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Dialogue Model Based on Data Transfer

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Abstract

In this paper, we propose a dialogue model based on data transfer. We deal with the dialogues having a goal of knowledge acquisition of a designated fact, such as hotel reservation and route guide.

In this model, a dialogue is regarded as a sequence of inner states representing agents' beliefs, and a new modal operator *need-to-know* is introduced to describe the timing of utterances. For example, when an agent is conveyed some specific fact, she believes that she needs to know another related fact. Then, the belief (called *a seed*) invokes the next utterance. We show that this mechanism is simple enough to implement.

Moreover, interactive belief revision can be handled in this model. If each data is represented as a proposition, we cannot express inconsistency between a pair of data. Thus, we use a data type *feature*, which is the pair of a label and a value. If two features have the same label and different values, then they are inconsistent. We show that the processes of confirmation and correction to achieve the mutual belief can be treated in a unified manner.

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1 Introduction

In the research areas of dialogue processing or discourse understanding, various models for giving semantics to dialogues have been proposed so far. Among such models, the goal-oriented dialogues are mainly investigated in the field of computer science and artificial intelligence [All95][CL90a][CL91] [GS90][Per90]. In these models, a goal is regarded as what is achieved by the sequence of actions, and each utterance corresponds to such an action.

On the other hand, when we look into the corpus of travel dialogues of ATR, we can find many dialogues whose goal is the knowledge acquirement of designated fact rather than the achievement of several actions. This corpus is a collection of spoken dialogues on topics such as hotel reservations and route guides. In such types of dialogues, it is more natural and appropriate to regard an utterance as a transmission of data such as date, roomtype, landmark and so on, rather than as an action to achieve a goal.

In this paper, we propose a dialogue model based on data transferred via utterances. A dialogue is regarded as a sequence of inner states representing the agents' beliefs, which are revised according as a dialogue proceeds.

In classical models based on inner aspects such as knowledge, belief, intention and so on [CL90b][Per90][RG91], the process of generating an utterance is explained in a detailed manner. Therefore, it is almost impossible to implement the process, although those models are effective on giving the reasons for the utterance by analyzing a given dialogue.

Our purpose is to present a model that is implementable as a human-computer dialogue system with a spoken language interface.

For this purpose, we use the following two notions to describe inner states.

First, we introduce the notion *seed* to show the invocation of the next utterance. It is represented using a new modal operator *need-to-know*. For example, for a hotel reservation, utterances on payment or arrival time do not occur until the guest expresses her decision to make a reservation on a specific condition. The seed is used to show the timing of an utterance on a specific topic. Once a fact is believed, then the belief is kept unless it is explicitly negated. On the other hand, the seed is a temporary element that appears when a specific fact is known, and that disappears when the corresponding utterance occurs.

Another notion to be introduced is *a feature*, which is a well-known concept in describing grammar of natural language [Ait86]. In most dialogue models proposed so far, only beliefs on propositions are treated. However, we can find many confirmations (including "yes" or "uh-huh") and several corrections caused by mishearing in the corpus of spoken dialogues. In order to treat such phenomena, we need a more expressive language.

