Problem Solving of Elementary Mathematics Based on Co-reference between Drill Text and Dialogue with Teacher

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1. Introduction

A dialogue plays an important role in learning how to solve a problem and forming a concept. In primary education, the dialogue between students and a teacher is the major part of the educational activity. A textbook, drill text, and figures on blackboard are used for students to understand teacher's utterance easily. Sentences of the text are written in the spoken language to associate them with the dialogue. The spoken language has such problems as deviation from grammar, ellipsis, or occurrence of anaphoric forms. Reference to the text and figures will be useful in solving these problems. In realizing a problem solving process using texts together with dialogue, it is necessary to understand the mutual relation between natural language expressions and picture expressions in the text, make each less ambiguous by referring to the other, transform one expression into another, and associate the text with the dialogue.

This research intends to develop a problem solving system based on co-reference between drill texts and dialogue with a teacher, focusing on the first grade mathematics.

2. Overview of Dialogue-Based Problem Solving System

Figure 1 is examples of first grade mathematical drill texts. The problem sentences in the text are (a) kazudake maruwo kakimasyou (draw as many circles as the number), and (b) onazi kazuno kaadowo sende musubimasyou (link cards with a same number with a line). Their meanings are described by the case structure after character recognition, morphological analysis, parsing, and semantic analysis. On the other hand, the meaning of problem pictures is represented by the picture descriptive form after matching them with picture models and text models. The command sequence for problem solving of the text is generated by co-reference of both descriptions, and is executed. When ambiguities arise or attempts to generate and execute the command sequence fail in that process, the system tries to communicate with a teacher using a dialogue control module. Each command is described by the frame-like representation which has such slots as super-frame, case-frame, collocation command, priority of construction and execution, source of command, status of command, parameters, and attached procedure. The parameter slot consists of such facets as type, role, concept, print-name, constraints, and value. Both the case-frame slot of each command and the print-name facet of the parameter slot are used for generation of utterance from the system.

3. Context of Dialogue

The context of dialogue is defined as linguistic and nonlinguistic environment in which language expressions are used and evaluated. It is subdivided into the following four constituents: (1) the explicit content of utterance and the communicative intention of the

Figure 1 Example of mathematical drill text

speaker, (2) the circumstances surrounding the utterance (i.e. speaker, hearer, location, time, things and events), (3) world knowledge that are relevant to the utterance, and (4) the attentional state (i.e. the speaker's focus of attention).

Let us consider the constituents of the context in an environment where the system understands a drill text and solves the problem in communication with a teacher. We represent the context by the sequence of a discrete state(S). Paying attention to the state transition, the components of S are divided into V and C. V changes according to dialogue-based problem solving process, and C is the unchanged component. V consists of utterance information(UT), attentional state(F), and set of command frames(CM). UT keeps such information as speaker, hearer, surface and case structure, communicative intention (e.g. information request and presenting, confirmation request, agreement and disagreement presenting, or correction request), relationship between current utterance and pairing utterance, and correspondence of language with things. On the other hand, C are case frame of problem sentence, picture descriptive form, picture model, text model, and hierachy of concept.

4. Dialogue Control in Problem Solving Process

The problem solving process consists of following three steps: First is extracting command candidates from the case structure of the problem sentence. From them, the system generates the instance command frames, and executes the procedure for command parameter extraction. The second step is planning of command construction and execution. Based on the priority and status of extracted commands, the system selects one command frame to be executed next, and passes the control right to its attached procedure. The initial state of the context is set at the time. The third step is executing the attached procedure.

The fundamental algorithm of the procedure can be summarized as follows:

[1] If the value of the source slot is "dialogue" or "inference", generate utterance in order to confirm the validity of the command generation.

[2] Do the following substeps to find values of the parameter slots.

- [2.1] If the value facet is empty but inferable, find the value using inference procedure, and generate utterance to confirm the validity of the inference.
- [2.2] If the value facet is empty and the type one is executable, find the value using command execution. Set the same value to the common parameter slots of other commands.

[2.3] If the value facet is unconditionally empty, generate utterance for information request.
[2.4] If the value facet has a value, but it does not satisfy the constraint, generate utterance for information request.

[3] If the command has allocation command, generate the instance frame, and execute the procedure for prameter extraction.
[4] Execute the command.

