Method and tools for analysis of collaborative problem-solving activities

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ABSTRACT
This paper provides an overview of the "Object-oriented Collaboration Analysis Framework (OCAF)" a method proposed for analysis and evaluation of collaborative problem solving activities of groups of actors, mediated by collaboration-support technology. This framework puts emphasis on the abstract and tangible objects that appear during the development of a solution to a given problem. The notions of the "*objects' histories*" and "*objects' ownership*" are introduced by this analytical framework. In the paper tools that have been developed to support this framework are described, together with extracts of studies that have been undertaken, during which OCAF has been effectively used.

Keywords
Collaborative Problem Solving, Analysis of collaborative activity, OCAF

INTRODUCTION

Analysis of activities of groups of people engaged in problem solving- collocated or at a distance- is important for gaining an insight in the problem-solving process and understanding of collaboration. Socially inspired theories, supported by the growing development of network and CSCW technology, have increased research on technology-based collaborative problem solving environments. The outcomes usually influence our considerations on quality of the collaborative problem solving process, as well as the design of the *collaboration-support tools* involved. According to both these perspectives, the methodological issues of collaboration analysis are of prime importance, given that they are directly related to the development of this research and technology area and the common understanding of the various disciplines involved.

In problem-solving collaborative learning activities in which the computer environment constitutes itself a mediational resource, it contributes to the creation of a shared referent between the social partners (Rochelle et al, 1995). Typically these direct manipulation environments are characterised by actions on objects representing entities or on concepts meaningful to the users. Usually operations on these objects have a reversible incremental effect on the 'environment' represented on a shared computer screen. Often more than one actor interact directly or indirectly with the objects in this world modifying their state, communicating between them and through the objects, as they advance problem solution. Analysis of these problem-solving situations is usually done through discourse analysis (Baker et al., 1999), task analysis (Van Welie et al, 2003), communication and interaction analysis (Bodker 1996), or even a combination of methods, with the objective to evaluate the situation, the problem-solving process and often the tools used. However in these analysis techniques the actors and the dialogues are usually the centre of attention, while the developed objects enter the scene as items on which operations are effected and as subjects of discussion. Using Activity Theory as a conceptual framework for analysis of such activities shifts the emphasis to the activity, which is directed towards *objects* that can be hierarchically decomposed. Breaking down the activity to actions and primitive operations directed towards these objects, permits refinement of the process and analysis of the activity at various levels of abstraction.

In this paper we outline an innovative framework for analysis of collaborative problem solving activities, inspired by key aspects of Activity Theory. This framework has been used for conceptualization of the situation of groups of individuals engaged in exploratory and design problem-solving activities and for evaluation of the effectiveness of the design of IT tools supporting the process. This methodological framework is called "Object-oriented Collaboration Analysis Framework (OCAF)" and was originally proposed by Avouris et al. (2002, 2003). Recently, analysis tools have been built to support this framework, while OCAF has been used in a number of field studies investigating various aspects of collaborative problem solving (e.g. Komis et al. 2002, Margaritis et al. 2003, Avouris et al. 2004).

In this paper we outline the main characteristics of the OCAF method, extending and refining the original proposal. The findings of the last two years of use of the method and the experience gained by the implication of the tools developed (*Synergo* and *ColAT*, described in Avouris et al 2004), have yield an improved process, discussed here.

OCAF studies the activity through the objects of the solution, that is the objects that exist in the problem-solving context, which 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 their existence. This view of the world, can be useful, as it reveals the contribution of the various actors in parts of the solution, and the relevant focus shifts (Bodker 1996, Bertelsen and Bodker, 2003), identifies areas of intense collaboration in relation to the final solution and can relate easily to other analysis frameworks like interaction analysis.

In this paper, a notation of the OCAF model is proposed. Subsequently, an outline of the OCAF method is included together with presentation of the functionality of the tools that have been proposed to support the method. The first tool, called *Synergo*, is associated to a synchronous collaboration-support environment, which permits direct communication and problem solving activity of a group of distant users, manipulating a shared diagramatic representation. Through the Synergo analysis tools, the researcher can playback the activity off-line and annotate the activity and the produced solution using an annotation scheme which can be defined and adapted according to the specific objectives of the study. The second tool, called *Collaboration Analysis Tool* (ColAT) is a tool to handle data of various forms, collected during field evaluation studies of collaborative activities and review the activity by building interpretative structures of operations and actions. Examples of use of the framework and the tools in collaborative problem-solving situations are also presented.

The importance of the proposed framework is also related to the fact that the existing Activity Theory based methodologies supporting information technology design, e.g. Activity Checklist (Kaptelinin et al. 1999), AODM (Mwanza 2002), ActAD (Korpela et al., 2000) do not include explicit models and tools for the analysis phase, so the proposed here framework can be seen as a proposal with wider implications.

MODELLING COLLABORATIVE PROBLEM SOLVING ACTIVITY

In this section we describe the key parameters through which we can model collaborative problem solving activity. The model of the activity is going subsequently to be used for analysis and evaluation of the process through the proposed method.

We suppose that the activity involves a group of subjects (actors) who are engaged in collaborative problem solving mediated by computing technology. The main motive of the activity is to produce collaboratively a solution to a given problem. This solution takes the form of a representation in symbolic form. The generation of this solution involves manipulation of intermediate objects (either tangible or abstract ones). Problem solving activity is usually considered as a process of refinement of abstract ideas ("abstract objects") and externalization of these ideas in the form of parts of the solution to the given problem. Collaborative activity is based on communication, which takes the form of either direct communication acts or by observing operations in the shared activity space (feed-through communication, Dix et al. (1999)). Operations of the group members are defined as events that are either non-trivial changes of the state of the activity space or communication messages. An example of such event is shown in fig.1 from a collaborative activity in physical space.