Consider the following utterances.

```
A: The guest's name is Ann.
B: The guest's name is Bob.
C: The date is January 10.
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The pair of A and B is a contradiction, while any other pair is not. However, if we use propositions to formally represent these utterances, we cannot express the contradiction in a simple manner. The feature is a pair of *a feature label* and *a feature value*. If two features have the same label and different values, then they are inconsistent. In this example, the data are denoted by $\langle name, Ann\rangle$, $\langle name, Bob\rangle$, $\langle date, Jan10\rangle$, respectively. Moreover, the belief over a partner's belief is only obtained by communication via utterances in a distributed environment. Thus, we sometime revise not only one's own belief but also the partner's belief, Therefore, it is essential to deal with confirmation and correction. The feature can provide an intelligent treatment of confirmation and correction process.

This paper is organized as follows. After explaining basic concepts in Section 2, we present the framework in Section 3. In Section 4, we show the mechanism of dialogue processing in this model. In Section 5, we discuss mutual belief and belief revision. In Section 6, we show some logical properties of this model and also show related works. And finally, we show the conclusion in Section 7.

2 Preliminaries

We assume that the dialogue is undertaken between the agents α and β.

2.1 Modal Operators

K and B are well-known modal operators that represent knowledge and belief [FH88]. We use B, the operator of belief, since an agent's belief is not always true [1]. In addition, we introduce a new modal operator N to represent the causes of an utterance. $B_\alpha\varphi$ indicates that an agent α believes φ, and $N_\alpha\varphi$ indicates α *need-to know* φ. B satisfies KD45 logic [Che80]. N is non-contradictory, since an agent does not need to know both of φ and $\neg\varphi$. N is not introspective, since an agent does not need to know what she needs to know nor what she does not need to know. It follows that, N satisfies KD logic.

2.2 Feature

Definition (feature)

The form of $\langle P, V\rangle$ is called *a feature*, where P is *a feature label* and V is *a feature value*.

A feature label is a constant and a feature value is either a variable or a constant. If two features have the same label and different values, then they are inconsistent.

Hereafter, we refer to the feature $\langle P, V\rangle$ by its label P and call V as "the value of P." We use the complete form $B_\alpha\langle P, c\rangle$ to show the feature only when it is necessary.

$\neg\langle P, c\rangle$ denotes that the value of P is not c. $B_\alpha P$ believes the value of P, and $N_\alpha P$ denote that α needs to know the value of P.

[1]Sometimes it is defined in the form: $K_\alpha\varphi \equiv B_\alpha\varphi \wedge \varphi$.

3 Framework

3.1 Description Language

fact

A fact is represented in the form of a feature or its negation.

belief

A belief is represented as either of $B_\alpha\varphi$ or $B_\alpha B_\beta\varphi$, where α, β are agents (probably $\alpha = \beta$), and φ is a fact.

seed

A seed is represented in the form of $B_\alpha N_\beta\varphi$, where α, β are agents (probably $\alpha = \beta$), and φ is a fact.

It shows that α believes that β needs to know φ.

