ELSEVIER

Expert Systems with Applications 14 (1998) 129–137

Expert Systems with Applications

A collaborative learning environment based on intelligent agents

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Abstract

One of the current trends in the research on AI applied to computer assisted learning is the area of Computer Supported Collaborative Learning (CSCL). A CSCL environment should include software elements that assist the learners in the application of the domain knowledge and promote opportunities of effective collaboration and learning. In this paper we present a CSCL environment based on two kinds of intelligent agents, domain agents and mediator agents, modeled based on ideas from distributed artificial intelligence. The domain agents are able to assist the learners in the application of domain knowledge elements. In order to support the collaboration between learners each mediator agent constructs and maintains a learner model represented as a set of beliefs about the capabilities, commitments, intentions and learning opportunities of its learner.

Mediator agents cooperate by exchanging their beliefs about the capabilities of their learners and proposing the practice of those knowledge elements that promote assistance among learners, keeping the group heterogeneous and collaborative. Based on its learner model the mediator agent is able to support awareness in the environment and maintain the learning possibilities of its learner in a community of practice. This framework provides a collaborative environment for second language learning based on an implementation of the theoretical concepts of social learning (Vygotsky, L. S., 1978, *Mind in Society: the Development of Higher Psychological Processes*. London: Harvard University Press) and agent oriented programming (Shoham, Y., 1993, Agent-oriented programming. Artificial Inteligence, **60**, 51–92). © 1998 Elsevier Science Ltd. All rights reserved

1. INTRODUCTION

In this paper we present our framework for Computer-Supported Collaborative Learning (CSCL) environments (Bannon, 1994; O'Malley, 1995). We propose a CSCL environment based on intelligent agents that support awareness and promote opportunities of effective collaboration and learning in a networked community of practice, based on the pedagogical organization of domain knowledge and the maintenance of a learner model.

Currently there has been an increasing interest in the research and modeling of CSCL environments (Dillenbourg et al., 1996). The application of techniques from computer-supported cooperative work (CSCW) to educational software gave birth to networked collaborative learning environments (Collis, 1994) also known as educational groupware (Gutwin et al., 1995). We would like to define CSCL as *the use of the computer as a mediational device that helps the learners to communicate and collaborate in joint activities through a network, providing assistance in their coordination and application of knowledge in a certain domain.*

The evolution of educational software from CAI systems to computer-supported collaborative learning environments is shown in Fig. 1. The theoretical foundations for educational software have changed through the years, as well as the software technology applied. The first attempt in the application of artificial intelligence techniques to the development of collaborative learning environments has been composing Intelligent Tutoring Systems (ITS) and CSCW components in an *intelligent collaborative learning system* (ICLS). Such a system includes a domain expertise and a pedagogical expertise modules, together with a student model, a group model and an interface (McManus & Aiken, 1993). This first proposal for collaborative intelligent learning systems also implies the representa-

PII S0957-4174(97)00075-4

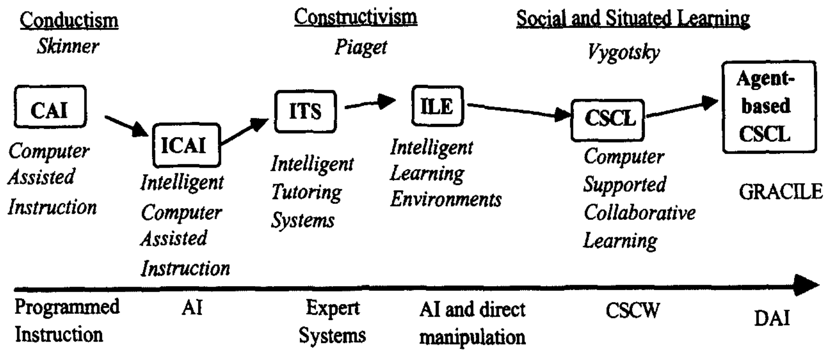

FIGURE 1. From CAI systems to agent based CSCL environments.

tion of a group model, but not of an individual learner.