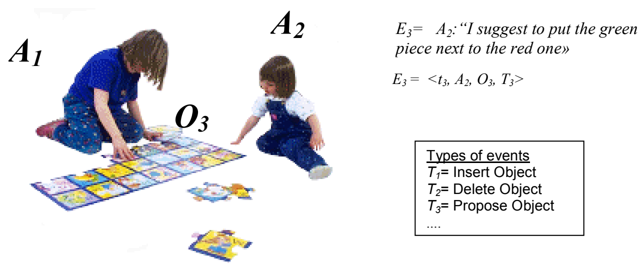

Fig. 1 Two partners A_1 and A_2 manipulate objects O_1, O_2, … and interact during problem solving. E_3 is an example of an event.

The activity is defined according to the following four dimensions:

The time dimension: A universal activity time is assumed. This is assumed discrete in order to handle issues of concurrency of distributed activities, as discussed below.

The actors dimension: All actors, remote or collocated, who are involved in this activity are defined here. If we assume k actors, then this dimension is related to the set $A = \{A_1, A_2, ..., A_k\}$.

The objects dimension: All objects that are involved in the problem solving activity define a set of l components:

$O = \{O_1, O_2, ..., O_\ell\}$. These objects can be either existing tangible objects (digital or physical), objects that can be built using available tools, or conceptual objects. In the example discussed in the following section these objects are components of a *concept map*. In the frame of the tools discussed later a solution is considered as made of:

(i) concrete components (objects that compose the final solution),

(ii) rejected components and

(iii) abstract components.

The typology of event dimension: This is a dimension through which interpretation of the activity can take place. We assume that there is an existing analytical framework, which defines this typology. If r is the finite number of expected event types, then we define a set $T = \{T_1, T_2, ..., T_r\}$ as the analytical framework of the study. While in the original OCAF proposal we have included such a closed set *T*, see fig 2 from (Avouris et al. 2003), in this current version, we consider the method as independent of a specific analytical framework, so set *T* can be defined by the framework user.

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 *Action:* 'Delete' Entity "Velo"
X=	Acknowledgement/ acceptance of the proposal	*Action and / or dialogue analysis*	*Message:* "That's right" *or* *Action: Insertion of* a proposed enitity
M=	Modification of the initial proposal	*action & dialogue analyses*	*Message:* I suggest we put the state to "unlock" *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 *Action:* Activate 'Graph Tool' , or 'Barchart Tool''

Fig.2 The set of types of events according to OCAF

Using the above four dimensions we can describe any given activity as a set of discrete non-trivial events produced by the actors. These define an ordered set of *m* events $E = \{E_1, E_2, ..., E_m\}$ of the activity. Each one of these events is related to meaningful operations of the actors who interact with objects of the set *O*. Each event is defined as a tuple $E_{i_{tAOT}} = (t_t, A_A, [O_O], [T_T])_i$ where $i \in [1, m]$, *t* the event timestamp, *A* the actor who performed the operation of the specific event, *O* an optional parameter referring to the object of the specific operation and *T* an optional parameter which interprets the event according to the analysis framework T.

This model of the activity is based on the assumption of events of zero duration, which is necessary in order to achieve serialization of the concurrent activities that may take place during collaborative problem solving. This is somehow restricted; however, in the case of actions of longer duration then a starting and an ending event need to be defined in order to describe such an action, which is usually of duration $t \neq 0$.

This is a useful model for ethnographic studies. Every time an event is produced by the actors, this is recorded and a history of such events, i.e. an ordered list of *Es* can be produced, as a result of such an activity. No mental or cognitive operators are defined, as these can be generated later as interpretations of the recorded activity. This model permits further analysis and interpretation of the activity, while quantitative indices of the activity can be easily produced or visualizations can be automatically generated (Margaritis et al. 2004).

Often the mediating computer tool adheres to a typology of generated events, thus automating the task of categorization of observed events, so for instance if a software tool is used that permits a number of operations, every time such an operation is recorded, this is automatically categorized according to a scheme of analysis.

A fundamental concept of the OCAF framework is the unified interpretation of action and communication acts. As also discussed in (Baker et al., 1999) mutual understanding among collaborating actors takes place via a combination of perception of action and communication. Furthermore, depending on the provided tools facilitating dialogue in a computer-mediated environment, 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 (Avouris et al. 2003). In this context, communicative acts are operations that also need to be interpreted in terms of the actors intentions in relation to the activity. In particular OCAF interprets exchanged messages (written dialogues during collaboration by distance), or oral utterances (during face to face collaboration), in relation to operations towards "objects" of the activity space, using a language for action approach (Winograd,1987, Searl 1976), defining a unifying framework for analysis of the activity, as can also be seen in fig.2.

Views of the OCAF Activity Model

Various analytical views of quantitative or qualitative nature can be generated using this model.

Some of them are related to quantitative measures of collaboration, like *density of activity*, if a time quantum is defined of t_q length.

An alternative index that often needs to be defined during collaborative problem solving activities is that of *balance of activity* between the partners. If an activity is monopolized by a certain partner, then this may be an indication that the activity is not truly collaborative. Definition of such index is not however easy, as all events are not of the same importance. A specific example of definition of an index of balance of activity has been proposed by Margaritis et al. (2004), related to activity that produces diagrammatic representation of a solution made of a set of interrelated objects *O*.

In addition, a *spatial representation* of the activity can be generated by mapping the events to the produced final solution. This is a form of a spatial representation, as the components of the solution can include the sequences of the events that lead to their creation, i.e for each object O of the solution, we can associate the sequence of events E_i for which O_i is of a specific object O. This is defined as the *object history*.

