Title A platform for collaboration analysis in CSCL. An ontological approach

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Abstract

Our goal is to build a platform for collaboration analysis in CSCL. We propose an integrated ontology for defining collaborative learning experiences and for analysing their processes and results. The identification of the main elements and the relationships amongst them based on the Activity Theory with some extensions for providing functionality for real computational applications. We detail the knowledge about analysis, the way of representing new methods in our ontology and also explain a new analysis method with the ontological approach, applied to the DEGREE system.

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Topic Collaboration and collaborative tools
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Introduction

CSCL is built upon a rich history of cognitive science research into how people work and learn. By combining the social perspective with the cognitive perspective, it has the potential to help us make important strides forward in understanding how we might facilitate learning in real situations (Kolodner & Guzdial, 1997). As part of this social and cognitive perspective, the socio-cultural theory proposes Activity Theory (AT) (Nardi, 1996) for representing the activities of groups where technology plays a role as mediator. Within this theory, an analysis model was developed for identifying and representing the human and artificial elements involved in joint tasks (Engeström, 1987). This socio-cultural framework provides the concept of *activity* as a unit of analysis, with a rich internal structure to make the context of a situation explicit, particularly interlinks between the individual and social levels stressing the role of the tools as mediating artefacts. Within an activity different related elements are represented: the *community* involved and the *social norms* that govern it; the *division of labour* to be followed; the *tools* to be used for working; the *subject* of the activity; the *object* of the activity; and, finally, the *outcome* produced by the group.

It is not possible to understand collaborative learning experiences as a single list of tasks or some learning goals that must be carried out by students in groups. The interest in this type of learning is in designing scenarios considering together all the elements involved and studying the influences among them. So, the tasks would be defined in keeping with the learning goals, the group structure and the tools that are available; the roles taking account the tasks, the goal, the groups and the restrictions of the use of the system; and all of them related with the context and the domain that involves each collaborative learning experience.

In our research, we have coordinated several different real experiences with university students (Verdejo & Barros, 1999) during three years using the system DEGREE. We learnt that for motivating and encouraging the students, clear definition of the tasks (open but guided), the responsibilities in the experience, the restrictions, access to the tools and communication facilities are required. We also proved that students are more involved in the tasks if they have feedback about their own process in solving the task and their way of working and collaborating (Barros & Verdejo, 2000). So, our interest is to focus on defining effective collaborative learning experiences with open and flexible spaces for working, and understanding (with empirical data) how actions and interactions are related to learning processes and outcomes. This understanding will result in us being able to interpret the real data from experiences according to higher-level concepts which we will store in a CSCL ontology. In this sense, ontologies are appropriate because they offer a conceptual metamodel for defining collaborative experiences and for analysis (Mizoguchi & Bourdeau, 2000).

At practice level, our goal is to build a platform for collaboration analysis in CSCL. It requires us the construction of a hidden conceptual structure (related to CSCL) as explicit as possible in order to make the concepts used by the system accessible. The platform needs to be generic and flexible to provide users with freedom in designing analysis approaches. An ontological engineering approach-based can also help us in this respect, since it reveals underlying conceptual structure of the target world in a declarative form and provides us with structured concepts that serve to build blocks used for the construction of any system.

Therefore, we propose an integrated ontology for defining collaborative learning experiences and for analysing their processes and results. We integrate two levels in our ontology, a higher level (corresponding to the higher roots) that is the bridge between AT (theoretical framework) and the collaborative systems (applied framework). This approach helps to define applications, to reuse intermediate definitions and data, and to assist in the analysis of the collaboration process. Some branches of this ontology are the roots of our previous ontologies. So as this new ontology is a meta-ontology that collects and relates the preceding ones. The identification of the main elements and these relations are based on the AT as theoretical framework with some extensions for providing functionality for real computational applications. We also detail the knowledge about analysis and the way of representing new methods in our ontology.

This paper is organised as follows: in the next section we develop our ideas about the content of the ontology considering the AT as theoretical approach. Then, we present a first version of our ontology of CSCL. In the fourth section, we focus on the analysis ontology knowledge and the methods that we have developed for interpreting it. Finally, we present our conclusions and we mention our future work on applying this ontology to real domains.