(inner) state

An inner state is a set of beliefs and seeds.

utterance description

Each utterance is described either as *request* or *inform*.

- $request(\alpha, \beta, P)$

  α requests from β the value of P, where P is a fact.

- $inform(\alpha, \beta, P)$

  α informs β of the value of P, where P is a fact.

3.2 Utterance Generation Rule

An utterance generation rule indicates the putting of seeds for the next utterance when the inner state satisfies some condition. It is represented in the following form:

$$B_\alpha\varphi_1 \wedge \ldots \wedge B_\alpha\varphi_k \wedge \neg B_\alpha\varphi_{k+1} \wedge \ldots \wedge \neg B_\alpha\varphi_n \rightarrow B_\alpha N_\beta Q_1 \wedge \ldots \wedge B_\alpha N_\beta Q_m$$

where $\varphi_1, \ldots, \varphi_n$ and $Q_1, \ldots, Q_m$ are facts.

This formula shows that when α believes $\varphi_1, \ldots, \varphi_k$, and does not believe $\varphi_{k+1}, \ldots, \varphi_n$, then she believes that β needs to know $Q_1 \ldots, Q_m$. If $\alpha = \beta$, then $B_\alpha N_\beta Q_1, \ldots, B_\alpha N_\beta Q_m$ are the seeds for *request*, and if $\alpha \neq \beta$, then they are the seeds for *inform*. Each rule is applied only once during a dialogue.

Each agent has the common domain-dependent knowledge in addition to the general axioms and inference rules. The utterance generation rules can be derived from the domain-dependent knowledge.

Domain-dependent knowledge $\mathcal{D}$ is represented as a set of logical relations in the following form:

$$P_1 \wedge \ldots \wedge P_n \rightarrow Q$$

where $P_1, \ldots, P_n, Q$ are facts. All the facts appeared in $\mathcal{D}$ are partially ordered. That is, for a pair of facts P and Q, the relation

$$P < Q$$

holds. This means that the request for Q is not performed until P is believed.

Derivation Rule 1 If $P < Q$, two rules are derived.

$$\begin{cases} \neg B_\alpha P \rightarrow B_\alpha N_\alpha P \\ B_\alpha P \wedge \neg B_\alpha Q \rightarrow B_\alpha N_\alpha Q \end{cases}$$

Derivation Rule 2 If both of $P < R$ and $Q < R$ hold, the following rules are derived.

$$\begin{cases} \neg B_\alpha P \rightarrow B_\alpha N_\alpha P \\ \neg B_\alpha Q \rightarrow B_\alpha N_\alpha Q \\ B_\alpha P \wedge B_\alpha Q \wedge \neg B_\alpha R \rightarrow B_\alpha N_\alpha R \end{cases}$$

Derivation Rule 3 If both of $P < Q$ and $P < R$ hold, the following rules are derived.

$$\begin{cases} \neg B_\alpha P \rightarrow B_\alpha N_\alpha P \\ B_\alpha P \wedge \neg B_\alpha Q \rightarrow B_\alpha N_\alpha Q \\ B_\alpha P \wedge \neg B_\alpha R \rightarrow B_\alpha N_\alpha R \end{cases}$$

These derivation rules can easily be extended for the case of more than three pairs of facts.

4 Mechanism of Dialogue Processing

When an utterance is made, it affects the current inner state's transit to the new state, and then seeding is performed in the new state to invoke the next utterance.

4.1 State

Each agent has her inner state that changes according as a dialogue proceeds. Assume that the state transits from S_{i-1} to S_i by an utterance $u_i (i = 1, \ldots, n)$. Then, the whole dialogue corresponds to the finite sequence of the inner states as follows.

$$S_0 \stackrel{u_1}{\Rightarrow} S_1 \stackrel{u_2}{\Rightarrow} \ldots \stackrel{u_n}{\Rightarrow} S_n.$$

the initial state

The dialogue starts from the state with all of the beliefs of α and β:

$S_0 = \{B_\alpha P_1, \ldots, B_\alpha P_n,\ B_\beta Q_1, \ldots, B_\beta Q_m\}$

where $P_1, \ldots, P_n, Q_1, \ldots, Q_m$ are facts.

consistency

For any set of beliefs $\psi_1, \ldots, \psi_n$ in a state S, if $\psi_1 \wedge \ldots \wedge \psi_n \rightarrow false$ does not hold, then S is said to be *consistent.*

mutual belief

For a fact P, if all of $B_\alpha\langle P, C\rangle$, $B_\beta\langle P, C\rangle$, $B_\alpha B_\beta\langle P, C\rangle$, $B_\beta B_\alpha\langle P, C\rangle$ are included in some state, then $\langle P, C\rangle$ is called a *mutual belief* between α and β.

success of dialogue

Let S be a state. If S satisfies the following conditions, then we say that the dialogue *succeeds.*

1. S is consistent.
2. There exist $\psi_1, \ldots, \psi_n \in S$ such that $\psi_1 \wedge \ldots \wedge \psi_n \rightarrow B_\alpha P$ where $B_\alpha P$ corresponds to the goal.

4.2 State Transition

When an agent receives an utterance as an input in the state S_{i-1}, the state transits to S_i according to the following procedures.

request

If $B_\alpha N_\alpha P \in S_{i-1}$ and $B_\alpha P \notin S_{i-1}$, then *request*$(\alpha, \beta, P)$ occurs. As a result, $S_i = (S_{i-1} - \{B_\alpha N_\alpha P\}) \cup \{B_\beta N_\alpha P\}$ holds. This means that if α believes that she needs to know P and she does not know it, she requests from β the value of P. As a result, β has become to believe that α needs to know P.

inform

If $B_\alpha N_\beta P, B_\alpha P \in S_{i-1}$, then $inform$ occurs. Let S be a set $(S_{i-1} - \{B_\alpha N_\beta P\}) \cup \{B_\beta B_\alpha P\} \cup \{B_\beta P\}$.

1. If S is consistent, $S_i = S$. This means that if α believes that β needs to know the value of P and α knows the value, then α informs β of the value. As a result, β has come to believe the fact that α believes it as well as the value itself.

2. If S is not consistent, let P_1 and P_2 be the abbreviated forms for $\langle P, C_1 \rangle$ and $\langle P, C_2 \rangle$, respectively, where $C_1 \neq C_2$. Assume that P_2 is the fact just informed, whereas P_1 is an older one.

   (a) If $B_\alpha P_2$ is a stronger belief than $B_\alpha P_1$, then $S_i = S_{i-1} - \{B_\alpha P_1\} - \{B_\alpha B_\beta P_1\}$. That is, her own database is corrected. Note that if either $B_\alpha P_1$ or $B_\alpha B_\beta P_1$ does not exist, then ignore it.

   (b) If $B_\alpha P_1$ is a stronger belief than $B_\alpha P_2$, then $S_i = S_{i-1} - \{B_\alpha P_2\} - \{B_\alpha B_\beta P_1\}$. That is, she rejects the new data to believe, although she changes her belief on her partner's belief. Note that if either $B_\alpha P_2$ or $B_\alpha B_\beta P_1$ does not exist, then ignore it.

4.3 Seeding

In the new state, seeding is performed to invoke the next utterance.

Let the utterance generation rule be:

$B_\alpha \varphi_1 \wedge \ldots \wedge B_\alpha \varphi_k \wedge \neg B_\alpha \varphi_{k+1} \wedge \ldots \wedge \neg B_\alpha \varphi_n \rightarrow B_\alpha N_\beta Q_1 \wedge \ldots \wedge B_\alpha N_\beta Q_m$

where $\varphi_1, \ldots, \varphi_n$ and $Q_1, \ldots, Q_m$ are the facts.

Then, seeding based on this rule is applied as follows.

If $B_\alpha \varphi_1, \ldots, B_\alpha \varphi_k \in S_i$ and $B_\alpha \varphi_{k+1}, \ldots, B_\alpha \varphi_n \notin S_i$, then add $B_\alpha N_\beta Q_1, \ldots, B_\alpha N_\beta Q_m$ to S_i.

example 1 a simple dialogue