Additional secondary indices may be associated to these objects, like the *diversity of actors A* that appear in such set of events, the length of this history, i.e. the number of events associated to a specific object, etc. Also measures of *focus* of activity and *focus shifts* can be generated through this view.

The views created by the OCAF model are useful for the analysis and evaluation of problem solving, providing a perceptual view on these parameters. This view can directly be related to the produced solution, associating the history of interaction to the items involved. Also items discussed but not included in the solution appear in this view. One can consider the generated views 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, supporting reflection of problem solvers in a metacognitive level.

One of the prime advantages of the OCAF framework is that the OCAF activity model is generated and processed by adequate automatic tools, attached to a collaboration support environment. In particular, the action part analysis can be directly automated, while the dialogue part needs human interaction for dialogues analysis approaches. These OCAF-compatible analysis tools can be used by researchers studying collaborative problem solving. Also tools for collaboration visualization can be produced for various indices like the ones discussed in this section, that can be even used by the problem solving actors as metacognitive tools in order to help them self-regulate their collaborative or problem solving process. In the following section the functionality of such tools and an example of their use is discussed through a step-by-step presentation of a method of analysis using the OCAF model and views.

OCAF METHOD AND TOOLS

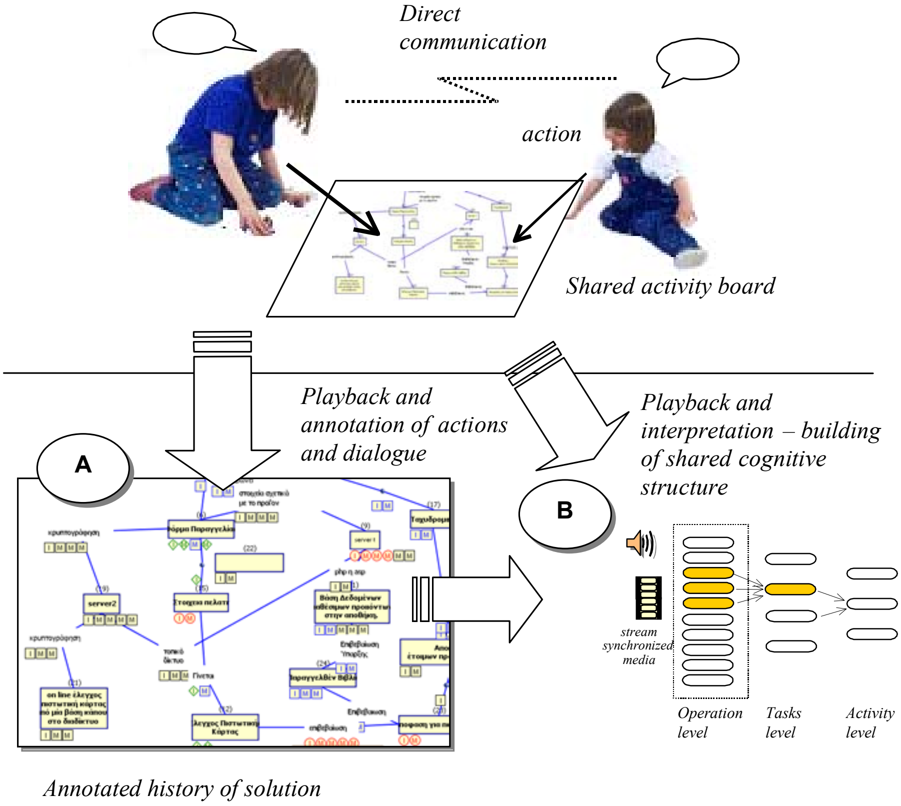

Figure 3 Overview of the OCAF method of analysis

Collaboration is a phenomenon for which we lack adequate analytic models. It is not claimed that the complex phenomena of social interaction and particularly of collaborative learning can be comprehensively re-constructed by analytic models. These models are bound to be partial, capturing only specific facets of actions or interactions in groups. The lack of such theoretical models is of prime concern for developers of CSCW technology. The value of an analytic model like OCAF, is related to its capacity to bring up interesting points of view and thus provide information to researchers aiming at answering relevant questions

Some of these points of view are related to quantitative aspects of interaction, and appear often in studies of collaborative environments, while others relate to a more cognitive and meta-cognitive view, as for instance is the case of solution validation strategies. These questions have been effectively tackled using OCAF, as demonstrated through various case studies.

In figure 3, an overview of the proposed method and related tools is outlined. An outline of a typical example of use of the proposed framework is discussed in this section, while in the next section specific examples of a case study of analysis are included.

In our example, a typical synchronous collaborative problem-solving situation, two or more actors, supported by networked equipment, collaborate at a distance by communicating directly and by acting in a shared activity board. A digital representation of a solution to a given problem may appear in this shared board. This activity is typically monitored through logging of the main events, recording the activity of the actors in the shared activity board and of the dialogue events, if they are in text form. In addition the dialogue can be captured, through video and audio recording, if videoconferencing technology has been implemented, while additional information of the activity and the context within which this has taken place, may be captured in other forms. The collaboration-support tool used in recent studies has been Synergo, a tool that permits collaborative building of diagrammatic solutions to problems in the form of flow charts, concept maps or other graphical representations (Voyiatzaki et al. 2004). This environment has been built using the *Abstract Collaborative Application Building Framework* developed in the frame of the ModellingSpace project (Avouris et al. 2004). Synergo includes tools for annotation of the solution according to the OCAF approach and visualization of a number of indices of the process. The analysis methodology involves three phases supported by associated tools, as discussed in the following.