In CLARE, a CSCL environment that facilitates knowledge construction (Wan & Johnson, 1994), learners work on the construction of a group knowledge base from research papers. While learners derive a representation of an artifact and an evaluation of its content, they are not allowed to see what others are doing or have done. Later they compare, discuss and integrate their individual representations. CLARE includes a representation of the group's knowledge base, but there is not an individual learner model in the framework. The *Learning Web* framework (Norrie & Gaines, 1995) presents a group of software agents designed to assist the learner, making intelligent decisions based on the content of their knowledge bases and the messages they receive. An *interface agent* learns from the user's actions, working as an intelligent assistant, while a *tutor agent* provides scaffolding to the learner, progressively removing it as the learner internalizes the knowledge. These agents require a model of the learner in order to perform their tasks.

We propose GRACILE as a new step in the development of CSCL environments including the use of intelligent agents modeled based on ideas from agent based programming (Shoham, 1993) in distributed artificial intelligence (DAI) and which behavior follows the guidelines of Vygotsky's social learning theory (Vygotsky, 1978) applied to second language learning. GRACILE (Japanese GRAmmar Collaborative Intelligent Learning Environment) is an agent-based CSCL environment developed as part of our research on the structures and procedures needed for the effective collaboration between learners of heterogeneous small groups (Ayala & Yano, 1996a). Interacting with GRACILE, foreign students, some of them more enculturated than others in the Japanese language and society, collaborate writing a dialogue in Japanese, assisting each other in the application of language patterns and expressions of the Japanese language. In Fig. 2 we present an example of interaction with GRACILE. A group of four foreign students constructs a dialogue as a sequence of situations or communicative acts. Each mediator agent of a group member is responsible to update the workspace and provide information concerning the contributions.

2. INTELLIGENT AGENTS FOR CSCL ENVIRONMENTS

The learner interacts with two software agents: a *mediator agent* and a *domain agent* (Ayala & Yano, 1996a). Our agents in GRACILE are deliberative agents (Nwana, 1996; Wooldridge & Jennings, 1995) since they reason based on an internal symbolic reasoning model implemented in Prolog. The capabilities of the domain agent consists of the analysis and construction of short sentences manipulating a set of Japanese language patterns and expressions implemented in Prolog predicates. The mediator agent supports the communication and collaboration between learners by proposing tasks to its learner, considering her/his capabilities and the collaboration and learning possibilities she/he would have as a member of the specific group.

2.1. Domain Agents

Domain agents are deliberative agents able to construct and analyze sentences constructed by the learner, applying their capabilities represented as a set of Prolog rules that represent Japanese language patterns and expressions. The grammar patterns are considered the domain knowledge elements and are pedagogically organized, being related by *part-of* relations and grouped into classes which represent the *communicative situations* where they are appropriately applied. Each one of these situations refers to a communicative act, like *greeting, affirmative request, ask for opinion, refusal,* etc. A dialogue constructed collaboratively by the learning group is a sequence of these communicative acts, each one corresponding to the application of domain knowledge elements. The part-of relations are used by the mediator agent in order to promote the learner's progress from simple to more complex language patterns and create its beliefs about the learning and assistance opportunities of the learner in the group.

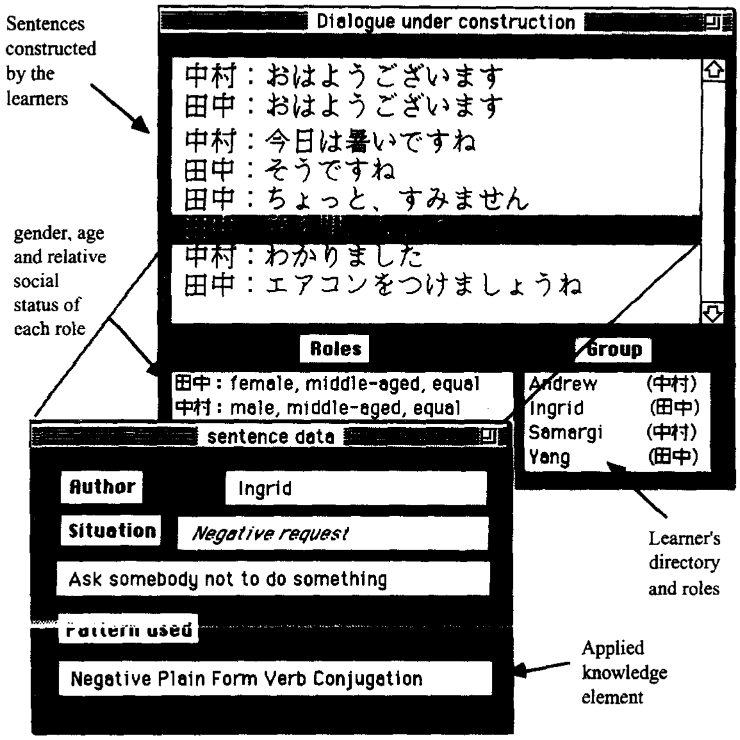

FIGURE 2. The common dialogue under construction.

