A Cooperative System for Collaborative Problem Solving

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Abstract

In the DSA-project (Dialogue Structure Analysis of interactive problem solving) we are studying the relationship between the cognitive aspects of information processing and the communicative process of information exchange during cooperative problem solving. On the basis of analyses of dialogues of students collaborating on a problem solving task, a prototype of an 'intelligent' computer-based cooperative system has been implemented.

This program, the 'Dialogue Monitor', is the central part of a computer-assisted educational program, which acts as a simulated student and which collaborates with a human student in jointly solving this problem task. In this paper we will focus on crucial aspects of cooperative interaction in problem-solving learning situations, which we found hard to implement in our system. These aspects concern the complex interaction between task strategies and communication processes during collaboration. Real collaboration requires that the cooperating subjects acquire a common frame of reference in order to negotiate and communicate their individual viewpoints and inferences.

Keywords — cooperative learning, intelligent tutoring systems, human-computer interaction.

1. Introduction

Contemporary views on learning and technology stress the importance of collaborative learning. Computer and telematics based environments seem especially suited for such learning.

Research on cooperative learning in education has a long-standing tradition. In recent educational research cooperative learning is re-emphasized [2]. This emphasis follows a reformulation of learning as a process of enculturation in recent constructivistic or situated learning views on cognition and instruction [3, 5] Aspects of cooperation play a central role in the constructivistic approach of learning. Peer cooperation is seen in a Vygotskian way as an intermediate stage in the developmental process of internalization of social activities. Furthermore notions like cognitive apprenticeship, anchored instruction and scaffolding partly seem to be based on a cooperative paradigm.

As for the role computers play with regard to education, the focus is on the construction of computer-based, multimedia environments: open learning environments which may give rise to multiple authentic learning experiences [3]. The cooperative aspect is mainly realized by offering computerized (intelligent) tools which can be helpful for collaborating students in solving the task at hand. Cooperative systems aimed at working together in one way or another with a student or a group of students, is another approach. In this approach a computer-based 'intelligent' partner or a simulated peer student is used to facilitate the effects of cooperative learning [4, 7, 10]. In order to implement a cooperative system as a partner in this sense, the emphasis will have to be on the requirements for communication and interaction between the collaborating partners, i.e. the system and the student(s).

However, we lack specific knowledge about the way students communicate and thereby coordinate their information processing while collaborating in problem solving contexts. When students cooperate and communicate in natural language, information is exchanged, not only concerning the problem itself but also about meta-cognitive aspects such as the plausibility of the information and beliefs about the state of the information of the other [8].

2. Cooperative Problem Solving

At the Utrecht University, the DSA-project ("Dialogue Structure Analysis of interactive problem solving") is concerned with research on the relation between information processing and information exchange during cooperative problem solving. In this project a simulation-program has been constructed that models a cooperative peer student on a problem-solving task.

2.1. Cooperation task

The task that is used to study the relation between information exchange and information processing during cooperative problem solving is called the "Camp Puzzle". It is meant for students from the highest grades of elementary school (10-12 years old). The Camp Puzzle may be compared to the so-called "Smith, Jones and Robinson" problems. In this kind of logical problems one has to combine different statements of information in order to derive some characteristics of a specified group of individuals. However, in the Camp Puzzle this task information has been split (in two 'letters' of children in this group) and has been distributed among the two cooperating partners. By this splitting of information cooperation becomes necessary in order to complete the task. The students have to infer several characteristics of the six children mentioned in the task. Each of the two partners receives a letter which contains different information about the children mentioned in the task.

2.2. Cooperation dialogues

In two research projects the Camp Puzzle was assigned to couples of students in the highest grade of elementary school (72 and 20 couples). Their task-dialogues were collected on video or audio tapes. By means of a comprehensive system the utterances in the dialogues could be coded along three main characteristics: content (in the form of a proposition), dialogue-act and illocution. The dialogue-act represents the communicative action of an utterance, for example: question, proposal, denial, statement, etc. The illocution part of an utterance provides the listener explicit information on how to interpret the information transferred. In most cases the illocution concerns the certainty of the information, for instance "I am not sure that..".

From analyses of the cooperative task-dialogues, it was learned that mutual coordination and communication of relevant information and inferences during cooperative problem solving is a complex intertwined and dynamically changing process. The topical structure in the argumentative dialogues coincide with the subproblem structure of the task. However, the sequence of sub-problems is not rigid and a solution path has to be found. For this purpose, topics have to be initiated, tried and evaluated in the ongoing dialogue. Remarkably, topics are seldom explicitly proposed, but are initiated implicitly by exchanging relevant information concerning a topic.

