Estimating a User Model with the Action Sequences in the Mind Reading Game between a Human and a Life-like Agent

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Abstract

This paper proposes an adaptive interaction between a human and a life-like agent. We present the method to estimate the partner's context with the nth order MDP model. In this framework, an agent plays a mind reading game with a user in which the agent estimates the user's current mind state by the previous game context.

I. Introduction

This paper describes an agent that identifies human's model in Human Agent Interaction (HAI, for short). In many cases, partner's model identification among their interaction is not one-way. Especially it is two-way interaction with a human or a learning agent that has learning ability. We call this problem as Human Agent Mutual Adaptation (HAMA, for short) in HAI. HAMA is the situation in that a human user (a user, for short) adapts an agent both consciously and subconsciously in the process of the agent adapts to personalize the user, then both adapt mutually. It is ideal in HAMA that the adaptation of them is cooperative and adequate. However, there are problems in previous methods that inadequate adaptation of an agent affects a user's adaptation to cause a cognitive load for the user.

To solve this, we proposed the HAMA task of a mind reading game between a user and an agent. In that, we proposed a framework that they learn each mind mapping that represents a set of mapping from an expression to a mind in parallel [2]. Then we made the learning experiments and discussed the conditions without interference in both learning [1]. We found that the learning ability of the agent is limited and weak contrast to the learning ability of a user is flexible, it is supposed that this causes one of the bottleneck to realize an ideal mutual adaptation. One of the limitations of the learning ability of the agent is that the agent learns only a mind mapping. The agent has the fixed mind transition rules, and it can not learn the regularity of the mind transitions of a user during the iterated game.

Therefore, the objective of this paper is to improve adaptation ability of the agent in the iterated mind reading game between a user and the agent. This paper presents online identification of the model for mind transition rules of a user to improve the guess accuracy of the game with the model. In this research, in the process of the iterated guesses of the user's mind by the agent, the agent identifies the regularity of the user's mind transitions using the mind transition sequence.

The position of this research to our previous one [1] is to improve the adaptation ability and it's accuracy through interactions by combining the model identification for mind transition rules in this paper with the leaning of mind mapping.

II. Identification of a user modeling in a mind reading game

A. Modeling for human agent interaction

In this section, we describe a common model for both a user and an agent on HAI. First, we assume that they have internal states and transition rules of them. An internal state is called *a mind*, and a rule that transits the mind according to the situation (will be described at Section II.c) is called *a mind transition rule*. Though a mind is not directly observable, an observable state that depends on a mind is called an *expression*. A mapping from a mind to an expression is called mind *mapping* [2].

Second, in this research, assumptions of the model for partner's identification are as following;

- Both set of minds and set of expressions are finite and known.
- Mind mappings for each user are fixed and individual.
- Mind transition rules for each user are individual.

Note that *individual* means the property that it is different for each user or agent, and is assumed to be known of itself, and is unknown of partner's. In this paper, the objective is to identify mind transition rules, and both an expression and a mind mapping are not treated.

B. Iterated mind reading game

First, a mind reading game is described. *The mind reading game* is a game in which when two players share a situation, one guesses the partner's mind before the partner tells his correct mind. Then the partner transits his mind according to the result of the game. Fig.1 shows a procedure of the game. *An iterated mind reading game* is some fixed number of iteration of the procedure shown in Fig.1.

In this paper, it is assumed that a situation depends on the sequence of the guess results in this game. There are two cases on a relation of the two players of the mind reading game to identify other's mind transition rules. One case is cooperative, another is competitive. This paper assumes the cooperative case.

step1 a mind transition: B transitshis mind according to a previous situation.
step2 guess: A estimates B's current mind, then tell it to B.
step3 judge and teach: B returns Yes or No as the judge of A's guess to A, then teaches B's correct mind to A.

Fig. 1. A procedure of a mind reading game

C. Mind transition rules of the mind reading game

This section describes mind transition rules used in the mind reading game. Fig.2 shows three kinds of minds used in this paper and symbols corresponding to them. *A mind transition rule* is a rule which consists of a sensed situation as input and a transited mind as output. *A situation* for an iterated mind reading game is a sequence of guess results of the game. *A guess result* is a combination of a right mind before transition and the mind of the partner's guess. A guess result for t times before is represented as r_t.