2.2. The Mediator Agent

Mediator agents are deliberative, cooperative, semi-autonomous learning agents, working together looking for learning opportunities for their learners in a given group. They generate their own commitments based on the messages received from other agents and what they learn from the performance of they learners. The capabilities of the mediator agent are performed according to the commitments it makes to its learner, the other mediator agents in the environment and to itself. The architecture of the mediator agent in presented in Fig. 3.

Mediator agents keep the learners' awareness on the environment and promote the collaboration possibilities of the learners in the group by supporting the communication of:

(1) the learning goals of the learners, so they can be aware of the intentions of each other;
(2) the learners' commitments, so they know the tasks learners are going to perform and who is going to assist who;

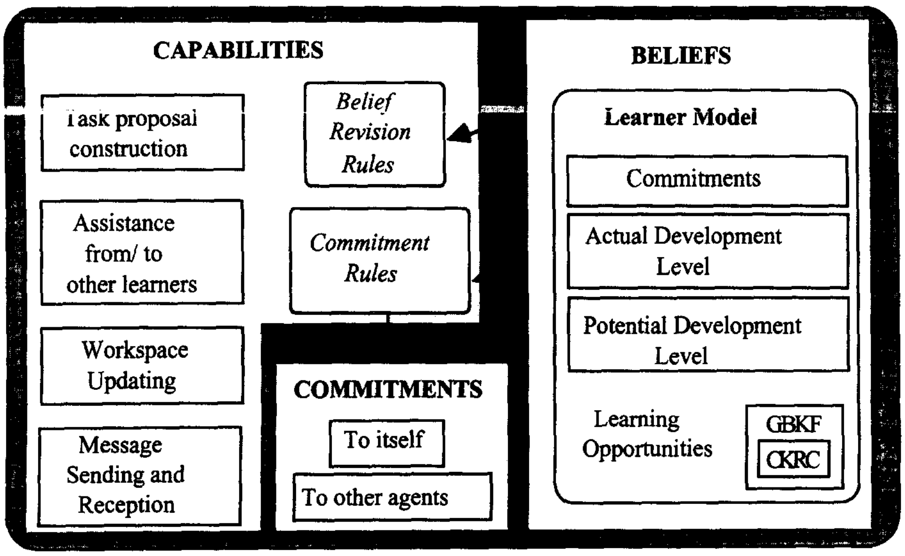

FIGURE 3. The model of the mediator agent.

(3) the learners' capabilities, so learners will understand who would be able to assist them in a given situation, being able to locate her/his level with respect to the group, reflecting on her/his and other's capabilities and commits to a task;
(4) the learners' constructions and exchange of viewpoints about the application of knowledge in the virtual workspace (dialogue under construction).

The iteration circle of the mediator agent is shown in Fig. 4. The mediator agent creates its commitments by reasoning with a set of *commitment rules*. A commitment rule has a *mental condition* (the mediator agent's beliefs about the learner's capabilities, commitments, learning goals and learning possibilities), a *message condition* (the received messages from the learner and other mediator agents) and an action, which may be a *communicative action* (to other mediator agents) or a *private action* (change its own commitments and beliefs). Then, the conditions of these rules refer to:

(1) the received messages from the learner and other mediator and domain agents;
(2) the mediator agent's beliefs about the learner's capabilities, commitments, learning goals and collaboration possibilities.