Most of the dialogue-acts in the Camp Puzzle are informative, supportive or argumentative. Contrary to what one would expect, the dialogues contain very few open questions (e.g. "Do you know the sports of Jan ?"). The students seem to hold on to another Cooperative Principle (compare Grice, [6]): "If my partner has found something interesting, he will tell me, I don't have to ask for it !". Yes/No questions are found more frequently (e.g. "Does Jan play volleyball?"). These latter type of questions function, mostly, to check information exchanged. Furthermore, the students are very concerned with the plausibility or certainty of the propositions transferred or inferred by themselves or by their partners (25% of the utterances have an explicit illocution part). Several plausibility levels (five in our model) can be distinguished, depending on the source of information and on the depth and complexity of the inference procedure.

2.3. Dialogue Monitor

Based on analysis of the dialogue protocols a prototype of a Dialogue Monitor for a cooperative system was developed, simulating a cooperative student. The 'Dialogue Monitor' program has been experimentally used with 51 students (10-12 years) of two elementary schools. The architecture model advanced in this program will be used for further development of 'intelligent' computer-based cooperative systems. In the model of the Dialogue Monitor five components, functioning as separate modules, may be distinguished.

The 'Problem Solving Component' contains knowledge about the content of the task and its domain and is able to apply inference procedures in order to solve this type of problems. The 'Dialogue Processor' contains expertise about interaction processes in general and has strategies for generating communicative actions: i.e. argumentative, supporting and eliciting scenario's. In the 'Alter Component' a discourse history is been updated in the ongoing dialogue. Based on this history a belief-system about the current activities of the partner is construed.

The 'Central Focusing Processor' contains the cooperation strategies. The general task of the Central Focusing Processor is to interpret and check incoming utterances of the partner and to generate utterances itself in a reacting or initiating way. The communication with the program takes place with the 'Menu-Based 'natural language' Interface'. By means of interconnected menu's the student can select constituents of the utterance he/she wants to make [9]. The selections made by the student are translated into a grammatically correct sentence. With the interface a large amount of different sentences can be made (about 3.2 million).

3. Implementation of Interactivity

3.1. Coordinating

When we look at sequences of communicative actions that occur frequently between human students, we can distinguish some prevailing dialogue-patterns. Every phase in the problem solving process has its congruent part in the topical structure of the task-dialogue:

- *Problem definition - Proposing*
  Initiating and agreeing about the next topic of discourse, i.e. the next sub-problem to be tackled.

- *Information search - Informing*
  Searching for relevant information in information sources, including communicating and eliciting information from the partner.

- *Inferencing - Argumenting*
  Getting a joint understanding about the way of combining the relevant information.

- *Evaluation - Concluding*
  Evaluating and agreeing upon a possible solution.

- *Finishing - Topic closure*
  Writing down a solution or giving up.

Coordination occurs by means of signaling, asking for attention before new information is transferred, and by means of explicitly accepting and re-concluding before writing down the solution. By these means, both partners explicitly make sure that they share the same understanding of the problem. However, a lot of coordination is achieved by implicit means. With respect to the implementation in the Dialogue Monitor, we tried to solve this by the interpretation of a verbal act on two levels: locally (the dialogue-act) and in regard to the topical structure (topic-step). In general however, a cooperative system should deal with this multiplicity of functions of discourse acts in the situated context of the ongoing dialogue.

3.2. Mixed initiative

Both system and student have to be able to take the initiative in interaction. They must be able to take initiative in asking questions, in making remarks, in transferring information, in suggesting solutions. However, questions for implementation concern the "when" and "what then" of taking initiative. When should the system take the initiative? And how should the program react on an initiative of the partner? Being concerned about taking initiative in the interaction is not a trivial matter, as most user-system interaction systems wait for a reaction of the user ('press enter or OK-button'). As a rule a cooperative system should take the initiative if it can contribute some interesting or helpful information.

A fragment of a dialogue between the Dialogue Monitor and a student is given in Figure 1, which illustrates this aspect of mixed-initiative and flexibility in change of focus. A fragment, literally translated from Dutch, is shown of the interaction of the monitor with a 12-year old student.

Dialogue fragment (translated from Dutch)	
1	*M: "Let's search: the city of Peter."*
2	*M: "Children living in Haarlem, sleep next to each other; that is in my letter."*
3	*A: "And Peter comes from Sittard; that is in my letter."*
4	*M: "Oh,..."*
5	*M: "We can write that : Peter comes from Sittard."*
6	*M: "I'll write that !"* [*i.e. fills the solution in the solution-matrix*]
7	*A: "Peter does the same sports as Mary; I am sure of that."*
8	*M: "Oh..."*
9	*M: "The sport of Peter; that is not in my letter."*
10	*A: "And only one child is playing volleyball, that is in my letter."*
11	*M: "Only one child is playing volleyball."*
12	*M: "I don't know that."*
13	*M: "Is only one child playing volleyball ?"*
14	*A: "Yes; that is correct."*
16	*M: "So, only one child is playing volleyball"*
17	*A: "Ann comes from Assen."*
18	*M: "Yes, Ann comes from Assen, that fits."*
20	*M: "That is in the solution-matrix."*

Figure 1. Dialogue between a 12 year-old male student (A:) and the Dialogue Monitor (M:).

