action:* Activate 'Graph Tool' , or 'Barchart Tool'' |

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*Table 1. Unified "functional roles" definitions*

An alternative, diagrammatic representation of the model involves association of the solution items to their history as shown in the Figure 1. The advantage of the textual representation is that it can be produced and processed by an adequate tool, while the diagrammatic representation is easier for the human to study. The figure 1 presents two OCAF models ('a', 'b'), that model the collaborative history of solutions provided by two different groups of students, referring to the same problem. Notice that the discontinued lines present the items discussed during problem solving but not presenting in the final solution.

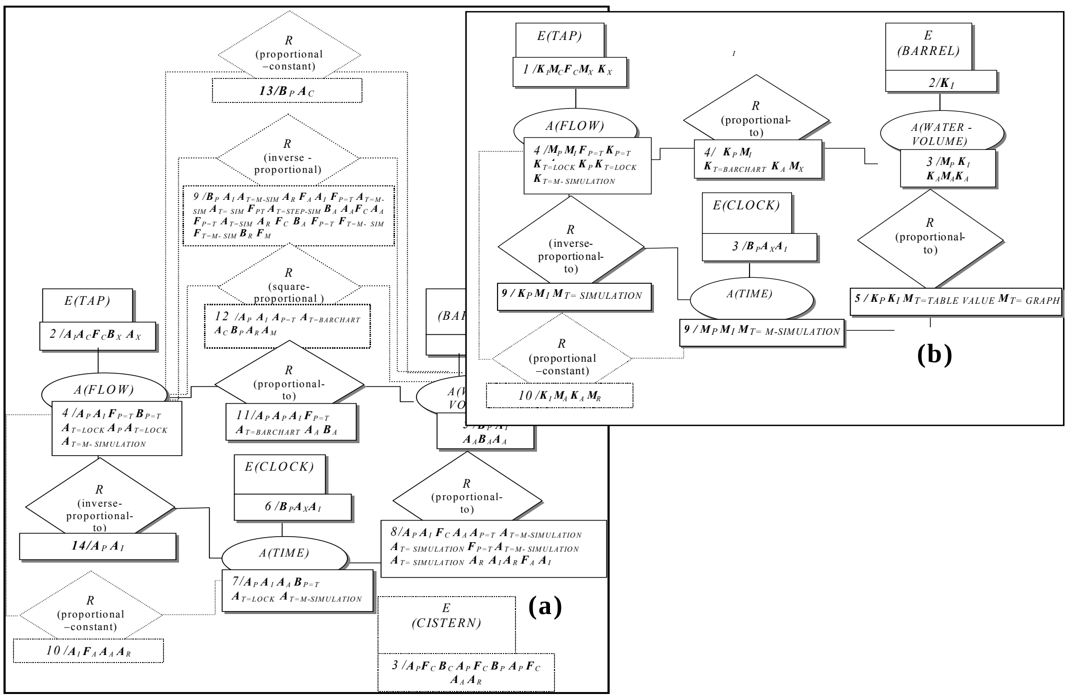


*Figure 1. OCAF diagrammatic models of two group solutions (students A,B and students K,M) on the same problem*

## DISCUSSION

Merely descriptive models, such as this provided by OCAF could not essentially reconstruct the complex phenomena of social interaction and particularly of collaborative learning. They could capture only specific facets of actions or interactions in groups. The value of a model like OCAF, is mainly related to its capacity to bring up interesting points of view and thus provide information mainly to researchers and teachers relating to the quality of the problem solution and the collaboration modes adopted by the participants, such as the following ones:

*A) Analysis oriented to the quality of the solution*: A constructed OCAF model, first of all, provides information on solution items that take part of the solution. Additional information that can help to interpret the solution and eventually to infer students difficulties on conceptual or problem solving aspects are: (a) *Items discussed and rejected* and items that were abandoned due to a conflict. (b) The collaborative history of objects, that for instance can help to distinguish which *non-appropriate solution items* have been *derived from low collaboration*, (c) The order ('τ') of each item discussion could provide *indications on conceptual difficulties* of participants. (d) Information on the problem solving strategy can be extracted by the study of some *'functional roles'* in objects' solution history related to *solution testing* approaches and especially to tools used.

The diagrammatic form of the OCAF model, contributes in a supplementary way to the analysis, providing a perceptual view. A teacher that examines and compares two diagrammatic OCAF models of solutions, can directly distinguish, for instance, solution objects that are not appropriate and were not discussed in a group, or others that were discussed a lot and revised. Such information can support teachers to propose intra-group collaboration in order to discuss specific issues. Teachers could easily identify conflict points, or not appropriate approaches and give advice on topics of the debriefing session internal to the group. They could also recognize semantically significant differences between approaches on problem solving and advice further intra-group discussions.