Towards an integrated ontology for CSCL

In CSCL we can work at different levels. Some of them are

- Proposing and defining experiences for groups: from classical, centred on defined methods for organizing of the classrooms to newer ones, centred on introducing new technologies to classical approaches (by example, (Riel, 1997)(Collis, 1998))
- Defining tools for conceptual modelling and construction of collaborative learning environments: for forming an appropriate group for CSCL considering how goals are related to the user as a group and as individual (Ikeda, Hoppe & Mizoguchi, 1995) (Ikeda, Go & Mizoguchi, 1997) (Inaba, Supnithi, Ikeda, Riichiro & Toyoda, 2000); giving support for representing knowledge sharing and co-construcion (Hoppe, Gaßner, Mühlenbrock, & Tewissen, 2000); developing tools for platform communication (Zhao & Hoppe, 1994).
- Defining environments for carrying out experiences, based on different means of communication, tasks, learning goals, etc.; either in schools (Scardamalia & Bereiter, 1994) (Edelson, Pea & Gomez, 1996) or at university level (Wang & Johnson, 1994) (Bell, Davis & Linn, 1995) (Barros &Verdejo, 2000) (Suthers & Jones, 1997).
- Analysing collaboration in CSCL, in order to establish whether, and under what circumstances, collaborative learning was more effective (Dillenburg, Baker, Blaye & O'Malley, 1995). In this work the authors identify three empirical issues for analysis: effects, conditions and interactions. We see that the proposals can be actually organised in three ways: interactions (Barros &Verdejo, 2000) (Ou, Liu, Huang & Chen, 2000), conditions or states (Inaba & Okamoto, 1997) (Soller &Lesgold, 2000) and actions (Mühlenbrock & Hoppe, 1999).

These approaches to collaborative learning mainly handle the concepts of role, communication tools, learning goals (sometimes differentiating between individual and group ones) and tasks. All these elements are considered in the *activity* concept (Kuuti, 1996). Moreover, AT insists on the importance on *relating* and *integrating* them considering also the *context* in which they are involved. How these relationships are defined and made explicit these in real computer science applications is also a challenge. Some initial theoretical studies have been made (Lewis, 1997) in this way. Our interest is to find representational mechanisms for relating and integrating the activity elements. We also want to work at a higher conceptual level: proposing tools for defining more complex activities (composed of other lower level activities) and for declaring generic activities and instantiate them in concrete domains.

One of the authors of this paper has made practical proposals for a CSCL ontology, centred on different topics involving collaborative learning: goals and communication models, problem-solving methods, learning goals and group formation (Inaba, Supnithi, Ikeda, Mizoguchi & Toyoda, 2000). We argue that in a real collaborative learning experience all the elements fit together and most of them have relationship or dependency with others. Also, the act of combining them can generate different modes of collaborative learning, guiding the students in their activity, as classical collaborative learning face-to-face studies showed. (Mizoguchi & Bourdeau, 2000) pointed out the advantages of having a common vocabulary and a theoretical framework for understanding and interpreting how real groups work. Our ultimate goal is to define an integrated ontology that considers and relates the elements that involve a collaborative learning scenario. We want to identify and define each element and provide mechanisms for relating them explicitly. We want to provide a common vocabulary and a conceptual level about collaboration, and to integrate it as part of a collaborative learning environment.

A first version of a CSCL ontology

We have designed a CSCL ontology in the context of AT in order to have clearer computational structure of the theory and to re-explain our understanding of the socio-cultural theory. A rough image of the ontology is shown in the OE Editor (Kozaki, Kitamura, Ikeda & Mizoguchi, 2000) in Figure 1. We distinguish between CSCL and CSCW activities in terms of the differences of *Division of labour* and *Objective*. That is, while *Division of labour* and *Objective* of CSCL are Roles of learners assigned and to learn, those of CSCW are *Division of labour* and to work collaboratively.

One of the unclear parts of Activity theory is the interpretation of the term "*Object*" that has two meanings: "a target thing" and "Objective". In our ontology, these two meanings are explicitly represented by introducing two relations as follows: *Outcome* is ***made-by*** "Activity" under the *Objectives* specified and is ***made-from*** Object. Thus, we explicate the relationship between *Outcome*, *Activity*, *Objective* and *Object.*

The AT-based CSCL ontology includes several ontologies we have already developed such as *Learning goal, OGF goal*, *OGF roles* (Inaba, Supnithi, Ikeda, Mizoguchi & Toyoda, 2000) and *tutoring action* ontologies. These specialize the concepts contained in previous ontologies. For example, the *OGF role*, which is a specialization of "*Division of labour*" in AT includes important roles played by the learners in various CSCL settings. These roles are assigned by the OGF system to define a group and group learning activity the learners should perform.