```
g: Yes, that's fine, thank you.
c: Thank you very much.
   May I have your name, please?
g: Yes, my name is Amy Harris.
```

This is a part of the dialogue about a hotel reservation, where g,c stand for a guest and a hotel clerk, respectively. At this point, the guest gets enough information and finds that the room satisfies her condition. The first utterance shows her decision to make the reservation. It is represented as $inform(g, c, dec)$. The corresponding utterance generation rule is shown below:

$$B_c(dec) \rightarrow B_c N_c(name) \wedge B_c N_c(paym) \wedge B_c N_c(arriv).$$

This denotes that when the hotel clerk knows the guest's decision to make the reservation, then he believes that he needs to know the guest's name, the method of payment and the arrival time. The rule causes the seed to invoke the second utterance $request(c, g, name)$. Then, the second utterance causes the seed for the third utterance represented as $inform(g, c, name)$. For the other seeds of $paym$ and $arriv$, the corresponding utterances will occur in the future.

5 Mutual Belief and Belief Revision

5.1 Confirmation

Confirmation is regarded as a process of repeating the obtained information. This means that when an agent knows a fact, then she believes that the partner needs to know the fact. Therefore, when $inform(\beta, a, P)$ is followed immediately after $inform(\alpha, \beta, P)$, it corresponds to confirmation of the fact P.

The utterance generation rule for confirmation is represented as:

$$B_\beta P \rightharpoonup B_\beta N_\alpha P.$$

Assume that the first informed fact may not be correctly conveyed, but all of the other utterances in the confirmation and correction procedures are correctly conveyed.

Figure 1 shows the state transition for confirmation. The left side shows α's inner state. The big circle shows α's own belief and the small one shows α's belief of β's belief. The dotted circle shows the seed. They are similar to the right side showing β's inner state. In the figure, P_1 and P_2 are the facts that have the same feature name and different feature values. In addition, we sometime say that an agent believes P_1, instead of saying the value of P_1.

In state S_1, α believes P_1, and she believes that β needs to believe it, then she informs β of P_1. As a result, since no contradiction is found, new information is put to β's inner state. However, P_1 may be incorrectly conveyed, so we add P_2 as the belief of β. Then, the seed $B_\beta N_\alpha P_2$ is invoked by an utterance generation rule (state S_2), and β informs α of P_2 as a confirmation. If P_1 is equivalent to P_2, then the state transits to S_3, in which P_1 is a mutual belief.

5.2 Correction

The utterance generation rule for correction is represented in the following form:

$B_\alpha P_1 \wedge B_\alpha B_\beta P_2 \rightharpoonup B_\alpha N_\beta \neg P_2 \wedge B_\alpha N_\beta P_1$

where P_1 and P_2 are the facts that have the same feature name and different feature values, and α, β are distinct agents.

The rule for correction is selected with the highest priority if there are several utterance generation rules that can be applied.

If P_1 is not equivalent to P_2 in the state S_2 in Figure 1, then α rejects accepting P_2 as her own belief, since $B_\alpha P_1$ is a stronger belief than $B_\alpha P_2$. Then, the utterance generation rule for correction is applied to invoke the seeds $B_\alpha N_\beta \neg P_2$ and $B_\alpha N_\beta P_1$. This means that α believes that β needs to know $\neg P_2$ and the correct value P_1 (state S_3'). So she informs $\neg P_2$. Then, β revises his belief, since $B_\beta \neg P_2$ is a stonger belief than $B_\beta P_2$ (state S_4). α also informs P_1. Since no contradiction occurs, it is accepted as β's belief. Then, the utterance generation rule for confirmation is applied to invoke the seeds $B_\beta N_\alpha P_1$ (state S_5).

After α's belief is revised again, the state finally transits to S_6 where the mutual belief of P_1 between α and β can be obtained. Note that the beliefs of $\neg P_2$ are redundant but do not contradict the main mutual belief.

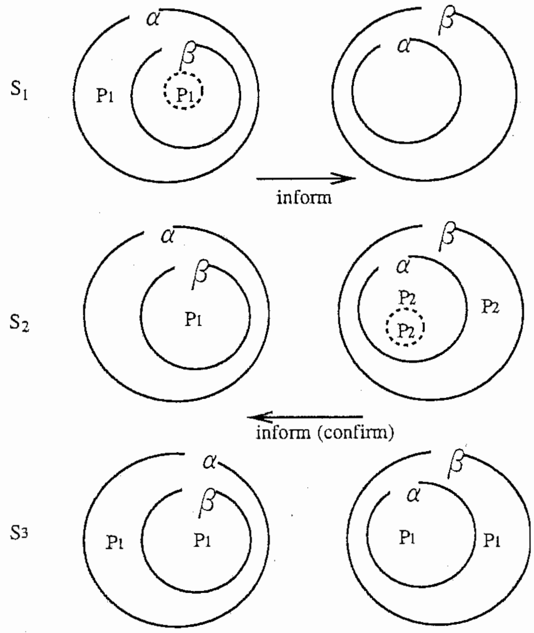

Figure 1: State transition for confirmation

example 2 mutual belief