Phase A: Definition of an event typology

During phase (A) we define an interpretative scheme of the expected operations during the problem solving activity. This scheme defines a closed set of event types *T*. In the provided analysis tool, the user can define such a set and associate typical events included in the log file to them. In figure 4 the dialogue box through which we defined the event typology for our experiment is shown. *Proposal, Contestation, Rejection and Acknowledgement* were the events that were related to dialogue acts and *Insert, Modify, Connect* were related to events on the activity space.

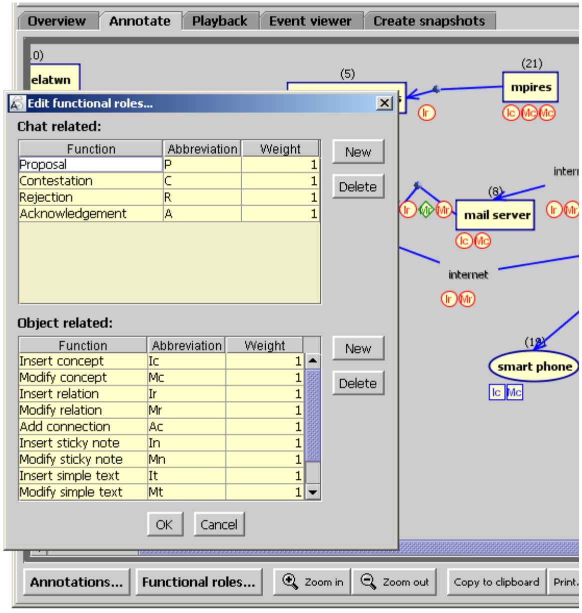

Figure 4. Definition of event typology

Phase B: Annotation of operations

During phase (B) the Synergo analysis tool is used for presentation and processing mainly of the logfiles, produced during collaborative problem solving activities. These logfiles contain time-stamped events, which concern actions and exchanged text messages of partners engaged in the activity, in sequential order. The logfile events are produced by exchanged control and textual dialogue messages and need to adhere to a defined XML syntax. These events can be viewed, commended and annotated by the tools discussed here. The activity can be reproduced using the Playback tool of Synergo that reconstructs the group problem solving activity on the actors' workstations desktop step by step, through a single view. Annotation of the events is done, according to the specific analysis typology defined in phase A, that permit building of an abstract view of the activity.

The activity playback and solution annotation tool is shown in fig.5. The result of this phase is an annotated history of the problem solving activity and of the produced diagrammatic solution, through this activity. In the example of fig.4 one can see the graphic representation of this history and annotation of the solution in the shared activity board. In a separate window, the history of textual dialogue events is presented. Each item of the diagrammatic solution of a problem (a concept map representing a web service in this case) is associated to the sequence of events that lead to its existence. So the sequence *(I),(C),(M),(R),* shown in figure 5, represents the following events: *(I)nsertion* of this object by actor A, *(C)ontestation* of this insertion by Actor B, *(M)odification* of the object by Actor A and *(R)ejection* of the modification of Actor B. This view of the activity depicts the intensity of collaboration in relation to specific parts of the diagram and identifies the collaboration patterns of the activity.

Generation of the annotated view by interpreting one by one the logfile events is a tedious process; the Synergo environment facilitates this process, by allowing association of the events, automatically generated by the software, to classes of annotations. So for instance, all the events of type "Modification of concept text" in a concept-mapping tool are associated to the "*Modification*" type of event of the OCAF scheme.

Not all events however can be automatically annotated in this way. For instance, textual dialogue messages need to be interpreted by the analyst and after establishing their meaning and intention of the interlocutor, to be annotated accordingly. So for instance, a suggestion of a student on modification of part of the solution can be done either through verbal interaction or through direct manipulation of the objects concerned in the shared activity board.

In fig. 6 the tool for annotation of a dialogue event and association to an object is shown. In this case a message by user [*thodoris*] is annotated as *(P) roposal* and related to the object [*server t*] of the solution. This new annotation, which has been introduced through this action, is added to the rest of the annotations that constitute the history of the object [*server t*].

This process often necessitates definition of new objects that do not appear in the activity space. These are the "abstract objects". In our case the actors negotiated during the initial phase the characteristics of the model to be built, so the concept "model" was an object of negotiation and was defined and accordingly annotated at this stage. The new annotated logfile can be inserted in the ColAT

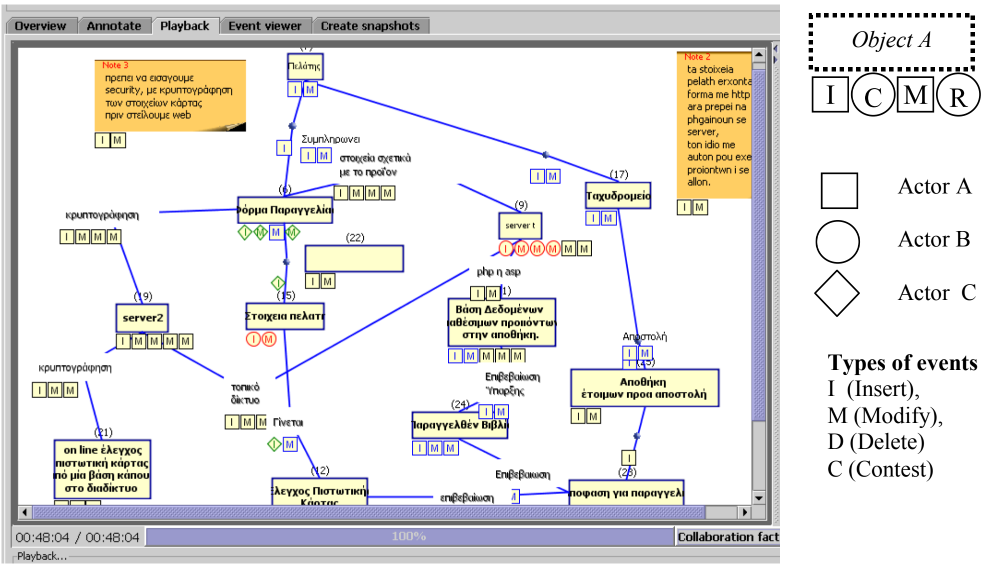

Figure 5. An annotated solution to a given problem

environment, used in phase (C), as discussed in the next section for further analysis and interpretation of the activity.