Our ontology views the key concepts in AT as *Role* concepts specified in the context of the theory and what/who can play the role of Learners as *subject*, Learning group as *community*, artefacts as *tool*, etc. The following is a rough description of each ontological role, some of them represented in Figure 2:

Tool: Represent the mediational tools used for carrying out the activity. An important mediational tool is language. In CSCL, as shown in the systems DEGREE or iDCLE (Inaba & Okamoto, 1997), conversational structure plays a very important role in coordinating the users and analysing the CSCL performance. We will discuss how we exploit the structure for collaboration analysis in next sections. We also consider other external resources that can be used as simulation tools, editors or external programs as tools.

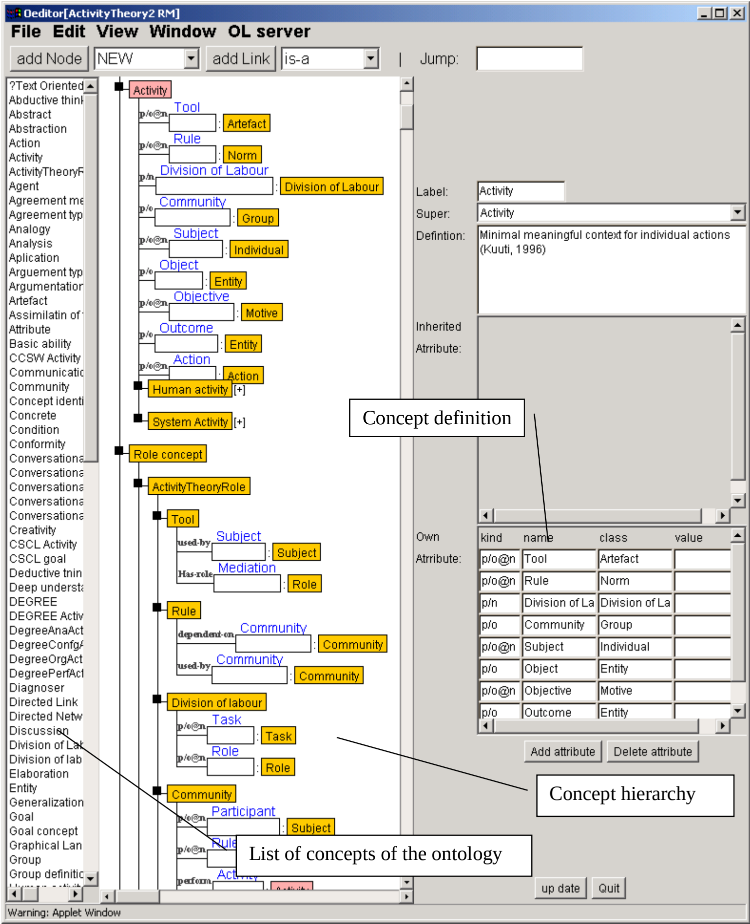

Figure 1. Snapshot of the Ontology editor with the CSCL ontology

```
-Activity
   -Human activity
     -CSCL Activity
     -CCSW Activity
   -System Activity
     -DegreeConfgAct
     -DegreePerfAct
     -DegreeAnaAct
     -DegreeOrgAct
     -OGF Activity
 -DEGREE Activity
 -Role concept
   -ActivityTheoryRole
     -Tool
     -Rule
     -Division of labour
     -Community
     -Subject
     -Object
     -Objective
     -Outcome
   -Division of Labour
     -Role
       -Teacher role
       -Learner role
       -Other roles
       -OGF role
         -Tutor
         -Tutee
         -Observer
         -Diagnoser
         -LPP
         -problem holder
         ......
     -Task
       -Group definition
       -Workspace definition
       -Other tasks
       -Task Description
 -Concrete
   -Entity
     -Agent
       -Individual
         -OGF Individual
       -Group
         -OGF-made Group
     -Artefact
       -Application
         -DEGREE
       -Internet Resource
       -Graphical Language
   -Process
     -Action
     -Operation
 -Abstract
   -Goal concept
     -Motive
     -Goal
       -CSCL goal
         -OGF goal
           -I-goal
           -Y:I-goal
           -W-goal
       -Learning Goal
         -Thinking ability
           -Basic ability
           -Scientific thinking
           -Social ability
           -Deep understanding of
            concepts
   -Norm concept
     -Norm
     -Agreement method
     -Condition
   -Conversational Unit
     -Conversational component
     -Transition
   -Structure
     -Directed Network
       -Conversational Structure
     -Node
     -Directed Link
 -Attribute
   -Conversational attribute
     -Creativity
     -Elaboration
     -Conformity
     -Initiative
   -Conversational Category
     -Argument type
     -Agreement type
     -Proposal type
```