As can be seen in the fragment, the dialogue has a "natural" stance with a lot of implicit proposals, ellipsis ("Yes", "Oh"), non-specific replies, plausibility checking (13) and unexpected topic-shifts (7, 17) of the partner. In the first topic (the city of Peter) the monitor takes the initiative (1) and the student follows. The second topic on the same subject (sports of Peter) is initiated by the student (7) and accepted by the monitor. When this topic fails, the student initiates a sub-problem (17), which already has been solved

3.3. Checking

One of the main findings of our analyses of the protocols, is that students spend a great deal of their time in these task-oriented dialogues on coordinating activities such as checking of plausibility and giving information about the status of information transferred .

Checking procedures were found to play an important role in the coordination of actions in the analyzed task-dialogues. We think that before information can be incorporated in a cognitive representation, this checking process on relevance and coherence with earlier knowledge is necessary. People can only relate external information to their own knowledge if it is perceived as relevant, plausible and consistent [1]. The importance of "checking" the information put forward by the partner is reflected by a checking procedure by the central focusing processor of the Dialogue Monitor, which operates on every incoming utterance.

3.4. Negotiating

If cooperation also means the negotiation of knowledge, this implies that under specified conditions the cooperative system will have to 'buy' the argumentation of its partner, even if it counters its own conclusions. We think this is a difficult problem to solve as it concerns belief revision. In contra-argumentation, disagreeing with the line of reasoning of the partner, one of the cooperation partners should be convinced in the end. The problem is to specify the conditions under which the program will have to loose its faith in its own line of reasoning. We are not satisfied with the rigid, standardized way the program acts in situations of contra-argumentation at this moment. Contra-argumentation will be accepted if the plausibility of the own information is minimal or if the partner persists in changing earlier found conclusions. More research on natural argumentation and persuasion will be needed in order to specify the negotiating of knowledge by a cooperative system

4. Conclusion

In this paper we focused on some aspects of cooperation, which in our view are crucial, but hard to implement in computer-based cooperative systems. Real collaboration requires that the cooperating subjects acquire a common frame of reference in order to be able to negotiate and communicate their individual viewpoints. Natural language communication is implicit by nature, viewpoints are not always advanced, task strategies are not always open to discussion, and so forth. While implicitness may be ineffective because it masks differences in knowledge, viewpoints and attitudes, it also results in efficient and non-redundant transfer of information. Coordination in information transfer is accomplished by multifunctional dialogue acts. With respect to the implementation of computer-based cooperative systems, this puts a heavy burden on the interpretative and generative power of the program. Most notably, it should deal with the functions of discourse acts in the situated context when interpreting verbal acts of its human partner and it should use those same functions when generating its own verbal acts.

References

1. Ausubel, D.P. & Robinson, F.G. 1969. School learning. Holt, Rinehart & Winston, New York.

2. Brown, A.L. & Palincsar, A.S. 1989. Guided, Cooperative Learning and Individual Knowledge Acquisition. In Knowing, Learning and Instruction. Resnick, L.B. (Ed.). Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 393-451.

3. Cognition and Technology Group at VanderBilt 1990. Anchored Instruction and Its Relationship to Situated Cognition. Educational Researcher, 19, 6, pp. 2-10

4. Cumming, G. & Self, J. 1991. Learner Modeling in Collaborative Intelligent Educational Systems. In Teaching Knowledge and Intelligent Tutoring. Goodyear P. (Ed.). Ablex Publishing Corporation. Norwood, NJ, pp. 85-104.

5. Duffy, T.M., Jonassen, D.H. 1991. Constructivism: New Implications for Instructional Technology?, Educational Technology, May 1991, pp. 7-12.

6. Grice, H.P. 1975. Logic and conversation. In Syntax and semantics, vol.3: Speech acts. Cole, P. and Morgan J.L. (eds.). Seminar Press, New York, pp. 41-58.

7. Kanselaar, G., Andriessen, J.E.B., Barnard, Y.F. & Erkens, G. 1989. Some issues on the construction of cooperative ITS. In Instructional aspects of Intelligent Tutoring Systems. Pieters, J. (Ed.). TH-Twente, Enschede, pp. 45-65.

8. Kanselaar, G. & Erkens, G. 1994. Interactivity in Cooperative Problem Solving with Computers. In Technology Based Learning Environments: Psychological and Educational foundations. Vosniadu, S., De Corte, E. and Mandl, H. (Eds.). NATO ASI Series F, Springer Verlag, Berlin, pp. 55-66.

9. Tennant, H.R., Ross, K.M., Saenz, R.M., Thompson, C.W. & Miller, J.R. 1983. Menu-based natural language understanding. Proceedings of the 21st Annual Meeting of the ACL. ACM, New York, pp. 151-158.

10. VanLehn, K., Ohlsson, S. & Nason, R. 1994. Applications of Simulated Students: An Exploration. Journal of Artificial Intelligence in Education, Vol 5, no.2, pp. 135-175.

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