One example of a commitment rule of the mediator agent is concerned with the proposal of tasks of mutual interest to its learner. The mediator agent Y makes a commitment to propose a task to its learner, but such a task is also of the interest of the mediator agent X of learner X. In this way the mediator agents cooperate, working on behalf of both learners:

Commitment rule i

IF there is a request from other mediator agent X asking it to propose to its learner (learner Y) a task where a knowledge element not internalized by both learners X and Y is applied **and** the mediator agent believes that its learner has opportunities to internalize that knowledge element
THEN *create the commitment* to mediator agent X to propose to its learner a list of tasks where to apply such knowledge element **and** *creates the commitment* to itself about the construction such list of tasks

Some commitment rules are concerned with the creation of commitments of the mediator agent to itself. For example, the next rule creates the commitment to inform the learner about a request of assistance from other learner in the network, only if the mediator agent believes that the learner is able to assist:

Commitment rule j

IF there is a request of assistance from other learner (learner X via her/his mediator agent X) to the learner in a given situation **and** the mediator agent believes that the learner is able to apply a knowl-

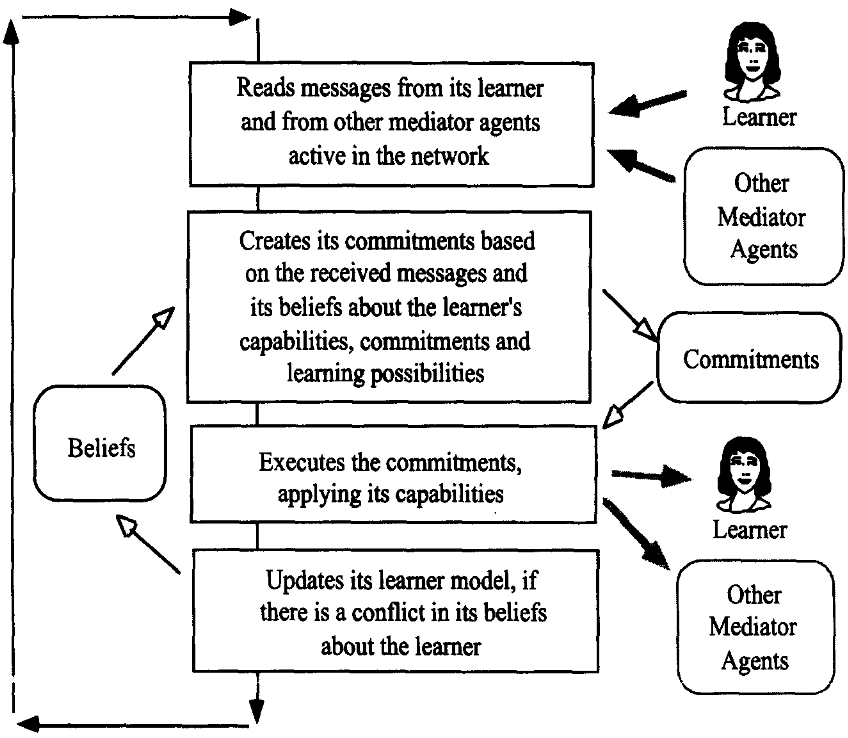

FIGURE 4. Iteration cycle of the mediator agent.

edge element for that situation (communicative act)

THEN *create the commitment* to inform its learner that learner X is asking for assistance in a given situation

Together with the modeling of our agents we have designed an agent communication language for our CSCL environment, as well as the respective protocols for the coordination and cooperation between mediator agents (Ayala & Yano, 1996b), based on the guidelines of Knowledge Query and Manipulation Language (KQML, Finin et al., 1993).

3. LEARNER MODELING FOR COLLABORATIVE LEARNING ENVIRONMENTS

As we mentioned in the previous section, the commitments of the mediator agent are generated based on its model of the learner. Learner modeling is the key concept concerning the application of artificial intelligence into educational software (Dillenbourg & Self, 1992). Currently, a learner model is considered as a set of beliefs hold by the system about the learner (Self, 1994). In CSCL environments the issue of learner modeling has not been discussed in detail. We propose that the role of the learner model in CSCL environments should not be to support tutoring or diagnosis, as in ITSs, but to enhance awareness and the effective collaboration between learners. Since in a CSCL environment we consider the learner as an active agent collaborating with her/his peers, we propose that the learner should be also modeled in terms of the basic concepts of agent modelling in distributed AI (Shoham, 1993) and Vygotsky's social learning theory (Vygotsky, 1978). In GRACILE the learner model is a set of beliefs the mediator agent holds about its learner and are organized as follows:

(1) The learner's capabilities (representing her/his actual and potential capabilities).
(2) The learner's commitments (the commitments to perform tasks for the group's common problem or to assist other learners).
(3) The learner's intentions (the knowledge elements or tasks s/he explicitly indicates that would like to practice).
(4) The learner's group-based knowledge frontier (GBKF) which represents the opportunities of progress and assistance the learner has while being assisted by other learners in the group.