Additional views have been generated, that represent the collaborative process. These are visualizations of indices of collaboration activity along the time dimension. In figure 7 some typical views are shown, which depict the evolution of various types of events during the activity. So in chart (a) of fig. 7 one can see the evolution of the Insert (red) and Delete (blue) events in the shared activity board, while in chart (b) the density of activity per actor for a four-members group is shown.

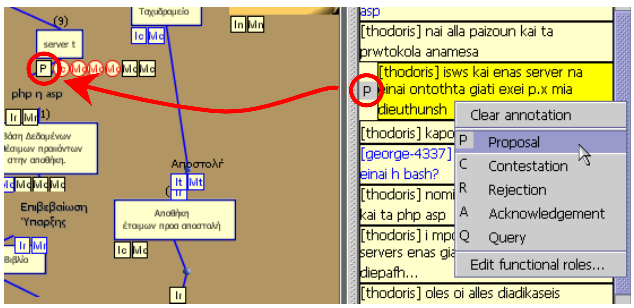

Figure 6. Annotation of a text message and association to an object of the solution

Another view relates to the graph of evolution of the Collaboration Factor (CF), see Margaritis et al. (2004) for details.

Through these views, one may observe the level of activity during various phases of problem solving.

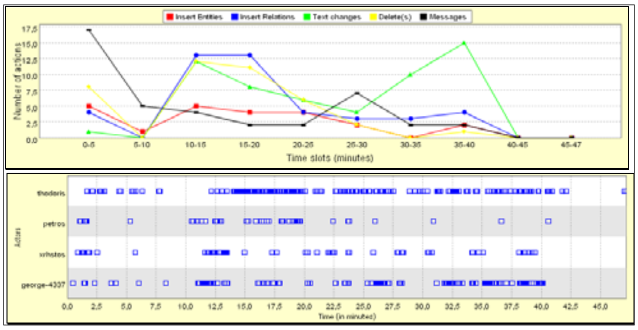

Figure 7. Views of the activity produced by Synergo: (a) density of activity per type of event, (b) activity per actor.

Phase C: Analysis of activity

In phase (C), the *Collaboration Analysis Tool (ColAT)* environment is used for building an interpretative model of the joint activity in the form of a multilevel structure, following an Activity Theory approach. ColAT permits fusion of multiple data by interrelating them through the concept of universal activity time. The analysis process during this phase, involves interpretation and annotation of the collected data, which takes the form of a multilevel description of the collaborative activity.

The ColAT tool, discussed in more detail in (Avouris et al. 2003c), uses the form of a theater's scene, in which one can observe the action by following the plot from various standpoints. The *Operations-view* permits study of the details of action and interaction, as generated in phase B, the *Actions-view* permits study of purposeful chunks of action, while the *Activity-view* studies the activity at the strategic level, where most probably decisions on collaboration and interleaving of various activities are more clearly depicted.

This three-level model is built gradually: the first level, the *Operations level*, is directly associated to log files of the main events, produced and annotated in phase B, and is related through the time-stamps to the media like video. The second level describes *Actions* at the actor or group level, while the third level is concerned with *motives* of either individual actors or the group. In fig. 8 the typical environment of the ColAT tool for creation and navigation of a multi-level annotation and the associated media is shown. The three-level model is shown on the screen, while the video/audio window is shown on the right-hand side.

The original sequence of events contained in the logfile is shown as level 1 (operations level) of this multilevel model. The format of events of this level in XML, is that produced by Synergo, ModellingSpace and other tools that adhere to this data interchange format. Thus the output of the first phase can feed into ColAT, as first level structure.