Figure 2. More details about some concepts in the CSCL ontology

Rules are *used-by* the community, control the behaviour of *Subjects* and are *dependent-on* the *Community*. Cultural issues sometimes influence on rules.
Division of labour: This usually means task decomposition in CSCW settings and sometimes means assigned roles in CSCL settings. Typical roles include tutee, tutor, observer, teacher, reviewer, etc. Related to tasks, the learning task is defined here as a list of subtasks that must be solve collaboratively using the mediation tools, with the assigned roles. This task is closely related to the problem-solving domain in which the activity is involved. In order to help define the activities, we provide a list of collaborative learning tasks.
Community: A learning group is composed of several learners (subjects) in CSCL and *performs* an activity following previously defined rules. It includes the group definition as a whole (related to whole goals) and the individual definition (related to individual goals and with the roles).
Subject is who will carry out the activity. It is usually a learner or a teacher who is part of the community.
Object: Something processed by learners through actions in a problem-solving domain mediated by the tools and collaboration. Computationally, it could be described as a whole task that should be solved that is decomposed in several subtasks in the "division of labour" slot.
Objective: A goal to be satisfied by the whole activity.
Outcome is *made-by* activity and is *made-from* object.

Each level of DEGREE's architecture is represented in the ontology. We define higher-level activities related to the use of the collaborative system, as configuring an environment for collaboration, carrying out a group experience or analysing collaboration. We can also use the ontology for representing our collaborative learning experiences. The CSCL ontology helps to the designer to identify the goals, define the tasks, assign roles (relating them with the tasks and goals) because it is integrated with the configuration level of the system. The definition of the experience and their meaning will is considered in the analysis. In following sections, we will explain how analysis is done, taking advantage of this ontological approach.

Applying the ontology for analysis collaboration

Collaborative learning research has paid close attention to the study of pupils interactions during peer-based work in order to analyse and identify the cognitive advantages of joint activity (Dillenbourg, Baker, Blaye, & O'Malley, 1996). The aim is to understand and interpret the collaborative process in order to be able to asses the conditions and elements for effective learning.

Technology is being used as mediation tool when group activities are carried out using a computer. This offers the researchers a framework in which they can store rich information about how people work: when they work, what kind of information they are using, the order of attempting different tasks, the information itself, etc… and any valuable data that observers consider important for their analytical processes. The contextual information that helps understanding the process, it is also important. .

Our aim is to develop, as *automatic* as possible, tools for analysis collaboration, without making an explicit study of the content of the contributions. We would like to advance towards more generic solutions in order to offer flexible tools that consider different points of view, like external observers, and to reuse existing methods in newer ones. We can do this by structuring and labelling the context of the learning experience and deriving conclusions from it. A researcher knows what artefacts are being used for the group, the learning task, context that involves a collaborative experience and what the wants to observe. In order to achieve this, we exploit the CSCL ontology and enlarge it with collaborative analysis concepts and methods for interpreting and applying them.