4.1 Generation of Utterance

The algorithm of generating utterance based on contextual information can be summarized as follows:

[1] Set parameters for utterance (i.e. communicative intention, request item, and current command name).
[2] Do the following substeps to generate the case structure of utterance.

[2.1] Extract a case frame from the case-frame slot of the command concerned and case elements from the print-name facet of the parameter slots.
[2.2] Substitute an appropriate interrogative for the unknown case element based on the request item and the role of parameter.
[2.3] Decide the mood of utterance based on the communicative intention.

[3]Do the following substeps to generate the surface sentence from the case structure.

[3.1] Decide the ending marker (e.g. "(no)desuka" or "(no)desune") based on the mood and the sentence pattern.
[3.2] Perform such rhetorical operations as anaphora, ellipsis, and thematization. For example, if a case element is the same as the focul one, then if the predicate is the same as that of the immediately preceding utterance, then eliminate the case element, else make it a theme, attach the syntactic case marker "wa", and move it to the head of of the sentence. When a new object or event is not introduced in that utterance, regard the previous utterance as the immediately preceding one.
[3.3] Perform ordering of elements according to the sentence pattern.

[4] Set the contextual information of the current utterance.
[5] Output the sentence.

4.2 Interpretation of Response

The algorithm of interpreting a response sentence from the teacher based on contextual information can be summarized as follows: [1] Read a response sentence. [2] Perform parsing and semantic analysis, and generate the case structure which represents the meaning of the sentence independent of the context. [3] Do the following substeps to interpret the above case structure. [3.1] Recognize the communicative intention of the response. For example, if the context component UT contains system's utterance which has the intention "information request", and has no pairing utterance, the sentence pattern of the response is noun or case element type, and the mood is affirmative, make the intention "information presenting". [3.2] Perform analysis of ellipsis. The final case structure of the utterance is constructed by replacing the corresponding subconstituent in the structure of the previous utterance with the substructure given in the elliptical utterance. [3.3] Find the picture descriptive form corresponding to object expressions in the response. [3.4] Set the attentional state which consists of the current command and the focul element. [3.5] If a new command candidate can be extracted from the case structure, generate the instance command frame and activate the procedure for command parameter extraction.

4.3 Implementation

The subsystem for dialogue processing was implemented on SPARK station. The command frames, dictionary, attached procedures, and modules for generating and interpreting utterance were written in PROLOG. A part of a dialogue between the system(S) and a teacher(T) in solving the problem of Figure 1-(b) is as follows:

S: nanto onazi kazudesuka. (What is the same number?)
T: hidariueno wakuno nakano chouno kazudesu
(Number of butterflies in the frame at the upper-left.)
S: korewo kazoerunodesune. (May I count them?)
T: soudesu. (Yes.)
S: koreto onazi kazuno kaadowo erabunodesune.
(May I select the card with the same number of them?)
T: soudesu. (Yes.)
S: dokokara erabunodesuka. (Where may I select it?)
T: sitani aru 4-tsuno zukei karadesu. (From 4 pictures below.)
S: sakihodono chouto kono kaadowo sende musubunodesune.
(May I link this card and the butterfly with a line?)
T: soudesu. (Yes.)
S: dokoto dokowo musubunodesuka. (What part of them may I link?)
T: chouno sitani aru kuroi tento kaadono ueni aru kuroi tendesu.
(Black dot below the butterfly and black dot above the card.)

5. Conclusion

We have presented a method of generating utterance from the system and interpreting utterance from a teacher in dialogue-based problem solving of an elementary mathematical drill text. A great number of methods or systems for dialogue understanding, recognition of communicative intention, cooperative answering, and dialogue control have been proposed. Their tasks are mainly information retrieval, question answering, and consultation. Many of them try to understand user's question, recognize his/her intention, and generate cooperative response. Our system takes the initiative in having a dialogue with a teacher. It has been designed with emphasis on the issue in what situation of problem solving process the system should utter, what sentence it should utter, and how it should interpret the response using contextual information. We believe that our case study has thrown light on the linkage of problem solving process with natural language expressins in dialogue.

Future studies will be undertaken in the following items: (1) integration of drill text understanding and dialogue-based problem solving, (2) multimodal communication with simultanious coodinated pointing gestures and drawing, and (3) knowledge acquisition from dialogue.

Keywords: dialogue-based problem solving, text understanding, elementary mathematics, contextual processing, communicative intention, natural language generation