Mediator agents in GRACILE support the collaboration and learning possibilities of the learners, by promoting the creation of *zones of proximal development*. In his theory of social learning Vygotsky defined the concept of zone of proximal development as the distance between the *actual development level* and the *potential development level* of the learner (Vygotsky, 1978). In the terms of Vygotsky, learning (knowledge internalization) occurs when an *interpersonal process*, at the social level, is transformed into an *intrapersonal* process, at the individual level. In GRACILE the actual development level of the learner is represented by the knowledge elements that the mediator agent believes have been internalized by her/him. This is the set of knowledge elements that have been applied by the learner *without the assistance* from other learners or the domain agents in the network. The potential development level corresponds to that knowledge elements the learner has applied correctly *with the assistance* of other learners or the domain agents. The objective of the mediator agent is to promote collaboration on the application of not internalized knowledge elements, incrementing the potential development level of its learner, from which her/his actual development level will be developed.

4. BELIEFS ABOUT THE LEARNING OPPORTUNITIES

In order to represent the beliefs of the mediator agent about the learner's assistance and learning opportunities in a given group we have defined the learner's *GBKF* as the *union* of the following two sets:

(1) The set of complex knowledge elements related (by *part-of* relations) to simpler elements believed to be already internalized by the learner.
(2) The set of knowledge elements believed to be internalized by other members of the current learning group, but still not believed to be internalized by the learner.

The learner's *candidate knowledge for relevant collaboration* (hereafter referred as CKRC) consists of the *intersection* of these two sets. The CKRC is then a subset of the GBKF which represents those knowledge elements still not internalized by the learner that have been already internalized by other learners and which are structurally related to the learner's internalized knowledge elements. In order to increment the potential development of its learner the mediator agent will propose to its learner those tasks where knowledge elements in the CKRC are applied. This results in the enhancement of opportunities of learning by collaboration with the group and the creation of zones of proximal development within which the learner can work and be assisted by more experienced learners. The mediator agent will propose task involving the application of knowledge elements in the GBKF in the case when the CKRC is empty. In order to construct the GBKF and the CKRC sets the mediator agents *cooperate* by exchanging their beliefs about their learners' capabilities.

5. PROMOTING COLLABORATION

In order to help the learner to reach a relevant commitment the mediator agent proposes to the learner a list of learning tasks based on her/his CKRC and GBKF sets. Then the learner commits to a task for the construction of the dialogue by selecting the knowledge elements to be applied in a situation for the dialogue in which a sentence must be constructed.

When the CKRC set of a learner is becoming empty, the mediator agent will believe that the learner's possibilities to commit to a learning task where s/he may obtain assistance and learn from other learners are decreasing. In such a case the mediator agent sends a request of *mutual interest task proposal* to all mediator agents in the network together with its learner's GBKF, asking the other mediator agents to propose to their respective learners those tasks where knowledge elements contained in the GBKF of its learner are applied. This results in the increment of the knowledge elements of the learner's CKRC, which results in a maintenance of her/his motivation, as well as more assistance and learning possibilities in the group.

6. SUPPORTING AWARENESS IN A CSCL ENVIRONMENT

A learner can learn and collaborate effectively only if s/he is aware of the intentions, commitments and capabilities of the other learners present in the environment. Gutwin et al. (1995) have proposed a framework for awareness in CSCL environments where workspace awareness has been defined as the up-to-the-minute knowledge that the learner needs about other learners, in order to collaborate effectively.

In GRACILE all learner models are *freely accessible* to the learners at any time, via the mediator agents (see Fig. 5). In this way the learner is invited to reflect on her/his own capabilities and locate her/his own level with regards to the rest of the group. Learners become aware of who would be able to assist them in the application of a knowledge element in a given situation. When learners have to make a commitment of a learning task as part of the group's common problem they tend to select tasks where they can practice those knowledge elements considered used and acquired by other learners in the group, so they can get assistance from them, if necessary. Supporting awareness increases the realistic collaboration and therefore motivation and learning possibilities in the group.