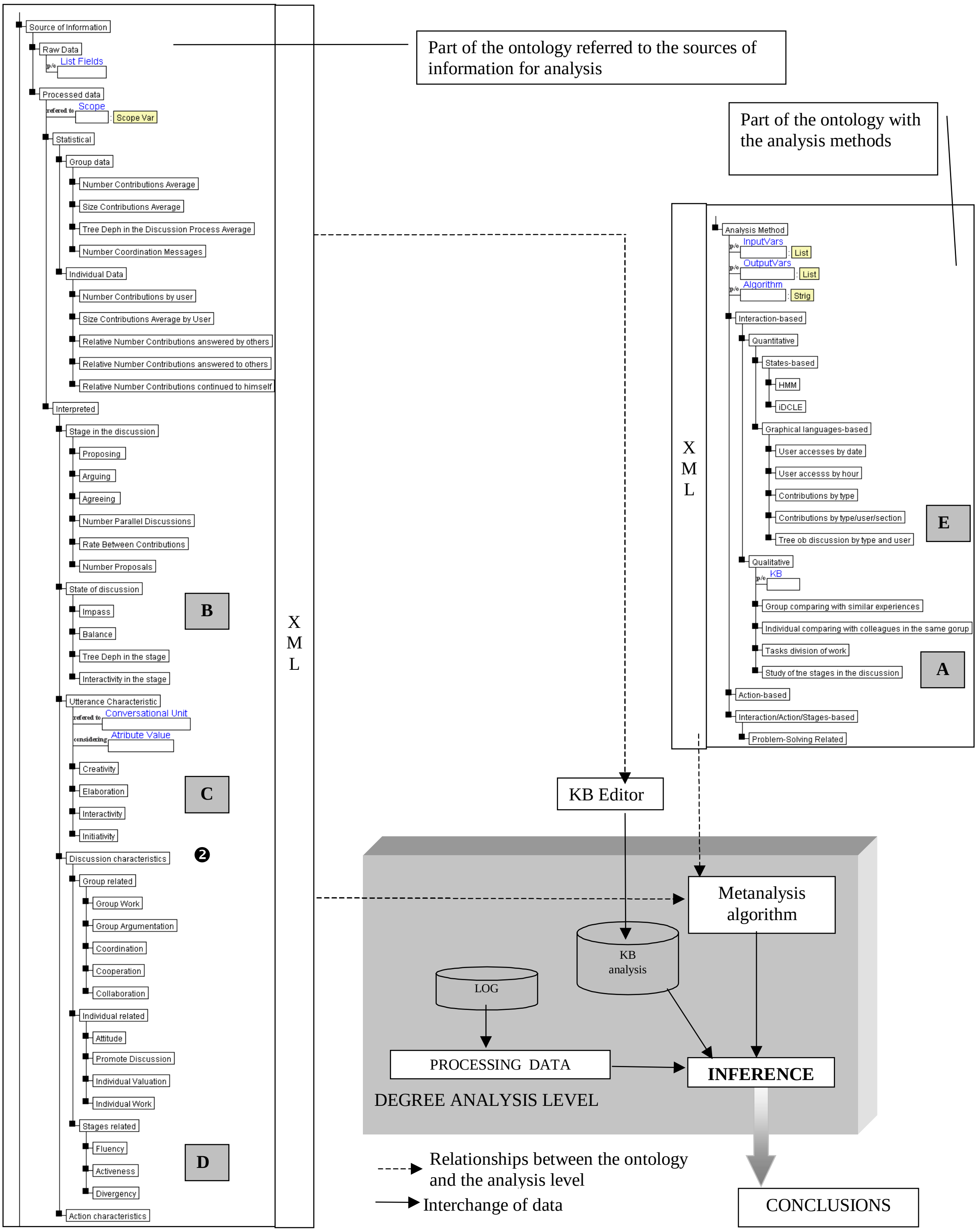

Figure 3. Relationship between the ontology contents and the analysis level in DEGREE system

For collaboration analysis, some points must to be taken into account:

– Identifying and defining *all the elements* that are managed in the collaborative learning experience, and understanding its function and its roles in collaboration. This information will be useful to interpret the context of a log, to know what elements are involved in the experience and their names, to know if they are related with others (in order to be able to identify similar or different stages in the experiences) and to have an explicit and common *vocabulary* for each element, stored in the ontology. This implies that, the more information we have about the definition of an experience and the more structured and concept related it is, the more objective the analysis process (that, by itself, is a very subjective process) will be.

- *Deciding what information will be necessary for the analysis* and therefore we would like to store in the log. This relies on several factors: the type of task, the group, the goals, and the tools used for communication, among others. This point is dependent on the collaborative environment used. In this case, it is the job of the researcher who that develops the system to provide the feature of storing as much data as possible about the use of the system and to document its meaning. The ideal situation is to have a very complete and structured log and also to store all the processes associated with it, in order to be able to choose what is useful and what is not.
- *Proposing and articulating mechanisms* for obtaining conclusions from the observed data. These mechanisms can be more or less complex but usually have a first step of transforming the data from the log (quantitative data), by considering the contextual information that comes from the configuration data. What data and how to obtain it, will depend on the type of analysis that the observer wants to do. Next, there will be also methods for inferring conclusions (qualitative data) that use, for example, external knowledge bases and inference methods.