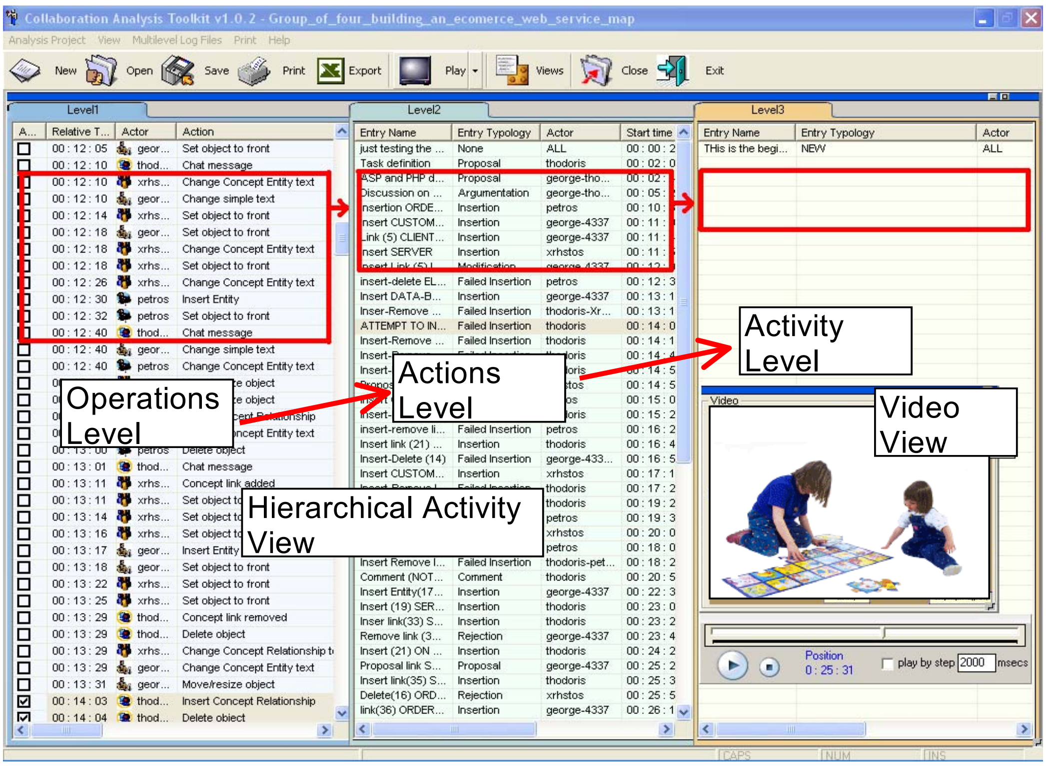

Figure 8. Navigation of multi-level interpretation of collaborative problem solving activity

A number of such events can be associated to an entry at the actions level 2. Such an entry can have the following structure: <ID, time-span, entry_type, actor(s), comment > where ID is a unique identity of the entry, time-span is the period of time during which the action took place, type is a classification of the entry according to a typology, defined by the researcher, followed by the actor or actors that participated in the task execution, a textual comment or attributes that are relevant to this type of action entry. Examples of entries of this level are:" Actor X inserts a link ", or "Actor Y contests the statement of Actor Z".

In a similar manner, the entries of the third level (Activity level) are also created. These are associated to entries of the previous Actions level. The entries of this level describe the activity at the strategy level as a sequence of interrelated goals of the actors involved or jointly decided. This is an appropriate level for description of plans, from which coordinated and collaborative activity patterns may emerge. In each of these three levels, a different typology for annotation of the entries may be defined. This may relate to the domain of observed activity or the analysis framework used. For entries of level 1 the OCAF typology may be used, while for the action and activity level different annotations have been proposed.

ColAT permits an alternative way of representation of the action and activity level. A typical view of this representation is shown in figure 9.

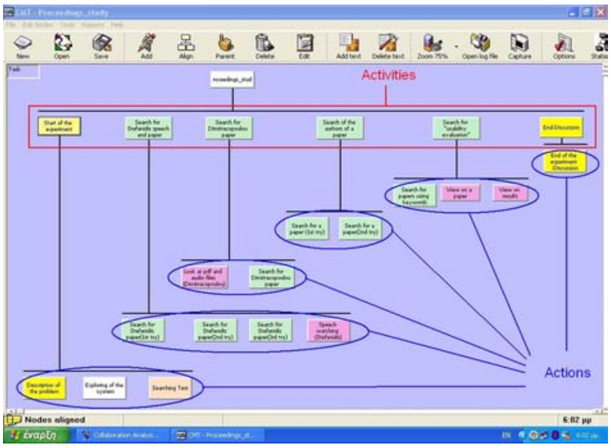

Figure 9. Graphical representation of actions and activities according to HTA

This view is one that describes the goals and tasks that an actor or a group of actors attempts to accomplish. So in figure 9 one can see the activities and actions in a graphical view similar to Hierarchical Task Analysis (HTA). Each activity and action is represented by a different colour that is established according to the OCAF scheme. This view is of high importance since it permits mapping annotated group activity to top-down decomposition of the observed actors' activities.

Use of media sources in analysis

Various media, like video or audio can be viewed, using the ColAT tool, from any level of its multi-level model of the activity. As a result, the analyst can decide to view the activity from any level of abstraction he/she wishes, i.e. to play back the activity by driving a video stream from the operations, actions or the activity level. This way the developed model of the activity is directly related to the observed field events, or their interpretation.

Other media, like still images of the activity or of a solution built, may also be associated to this multilevel model. Any such snapshot may be associated through a timestamp to a point in time, or a time slot, for which this image is valid. Any time the analyst requests playback of relevant sequence of events, the still images appear in the relative window. This facility may be used to show the environment of various distributed users during collaboration, tools and other artefacts used, etc.

The possibility of viewing a process using various media (video, audio, text, logfiles, still images), from various levels of abstraction (operation, action, activity), is an innovative approach. It combines in a single environment the hierarchical analysis of a collaborative activity, as proposed by Activity Theory, to the sequential character of ethnographic data.

CASE STUDY OF ANALYSIS

A number of experimental studies have been performed using the outlined methodology and tools. These relate to various aspects of collaborative problem solving analysis. In Avouris et al. (2004) the group size is related to the group performance and patterns of collaborative activity. In Fidas et al. (2005) the effect of heterogeneity of the available resources has been studied for various collaborative-learning experiments. In Avouris et al. (2003) the effect of the floor control mechanism is studied, while in Komis et al. (2002) evaluation of the effectiveness of the environment in the educational process is discussed along various dimensions, like group synthesis, task control, content of communication, roles of the actors and the effect of the tools used. In these studies, various versions of the presented tools have been used.

First the Synergo tools have been used for playback and annotation of the activity, while visualizations of the collaboration factor have been produced. Subsequently the produced video and sequences of still images, along with the logfiles of the studies were fed in the ColAT environment through which the action structures of the activities were built. A specific extract of the analysis of one of these studies is described in this section.

Context of the study

The discussed study took place in the frame of the laboratory work of the undergraduate course "Software Internet Technology" of the Electrical & Computer Engineering Department of the University of Patras. Eighteen (18) students participated in the experiment in the frame of a scheduled laboratory class that took place in two lab sessions. A number of groups of students with similar characteristics were formed. Each group consisted of 3 or 4 members.