```
g: Telephone number is 213,443,1700.
c: All right, your telephone number there
   is 213,443,1700.
```

Assume that P_1 denotes the feature $\langle tel, 2134431700\rangle$. Then, the state transition S_1, S_2, S_3 in Figure 1 occurs, and finally P_1 becomes the mutual belief.

example 3 mishearing and correction

```
g: Telephone number is 213,443,1700.
c: All right, your telephone number there
   is 714,443,1700.
g: No, the telephone number is 213,443,1700.
c: 213,443,1700. I'm terribly sorry.
```

Assume that P_1 and P_2 denote the features $\langle tel, 2134431700\rangle$ and $\langle tel, 7144431700\rangle$, respectively. Then, the state transition S_1 to S_6 via S_3' in Figure 1 and Figure 2 occurs, and finally, P_1 becomes a mutual belief.

6 Discussions

6.1 Logical Properties

We show several properties on the proposed model. Each of them can easily be proved.

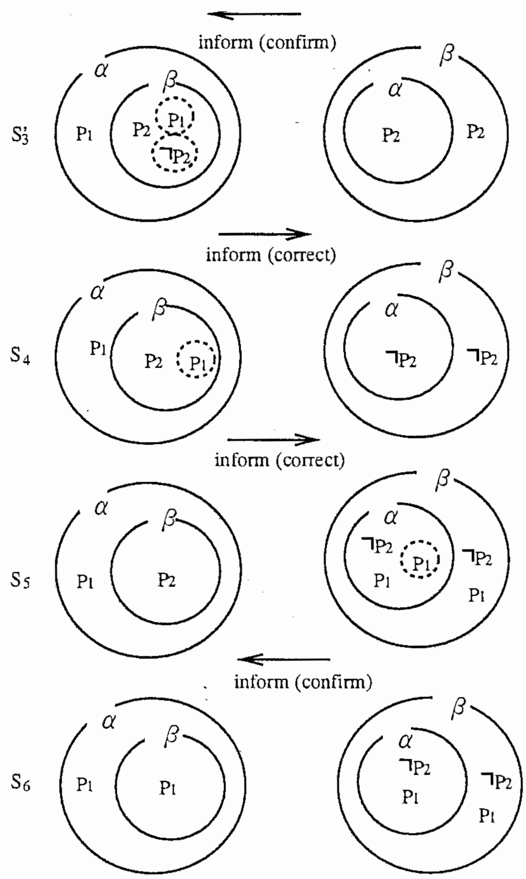

Figure 2: State transition for correction

Proposition1.

Assume that mishearing never occurs. Let S_i be an inner state. For any fact P, if $B_\alpha N_\alpha P \in S_i$, then $\exists j \geq i$ *s.t.* $B_\alpha P \in S_j$.

Proof)

1. $B_\alpha P \in S_i$
   Trivial.

2. $B_\alpha P \notin S_i$
   $request(\alpha, \beta, P)$ occurs, and as a result, $B_\beta B_\alpha P \in S_{i+1}$ holds. On the other hand, since $B_\alpha P \in S_{i+1}$ holds by the persistency of the belief, $inform(\beta, \alpha, P)$ occurs. As a result, $B_\alpha P \in S_{i+1}$ holds.

This proposition indicates that if an agent believes that she needs to know some fact, then she will become to know the fact.

Proposition2.

Assume that mishearing never occurs. Let S_i be an inner state. For any fact P, if $B_\alpha P \notin S_i$, then $\exists j \geq i$ *s.t.* $B_\alpha N_\alpha P \in S_j$.

Proof)

Let G be the utterance generation rule that has $B_\alpha N_\alpha P$ on the right-hand-side. The left-hand-side comprises $\neg B_\alpha N_\alpha P$.

1. G is in the form: $\neg B_\alpha N_\alpha P \rightarrow B_\alpha N_\alpha P$.
   It is trivial that $B_\alpha N_\alpha P \in S_i$ holds.

2. G is in the form: $\neg B_\alpha N_\alpha P \wedge B_\alpha Q \rightarrow B_\alpha N_\alpha P$.
   (For a simple explanation, we assume that the left-hand-side comprises only two terms without losing generality.)

   If $B_\alpha Q \in S_i$, then $B_\alpha N_\alpha P \in S_i$. Otherwise, $B_\alpha N_\alpha Q \in S_i$ hold, since $\neg B_\alpha Q \rightarrow B_\alpha N_\alpha Q$ should exist. Therefore, $\exists j \geq i$ *s.t.* $B_\alpha P \in S_j$ holds by Proposition1. Thus, $B_\alpha N_\alpha P \in S_j$.

This proposition indicates that if an agent does not know some fact, then she will become to believe that she needs to know the fact.

Proposition3.

Dialogue succeeds in the finite number of utterances on the assumption that mishearing never occurs.

Proof)

It is trivial by Proposition1 and Proposition2.

For the state transition algorithm, the following property holds, which is easily be proved.

Proposition4.

(1) When new information $B_\alpha \langle P, C \rangle$ is given at a state S, then $S \cup B_\alpha \langle P, C \rangle$ is consistent if $B_\alpha \langle P, C' \rangle$ is not included in S where $C \neq C'$.