Based on the learner model the mediator agent in GRACILE is capable of the following activities:

(1) Support awareness, by allowing the communication of the learning goals (intentions), commitments, capabilities and constructions of the learner in the networked community of practice.
(2) Cooperate with the other mediator agents by sending information about the capabilities of its learner, so they can construct the GBKF and CKRC of their learners.
(3) Make an intelligent task proposal to the learner, considering the situations (communicative acts) where knowledge elements in the GBKF and CKRC sets are applied, promoting the construction of zones of proximal development and therefore learning.
(4) Decide present or not to its learner a request of assistance from other learner in the network, based

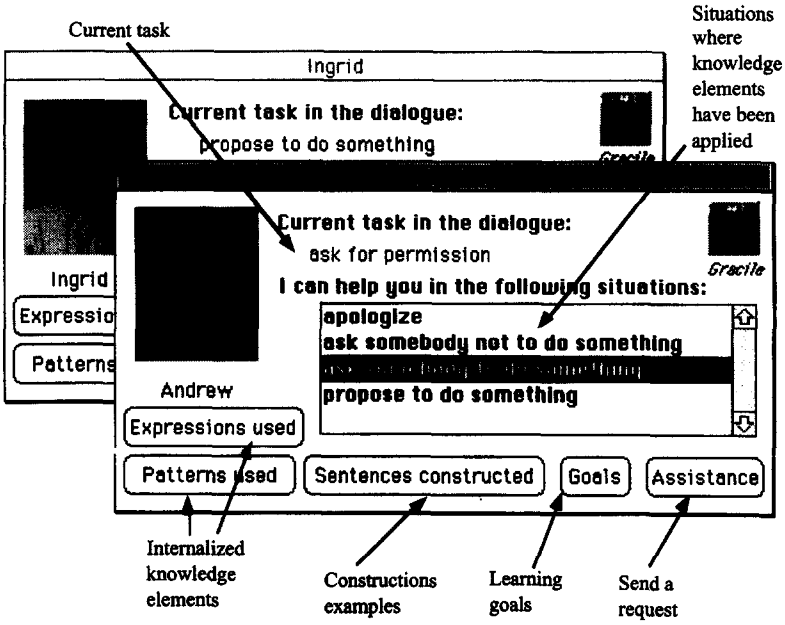

FIGURE 5. Awareness based on accessible learner models.

on the beliefs of the learner's current commitments (task load) and capabilities.

(5) Look for consistency in its beliefs about the capabilities of the learner. The representation of the GBKF, the CKRC and the potential development level are also used in the creation and justification of basic and derived beliefs, as well as in the decision to discard beliefs about the learner's capabilities.

7. THE LEARNER MODELING PROCESS

For an ITS learner modeling has been considered as a cognitive diagnosis process, where the computer system infers the learner's knowledge by analysing her/his behavior (Dillenbourg & Self, 1992). Learner modeling is a process of beliefs revision since the learner model is considered as a set of beliefs the mediator agent holds about the learner. In GRACILE, the justification of beliefs on the learner's capabilities includes not only the structural aspects of knowledge progress (part-of relations) but also the social aspects represented by the potential development level, the GBKF and the CKRC of the learner.

During the belief revision process the mediator agent applies a set of rules in order to decide to create or discard its beliefs. These rules create basic and derived beliefs about the learner's capabilities with their respective justification. The conditions of these rules refer to the result of the analysis from the domain agents of the learner's construction, the current state of the beliefs about the capabilities of the learner, represented in the learner model, and the structural relations between knowledge elements, represented by their part-of relations. In addition, the potential development level, the GBKF and the CKRC are used by the mediator agent in order to justify the beliefs created and decide when to create a derived belief from a basic one.

Here we present one of these rules which creates a belief about the internalization of a knowledge element by the learner, when she/he correctly applies a knowledge element without help from the domain agents or other learners in the network:

belief revision rule i

IF the domain agent indicates that the learner was able to apply knowledge element K without assistance from the domain agent or other learners **and** the learner was not believed capable to do it **and** **K** is in the learner's candidate knowledge for relevant collaboration (CKRC)
THEN *create the basic belief* that the learner is able to apply knowledge element K **and** *justify* it with the fact was applied without help and that K was in the learner's CKRC.

One example of a rule that creates a derived belief is:

belief revision rule j

IF there is a basic belief that the learner is capable of applying knowledge element K **and** there is a knowledge element X which is part-of K **and** X is in the learner's potential development level
THEN *create the derived belief* that the learner is able to apply knowledge element X **and** *justify* it with the fact that X is part-of K and has been applied before with the assistance of other agent in the environment.