The members of the collaborating groups, were dispersed in the computer lab. They interacted for a certain period of time, using exclusively the Synergo environment (chat tool and a shared drawing board) in order to tackle a given data-modelling problem in a simulated distance-collaboration setting. Each collaborating group of students was asked to produce, by the end of the laboratory session, a conceptual map of a *web service*. The tutor intervened mainly at the beginning of the session to introduce the activity and the tools, and at the final stage for making comments on some of the produced solutions. Also activity logging was performed using the logging facility of the collaborative modeling tool itself.

Building a multi-level view of the activity

The objective of this study was to examine the effect of group size on problem solving and group coordination strategy. An additional objective was to test the usability of the collaboration-support tool in cases of groups of more than 2 members. At the end of the lab session, the observers collected field notes, the detailed logfile of events, a few snapshots (jpeg pictures) describing the main phases of the solution of the given problem. The analysis of activity was performed for all the groups that were formed. In the following we concentrate in the study of a specific four-member group.

We created a ColAT project, including all the data of the experiment, and synchronized them in the form of a master activity logfile using the appropriate tools of ColAT. The next step was to reproduce students activities, based on the analytical study of the logfile. This process requires adequate experience. Studying the logfile, we have built the Actions Level that is displayed in figure 10.

The original operations logfile contained 560 events, which were extracted from the automatically produced logfile of activity of duration of 47 min, after introducing annotations of phase B and clearing out trivial events. The purposeful *actions* built in level 2 were 69. These were related to identified goals of the actors. Certain actions of this level involved more than one actor. The actions of this level, contrary to the events of the first level have a certain duration which is defined according to the starting event and final event of the operations level. The ColAT tool through a drag and drop operation can define an action of level #2 as a set of operations of level #1. The actors involved are identified from the actors of the primitive operations, while the tools engaged and the objects of the action are deduced from the attributes of the events of the lower level. In figure 9 an extract of the actions level for our example is shown. The operations that define an action are not necessarily consecutive in level #1. This is due to the concurrency of a collaborative activity. The typology of events defined in phase (A) may apply to this level as well. A mapping of patterns of types of operations to types of actions is in the current version of the tool performed by the analyst, while a machine learning approach that will automate this process in some degree is under investigation.

Level2

Entry Name	Entry Typology	Actor	Start time	End time	Comments
just testing the functionality of the tool	None	ALL	00 : 00 : 29	00 : 01 : 52	no task relatec
Task definition	Proposal	thodoris	00 : 02 : 05	00 : 02 : 32	Agreement of
ASP and PHP defined as entities	Proposal	george-thodoris	00 : 02 : 49	00 : 04 : 30	
Discussion on entity SERVER and CLIE...	Argumentation	george-thodoris	00 : 05 : 27	00 : 08 : 19	
Insertion ORDER-FORM(6)	Insertion	petros	00 : 10 : 31	00 : 11 : 05	
Insert CUSTOMER(7)	Insertion	george-4337	00 : 11 : 06	00 : 11 : 41	
Link (5) CLIENT to ORDER-FORM	Insertion	george-4337	00 : 11 : 47	00 : 11 : 48	
Insert SERVER	Insertion	xrhstos	00 : 11 : 57	00 : 12 : 26	
Insert Link (5) Label	Modification	george-4337	00 : 12 : 04	00 : 12 : 40	
insert-delete ELEG	Failed Insertion	petros	00 : 12 : 30	00 : 13 : 00	
Insert DATA-BASE (11)	Insertion	george-4337	00 : 13 : 17	00 : 13 : 31	
Inser-Remove Link(6)	Failed Insertion	thodoris-Xrhstos	00 : 13 : 11	00 : 13 : 29	
ATTEMPT TO INSERT RELATION	Failed Insertion	thodoris	00 : 14 : 03	00 : 14 : 06	
Insert-Remove Link(10)	Failed Insertion	thodoris	00 : 14 : 17	00 : 14 : 37	

Figure 10: Extract of the action level interpretation of the collaborative problem solving activity

As a result of this process visualization of activity at the action level may be produced. An example of this is shown in figure 11. This has been produced by representing an action as a bar in a Gannt chart fashion in the time dimension (vertical view). The view included in fig. 11 corresponds to the extract of the actions of fig. 10.

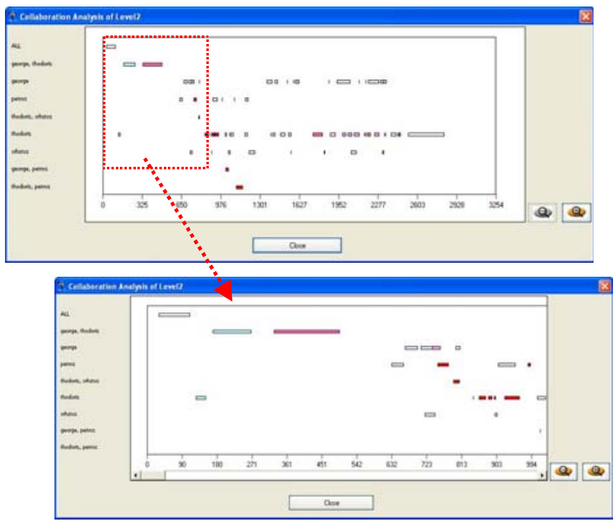

Figure 11. Diagrammatic representation of actions

The duration of the actions and the concurrency of activity of the group are shown through this view. Spells of inactivity appear, perhaps attributed to cognitive or preparatory mental activity. Also the actors that participate in actions are shown in this view. As an example of the activity of our study, during the initial phase (0-500 sec) there is a sequential collaborative action involving all actors. For a certain period, between 300 and 500 sec, an action takes place involving actors *George* and *Thodoris* without participation of the rest of the group, who presumably are observing the activity. Subsequently there is a period of autonomous actions of the actors with a degree of overlap (period 660-780 sec). This phase of activity was the result of the original negotiation, which resulted in a phase of individual experimentation with the concept mapping tool by the partners who attempted to introduce key concepts and relations before later on entering a new phase of negotiation of the externalized ideas. Some of the actions were clearly related to usability problems of the tool and misconceptions of its opearation. For instance both users *Thodoris* and *Xrhstos* experienced difficulty with linking of concepts in the activity space, identified as actions of "*failed insertion of relation*" in fig. 10.