(2) When new information $B_\alpha B_\beta \langle P, C \rangle$ is given at a state S, then $S \cup B_\alpha \langle P, C \rangle$ is consistent if $B_\alpha B_\beta \langle P, C' \rangle$ is not included in S where $C \neq C'$.

6.2 Related Works

Sadek et al. proposed the formalization using first-order modal language and applied the theory to the dialogue system with spoken dialogue interface [SBP97]. This work is valuable in the sense that an application to the real-world problem is demonstrated, however, the function of the system is a simple information retrieval in which the theory seems not to be fully used.

There are many studies on handling the inner state of agents [RG91][SC94][WJ94]. In most of these studies, new information comes synchronously as an observed fact between the agents, while an agent can only get new information by hearing from the partner in our model. In addition, they did not discuss the correction of the other's belief.

In the studies on belief revision [AGM85][GM88], belief revision of one's own database mostly has been discussed, but active revision of a partner's database has not been discussed. In this paper, we show the procedure for interactive belief revision and show the final achievement of the mutual belief.

Although one may argue that mutual proof should be defined as the infinitely nested form of α's belief on β and β's belief on α, this is too complicated to be implemented and the nesting of two-layers is adequate for our purpose.

After the utterance of informing some fact, it is not clear whether the agent who states the fact becomes to believe that her addressee believes the fact. The agent becomes to believe it in some models [Per90], and in others [Mey94], it does not. In our model, it does not, because of the possibility of mishearing.

7 Conclusion

We have presented a dialogue model based on data transfer and discussed the belief revision procedure in this model.

In the model, a dialogue is regarded as a sequence of inner states representing the agents' beliefs, which are revised as a dialogue proceeds.

We have introduced the following two notions to describe inner states.

1. *seed*
   This is a temporal element in the inner state and it is described using a new modal operator *need-to-know*. Thus, we can deal with a topic change and give a simple mechanism for invoking an utterance on specific contents of information.

2. *feature*
   This is a data type of the pair of a certain name and the value. Thus, we can intelligently deal with the process of confirmation and correction process.

We have also shown that the correction procedure of the partner's belief as well as the agent's own belief as a result of mishearing.

These characteristics can make some of the most essential mechanisms possible for constructing a dialogue system with a spoken language interface.

In this paper, although we only dealt with a simple belief revision resulting from mishearing, in the future we will consider verifying significant case of belief revision caused by a lie or anticipation in this model.

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