In the CSCL ontology we declare the analysis concepts:

- *Sources of information for analysis.* We declare the different data that can be obtained from the log of a system, of different scopes (as a whole group, for individuals, for tasks, for stages…). This data is obtained, in a generic way, from single mathematical calculus (for example, number of contributions, number of contributions of each type, size medium of contributions, number of parallel discussions related to a topic, etc.), relating different elements in the process (tree depth of related contributions, number of contributions made by a user that were answered by others), considering external semantic data (conformity, creativity, elaboration, initiative) (Barros, Verdejo 2000) or obtaining more complex structures (as the path solution in a discussion, or the stages in a discussion). This part of the ontology is shown. In the left of the figure 3 (marked with ❶).
  The inferred data is also declared in the ontology. Here all data that can be inferred is represented. We differentiate some types of methods of analysis and therefore, in the ontology, we divide the data considering from what method it is obtained. The inferred data from interaction methods is represented, in figure 3 (marked with).
- *Methods* for carrying out the analysis are defined as the list of inputs, its code and the list of the names of the result variables. We separate the process of analysing from the display of the results. In our ontology, we consider several types of analysis methods. For each type, we consider quantitative methods (that obtain some processed data and represents it) and qualitative (that uses the processed data as input for an inference method, that uses a knowledge base for declaring the way of interpreting the observed data). This part of the ontology is shown in figure 3 (marked with).
- The *interface* method for presenting the results to the users. It is also a generic method that it is useful for presenting the results and for exchanging data between chained methods. So, in the ontology we have the following methods defined: Drawing method, Writing in a table, Writing message and Storing in a variable.

In order to integrate the ontological knowledge into the analysis level in the architecture of the DEGREE system, we have implemented a meta-algorithm with access to the sources of information for the methods which interprets it, applies the method to the processed log data (through explicit evaluation), and shows the results (figure 3, marked with). In this sense, we proceed with the analysis methods as generic tasks (Chandrasekaran, 1989).

We have tested the algorithm with several analysis methods. This new organization of knowledge at the analysis level of our architecture gives more flexibility, allows to the observer to consider new variables for the inference methods, offers the possibility of defining new methods combining the existing ones or creating new ones, without modifying the architecture definition and allows the presentation of results as needed.

Exploiting the new ontological analysis approach for developing a new methods of analysis

We have developed several methods based on interaction that study collaboration process in groups. These methods elaborate their conclusions with a wide perspective: globally comparing with other groups doing similar collaborative tasks, individually comparing with colleagues in the same group and examinating the type of work carried out by each student by task. With the ontological approach the analysis methods can be defined in a generic way and, with the meta-algorithm, it is possible to specify to what data or log it must be applied, define new methods combining existing ones or introduce new ones. In this sense, we provide a platform for analysis of collaboration processes, based on ontological engineering.

With this platform, we have defined a new method that reuses an existing method in a previous version of DEGREE for studying different stages in an argumentative discussion, trying to understand how the discussion occurred and to represent how the group advance from one stage to the next. We were also interested in being able to infer states from the process in terms of collaboration-related concepts such as activeness, impasse and convergence/divergence. Our aim is to apply this new method to the log of our experiences with DEGREE, but like the other methods in DEGREE it could be applied to any structured log from other systems.