B) *Analysis oriented* to *collaboration modes adopted by participants*: Information that can be derived from queries on a constructed OCAF model can concern among others the following:

- *Degree of participation* of group members, based on indicators such as *distribution of solution items per member*: For instance, from the model presenting to the figure 1a, it can be derived that in the specific collaborating team 14 items have been discussed, of which 2 (14%) had one owner, 7 two owners (50%) and 5 three owners (36%).
- *Contribution of group members* to the developed solution, determination of *roles of group members* and determination of the degree of their involvement: Regarding the functional roles of each member contribution, it can be accounted, for instance, the distribution of 'items proposals' (functional role 'P') among the agents participating that provides an indication of ownership and involvement. In the example used previously, it was as following: A=10 (71%), B=4 (29%), F=0, ratio=2,5. It infers that actor A was mainly the operator ('Insertions' from A=15 and 'Insertions' from B=0), so this non-uniform distribution of ownership reflects these roles.
- Existence of some *significant functional roles for problem solving approach*: It is often important to examine closer the degree of some functional roles existence, for instance these of 'Argumentation' or 'Test', that help to distinguish some strategies concerning the evaluation process of the produced solution, in each specific collaborative environment. In the example presenting in Figure 1a, it was derived that the pupils have tested parts of the solution (e.g. the relations) by using mostly the available manual simulation (Tool: M-SIMULATION) and did not validate the overall model. Examining the indices of T(est) role, it was derived that only some of the available alternative representations (graphs, bar-charts, tables of values) have been used, and this in a limited degree.
- Identification of *interaction patterns* per item of solution and *Density of interaction*: From the model presenting in figure 1a., it was derived that to the 8 of the 14 solutions items have been assigned long interaction patterns (involving from 5 to 18 exchanges though messages and actions) indication of an intense interaction.

Some of the above analysis dimensions are related to quantitative aspects of interaction, and appear often in studies of collaborative distance learning environments, while others relate to a more cognitive and meta-cognitive view, as for instance is the case of solution validation strategies.

Concerning the diagrammatic form, one can consider this view as an attempt to relate the time dimension (predominant in interaction analysis) to the space dimension (predominant in diagrammatic solution representation). Various transformations of this view can make it suitable for different users. For instance, by adequate color-coding of the participants and their roles, the association of ownership to solution items could become vivid. In every case, it is to be noted that the presented abstract form of this diagram, even if it seems to be useful to researcher or teachers, it is not appropriate to students.

The OCAF framework was applied in two cases: a) in synchronous distance-collaboration environments with dialogue via written messages and b) in co-located group collaboration where a more oral-dialogue oriented collaboration occurs). Both of them involved diagrammatic problem solutions where the constitutive items of the solution were entities, relations and attributes or properties. The collaborative problem solving was supported by two different systems, a concept map system (Komis et al. 2001) and a modeling system (Dimitracopoulou et al. 1999) that are addressed to secondary education students. In both of these cases, it is shown that the analysis provided and derived by OCAF models was particularly useful to researchers (Avouris et al. 2001).

It is believed that using the framework, similar models can be produced containing various kinds of solution items, the only restriction being that the problem solution is made of independent items. So many diagrammatic or object-based solutions, like diagrams, puzzles, etc., can be analyzed. In contrary, this framework cannot easily be applied in text-based or algebraic solutions.

The presented work is part of a research agenda that seeks to conceive and develop flexible and open tools, able to assist users of collaborative learning environments to monitor or self-regulate their actions. The tools are designed to be open in order to allow a substantial adaptation of (a) the set of the *basic objects* that make a diagrammatic solution and (b) the main *functional roles of collaborators*. These tools are currently designed in such a way that could be linked with different kinds of systems supporting collaborative diagrammatic problem solving, incorporating various structured dialogue interfaces.

A basic tool is this, which functions as a logging data storing and presentation tool. The events are serialized and stored in a database. A web-based interface has been built, through which inspection of these log files and grouping of information is achieved. Every time a new object is inserted in the activity space, a hyperlink is built to it, which allows the researcher to see the object view of this particular item. Alternative views are also created according to actors, items of the solution, structure of the solution, etc. These views are created dynamically through queries to the database. Complementary tools are planned to be developed enabling an automated production of diagrammatic models of OCAF framework, either in a generic form (as these shown in figure2) or in a more task specific form such as this where the objects' history is shown and attached to the problem solving objects as they were presented on the students' workspace. The same tools will be used in order to present further information that can be extracted by OCAF model through a set of queries.

The tools related to OCAF models are actually developed and tested for use by researchers. Their full implementation and substantial experimentations will allow us to explore further questions such as:

- How teachers exploit brut diagrammatic model during a synchronous or asynchronous collaboration of their group of students?
- How teachers exploit the information derived by OCAF models. These kinds of data could contribute to develop more elaborated tools that provide further automated-produced indicators useful for online monitoring of secondary education students.
- What kind of the information provided or derived by OCAF model could be presented directly to students, in order to self-regulate their activity?

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