Analysis of action level

The action level of this multi-level view is particularly important, since through this view conscious goal-directed activity is described. In this view a sequence of individual or common goals are identified and tracking of their achievement through operations and mediating tools is identified. The analyst can move between level #1 and level #2 smoothly by identifying the means by which the action goals are achieved, as identified by the operations of level #1. The ColAT tool supports this by highlighting the operations corresponding to a selected action. Since goals can be hierarchically structured, we used the third level for representation of high level goals. However in a study of more complex activity, this third level is destined to be used for representation of webs of activities.

In our case the action view made evident and gave a quantitative representation of the collaboration strategy used in this group. The students first experimented with the tool and negotiated the specific problem to be solved (in this particular case they decided to built a concept map of an electronic bookshop). Building of the actual concept map involved consecutive phases of independent concurrent activity of group members and negotiation of the externalized ideas in the form of chunks of concept maps. .

Generation of quantitative representations of the multilevel view of the activity is a straightforward process. For instance in fig. 12 the contribution of the partners according to the various levels of activity is included. From fig. 12, actors *Thodoris* and *George* seem to contribute more significantly than *Xrhstos* and *Petros* in both the operations level and actions level. Actor *Thodoris* has even more prominent role in actions than in operations, since *Thodoris* participated in 50% of actions.

Actor	Operations Level	Actions Level
George	32%	27%
Xrhstos	12%	13%
Petros	11%	10%
Thodoris	44%	50%

Figure 12. Contribution of the group members in the collaborative activity

Observing fig. 12 we come to the conclusion that in this group of four non-coordinated distant partners (mediated by collaboration support tool involving textual and shared activity board interaction support), eventually a small kernel of actors plays the leading role, while the rest take secondary roles or just observe the activity. This conclusion is reached also by qualitative analysis of dialogue and interaction. This asymmetry may be attributed partly to the nature of the mediating tools, thus identifying a relation between the division of labor and tools for this particular case of activity.

CONCLUSIONS

The OCAF method presented in this paper constitutes an analytical framework that supports contextual studies of collaborative problem solving activities. OCAF implements many of the key concepts of Activity Theory: The unit of analysis is an activity, which is studied through an object-oriented view. The itnernalization-externalization process of objects is supported through views of spatial representation of the concepts that are subject of discussion and later take the form of tangible objects upon which operations are effected, through a refinement process. The activity is decomposed in a hierarchy of purposeful actions, which are effected through operations. The OCAF method supports analysis of data collected during ethnographic studies of various forms through which interpretation of the activity can take place. It has been used effectively for evaluation of IT design in the case of collaboration support groupware.

New innovative concepts of the OCAF method are the history and ownership of the objects, as well as the various views over the activity, supported by the tools that have been developed. A key concept is the unification of dialogue and action and the object oriented character of both, through the event analysis scheme. In the original OCAF method proposal, such a scheme was included, while since then other researchers have applied different analytical frameworks using the same method effectively, (e.g. Voyiatzaki et al. 2004, Lavidas et al. 2004). A number of quantitative indices have been generated from the proposed OCAF model, like the collaboration factor, which produce a visual effect of the activity at run time, or can be used for analysis later on.

The contribution of the OCAF tools to interpretation of the activity using various views and levels of abstraction is substantial, since the tools are capable of reproducing the activity, either using the logfile in the case of Synergo or video and audio sources in ColAT.

OCAF is a simple method to apply, since it incorporates three steps supported by the provided tools:

(a) Definition of the event analysis scheme, which can be based on a theoretical or empirical framework of the study.

(b) Annotation of the observed events using this scheme, inspection and interpretation of the produced views of the activity in the time and space dimensions (density of activity, symmetry of interaction, annotated solution, etc.)

(c) Finally building of a multilevel interpretation of the activity by assigning the recorded operations to purposeful actions and generation of quantitative views of them.

However, one current drawback of the OCAF approach is that it does not yet fully incorporate some of the more recently developed refinements of Activity Theory, relating to subject and object orientedness of collaborative activities, e.g. (Bedny & Karwowski, 2004). One specific concept that needs to be further developed is that of “object-orientedness” and “object-ownership”. Originally the term in OCAF was meant to be specific to the “world” of a shared distributed modelling software environment, while in this paper we have made an attempt to extend it to collaborative problem-solving in general. However in this wider context, the components of collaborative activity - subjects, motives, tools, objects, goals, results – need to be seen as functionally variant as their specific content may change with time. This implies that the term “object” needs to be considered as a functional label given to that which is being explored or manipulated through the actions of a subject, those actions being mediated by various mental or material tools, as proposed by the Systemic-Structural Theory of Activity, see (Harris 2004).

The proposed here method has been applied in various cases of analysis and evaluation of problem solving activity of collocated or distant groups in the frame of studies like usability evaluation of IT technology, understanding of collaborative learning process etc. It is the objective of future research to examine applicability of the framework in other cases, like asynchronous collaborative activities, larger groups like communities of practice, organizational structures etc.

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