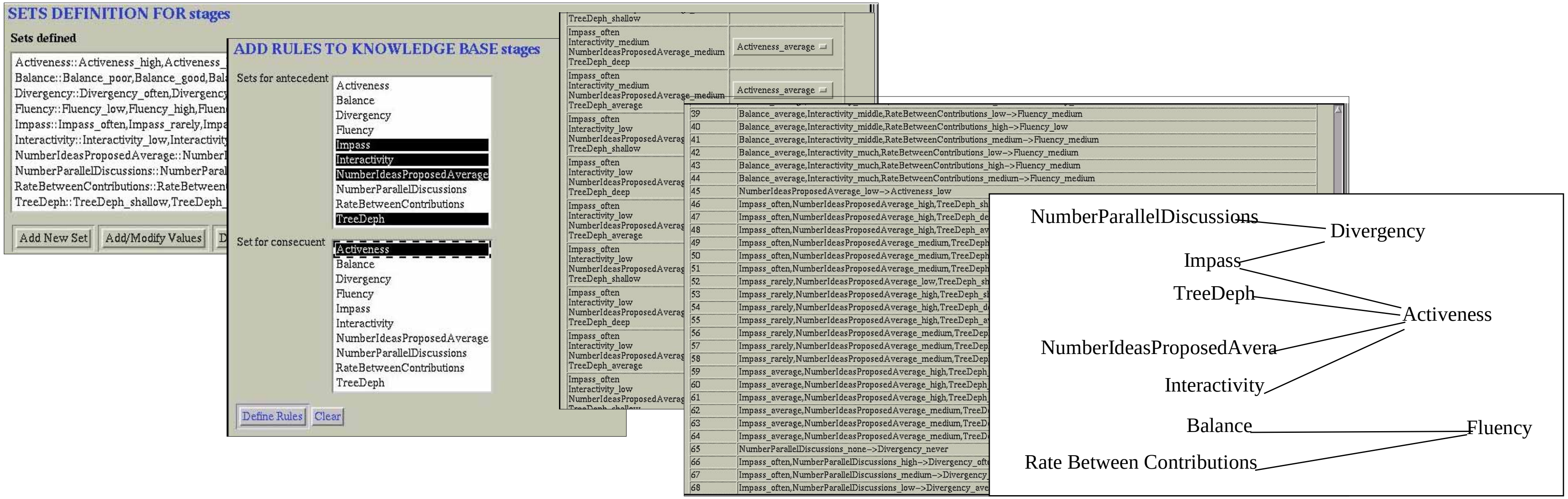

Figure 4. Relationship among data in the Stages/States method, and its representation in rules in the KB editor of DEGREE

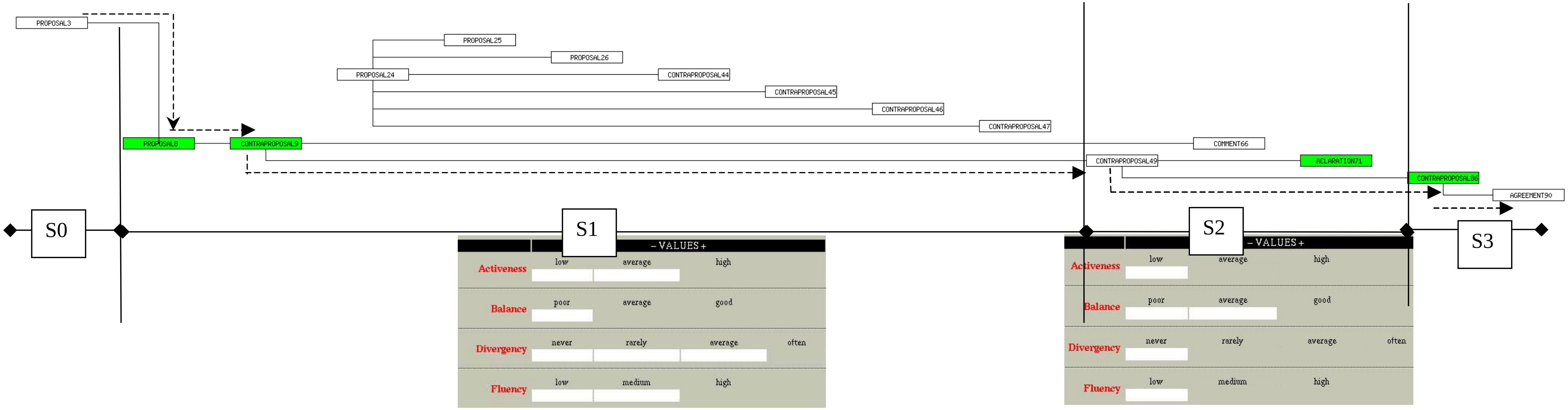

Figure 5. An example of argumentative discussion and its analysis with the stages/states method. .

DEGREE collaboration is conversation based and uses a conversational structure that could be defined for each activity. Related contribution types that are speech-acts form this structure. Each contribution type belongs to category "propose", "argue" or "agree" depending of its role in the conversation. Examples of conversational types are proposal, counterproposal (belonging to propose category), answer, question, clarification (belonging to argue category) or agreement (belonging to agree category).

The learners work in an argumentative discussion until they reach agreement. In the discussion, they work on a proposed idea until someone proposes a new idea (related with the previous one or not) and they continue with this, in process of refining, counter proposing, proposing new ideas, convincing or agreeing. As result of this collaborative process they can have different discussions open at the same time or they can follow the same argumentative line round an idea. This generates a tree of possibilities in the collaboration process (figure 5). If the agreement is reached, only one branch of this tree will be the result of the discussion. So, we will apply this method in two cases, the agreement was and was not reached. We will explain the former here, when the agreement is reached, using a interaction-based method called "Stages/States analysis method" (indicated by $\boxed{A}$ in the ontology in figure 3).

The algorithm studies the tree formed in an argumentative discussion, identifies the path of the discussion and divides all contributions into the tree in several stages. Each proposed-category contribution in the successful path will delimit the stages of the conversation. Each stage means all sub-conversations related to a proposed idea are a step in the collaboration process. Therefore each stage can have many branches of partial discussions about intermediate proposals. We can observe that this sub-conversation have contributions related to the proposal that leads the stage (with some parallel discussions) or other sub-conversations but not related to it.