The beliefs about the learner's capabilities are considered to be discarded when the mediator agent notices inconsistencies in its beliefs according to the learner's performance. This happens when the learner asks for assistance from another learner or from a domain agent about the use of a knowledge element believed to be in her/his actual development level, or when she/he makes an incorrect construction, applying a knowledge element incorrectly which is believed to be in her/his actual development level.

Discarding a derived belief implies discarding at least one of the basic beliefs which gave origin to it (Self, 1994). The mediator agent reasons with rules that consider the justification of the beliefs to be discarded, such as:

belief revision rule k

IF the domain agent indicates that the learner was not able to apply knowledge element K **and** there is a derived belief that the learner is able to apply K **and** the justification of the derived belief does not indicate that knowledge element K was in the CKRC when the belief was created **and** there is a set of basic beliefs that support this derived belief
THEN *discard* that derived belief **and** *discard* the less justified belief of the set of basic beliefs

In order to determine the *less justified belief* the mediator agent applies some heuristics about the strength of a justification. The strongest justification concerns those knowledge elements that were in the learner's potential development level when the belief was created, then those that were in the learner's CKRC, next those in the learner's GBKF, (but not in the CKRC) and finally (the less justified) those not related.

8. AN EXAMPLE OF INTERACTION WITH GRACILE

Working with GRACILE, Ingrid, Helen and Andrew are writing a dialogue in Japanese. The mediator agents cooperate by exchanging their beliefs about the capabilities of their learners. Therefore the mediator agent of Ingrid is able to create her GBKF and CKRC sets and make an intelligent task proposal to her. The mediator agent presents to Ingrid its task proposal as a list of situations where knowledge elements in the CKRC of Ingrid need to be applied, which are believed already internalized by Andrew and Helen and related by part-of relations to Ingrid's actual knowledge. The situation *apologize* appears in the list and she makes a commitment to construct a sentence for that situation in the dialogue.

Before Ingrid commits to construct a sentence for the dialogue she asks her mediator agent to present information about Andrew (see Fig. 5). She becomes aware that Andrew is believed to be able to construct sentences in Japanese for the situations *apologize, ask somebody to do something, ask somebody not to do something and propose to do something*. Ingrid considers that Andrew may be able to help her in the application of the language patterns needed for such situations. Ingrid commits to construct a sentence for the situation *apologize* because she is aware that Andrew may help her. She can send a request for assistance to him by clicking on the 'Assistance' button in Andrew's window or send a request for assistance to the domain agents via her mediator agent, which works as a facilitator. By selecting the situation *ask somebody to do something* and clicking on the 'Expressions Used' and 'Patterns Used' buttons, she can see the knowledge elements applied by Andrew in that situation, or take a look at the sentences previously constructed by him by clicking on the 'Sentences Constructed' button.

During the construction of the dialogue, Helen sends a request for assistance to Ingrid concerning a situation where Ingrid is believed to be able to construct a sentence, however Ingrid refuses to provide assistance since she considers herself not capable to help. Ingrid constructs the sentence for the dialogue and the domain agent analyses it, sending a message to her mediator agent indicating if the sentence constructed is correct and appropriate as an apology in Japanese. These last three actions of Ingrid imply a revision of the mediator agent's beliefs about her capabilities. Finally her mediator agent informs the changes in its beliefs to the mediator agents of Andrew and Helen and makes the corresponding changes in the GBKF and CKRC of Ingrid, taking into account the changes in its beliefs and after receiving new information concerning the capabilities of Andrew and Helen from their mediator agents.

9. CONCLUSIONS

We have presented how intelligent agents in a CSCL environment can promote the effective collaboration and the creation of zones of proximal development in a learning group. With GRACILE we propose a framework for an agent-based CSCL environment consisting of two typess of intelligent agents: domain agents and mediator agents. We have presented in detail the design, modeling and performance of them. Domain agents are distributed domain knowledge sources that assist the learners in the application of domain knowledge, partially distributed in the network. The mediator agent is designed to cooperate in order to support the conditions for effective collaboration between learners in a networked community of practice. Our approach in learner modelling for CSCL environments proposes that the role of the learner model in these environments should be support awareness and enhance the effective collaboration between learners. In GRACILE the learner model is considered a set of beliefs held by the mediator agent about the learning goals, commitments and capabilities of the learner. Learner models are accessible to the learners at any time, making them aware of the current capabilities, commitments and intentions of the learning group members.

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