For each stage we studied the evolution of the discussion in order to try to understand how the discussion in each stage was relating some observed data in terms of fuzzy rules for obtaining the conclusions. The method carries out a study at each stage. To carry it out we apply the DEGREE analysis method to each stage with a knowledge base that relates all data that it is represented in Figure 4 and that shows the processed data (Number of ideas Proposed, Impass, Tree Depth, Interactivity, Balance and Rate between Contributions, indicated as $\boxed{B}$ an $\boxed{C}$ in figure 3) that is used from the log used for inferring states such as divergency, activeness and fluency (indicated as $\boxed{D}$ in figure 3) in each stage of the conversation.

Let us use a simple discussion example shown in Figure 5, obtained from a real discussion in a collaborative learning experience, for illustrating the method[1]. Two learners are involved in the discussion: L_1 whose contributions in figure 5 are drawn with white boxes, and L_2 with dark boxes. In this example, L_1 proposes one idea that is replied to by L_2 and refined by himself with a counterproposal[2] (CONTRAPROPOSAL9). L_1 proposes another idea not related to his first idea and refines it with several counterproposals that are not answered by L_2. Finally, L_1 proposes CONTRAPOSOPAL49 related to CONTRAPROPOSAL9[3]. Here, they have a very short argument and L_2 proposes CONTRAPOSPOSAL89 that gets the agreement of L_1.

The first step in the algorithm is to obtain the succeeded path in the discussion tree. We draw it with a dotted arrow in figure 5, from the first proposal to the agreement. Then it identifies the stages in the discussion considering alternating propose-category contributions. We can see, in our example that after the first proposal there are three stages, two with sub discussions and the agreement stage. The stage S1, has another discussion in parallel that it is not related to the main discussion and that is made only for L_1. When he replied or debugged the counterproposal from his colleague (L_2), stage S2 begins. In this example, S1 is a sub-discussion in which there is an active student and the other does not participate. S2, is an example of a more interactive discussion. Bellow the conversation tree, in figure 5, the results for the attributes divergency, activeness and fluency are shown[4].

As result, in DEGREE, we provide a new analysis method based on interaction that obtains and studies some general states of different stages held during an argumentative discussion. We study each stage in terms of characteristics that are close related with collaboration such as the grade of divergence, the balance or fluency in the conversation. This type of analysis method let's us understand the different steps in the process, that combined with the global analysis give us a richer information about how the students work and about how the discussion evolves for solving common tasks. Therefore, this stage/state analysis method is complementary to the other analysis methods that we have developed previously.

Conclusions

Ontology engineering seems to be an effective approach for collaborative learning that needs comprehensive and comprehensible vocabulary for better understanding of the current state of the art and for identifying the directions to go. In this paper we presented a first step towards an integrated CSCL ontology taking the Activity Theory theoretical approach as base. We applied it to two concrete actions in collaborative learning: for defining collaborative learning experiences and for analysing the results. We have shown the continuity of the CSCL ontology from the higher-level to the implementation-level to demonstrate how higher-level concepts help us understand the conceptual structure of CSCL systems and how they facilitate formulating methods for analysis. We have also presented a new interaction analysis method based on stages that complements the global analysis approaches in the DEGREE system. This method reveals that it is possible to identify different steps in a group discussion and quantifies them in terms of attributes that could indicate a state in the discussion.

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[1] The discussion tree of Figure 5, that represents the discussion, was generated by a DEGREE quantitative analysis method. X is time evolution and Y is turn-taking. It is indicated with $\boxed{E}$ in the ontology of Figure 3.

[2] Because it is made for the same author we consider that it is in the same stage

[3] It marks the beginning of the stage S2

[4] The algorithm shows all the data for each stage, as output. They were been omitted some of them due to space limitations

We have checked the analysis platform with the results of experiences carried out with DEGREE. Now, we are involved in a project related to experimental learning, in which the students work in pairs in the lab performing Chemistry-related experiments. With only interaction-based data it was not possible to analyse the actions made by the students. But, as we presented here, we can identify and estimate the different stages of the discussion. Now, with this new project we will have the opportunity of combining the interaction data with the problem-solving task data. It will give us the chance to combine interaction analysis with action analysis in an experimental collaborative learning domain. The ontological approach will help us to commence this new research.

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