Fig.3 shows an example of a simple mind transition rule of the mind reading game. Fig.3(a) shows a rule which represents a transition to *Pleased* mind according to the guess r_1 that corresponds to previous mind of $Normal$. Fig.3(b) shows a rule which represents a transition to *Confused* mind according to the guess r_1 in that *Pleased* dose not correspond to previous mind of $Normal$. Note that *simple* means that a situation depends on not a sequence of guess results but only previous guess result (i.e. t = 1).

Next, an example of not simple mind transition rule is shown in Fig.3(c). In this case, the situation is the sequence of guess results r_2 and r_1. This example expresses a rule that has the input of the sequence of guess results. After two times before guess of $Normal$ mind is right and it transited to *Pleased* mind, the *Pleased* mind is also the right guess, and the output of transited *Pleased* mind.

$$C : Confused, N : Normal, P : Pleased$$

Fig. 2. The relation between a symbol and a mind we used

$$\begin{array}{ll} r_1(N,N) \to P & (a) \\ r_2(N,P) \to C & (b) \\ r_2(N,N),\ r_1(P,P) \to P & (c) \end{array}$$

Fig. 3. An example of mind transition rules in the mind reading game

D. Representation of the mind transition rules by nth MDP model

This section describes the modeling of mind transition rules by nth Markov decision processes (MDP, for short) model. First, MDP model is the model which has Markov property and which represents probabilistic state transition. It can be represented a probabilistic state transition graph which consists of a state as a node and an action as an arc.

Markov property (exactly, uniform simple discrete Markov processes) is the property in that any state transition occurs at discrete time, any state transition probability is constant (uniformly in time) and it is able to decide only previous state transition. If the transition probability of current state and action pair is known, next state can be estimated. Nth Markov property is that any state transition probability depends on only state transition sequence from current state to n times before one. The case n = 1 is called *simple*. Nth MDP model is translated into simple MDP model if a state transition sequence from current state to n times before one is included into a state description.

Now the modeling of a simple mind transition rule by a simple MDP model is described. A simple mind transition rules is modeled by a simple MDP model that consists of a state as a mind of itself and an action as a partner's guess. Fig.4 shows an example of modeling of Fig.3(a). Note that N is $Normal$, and P is $Pleased$.

Next, the modeling of non-simple mind transition rule is described. In that, the input situation is a sequence of guess results. In the model, each state is segmented by a *context*, which is a sequence of mind transitions from current to n times before to avoid a partially observable state. Note that in this paper, a mind of a partner's guess is not included to the context. The reason is to reduce the cost for the model and it's identification instead of the accuracy of them. This makes the identification of a state transition from probabilistic by a partially observation to almost deterministic.

Fig.5 shows an example. Fig.5 is a set of mind transition rules. Note that * is a don't care symbol. Fig.6 show the model representation of the state transitions for Fig.5. When previous guess result is $r_1(P,P)$, the state is segmented into three states as PP, NP and CP by including two times before guess result r_2 as context. The transition that branches into N and P probabilistically becomes different deterministic state transitions.

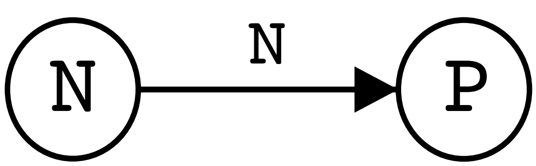

Fig. 4. modeling a simple mind transition rule

E. identification of mind transition rules by nth MDP model

The identification of mind transition rules for a partner by nth MDP model is described. The objective of the identification is to guess the partner's a mind correctly. The goal of the model identification is to model the accurate and deterministic mind transition rules for a partner.

$$r_2(P,*), r_1(P,P) \rightarrow N$$
$$r_2(N,*), r_1(P,P) \rightarrow P$$
$$r_2(C,*), r_1(P,P) \rightarrow P$$

Fig. 5. a set of mind transition rules

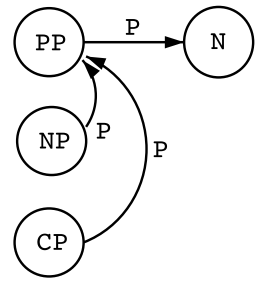

Fig. 6. the model representation of the state transitions for figure 5

First, the identification of a simple mind transition rule is described. The objective of partner's model identification is to perform maximum likelihood estimation of transition probabilities for all state transitions. In statistical science, it is known that a maximum likelihood estimation probability is equivalent to the probability calculated by the frequencies. So, in a transition $rule(i,a)$ from state i and action a, the transition probability $P(i,a,j)$ to state j is estimated incrementally by the equation (1) as follows;

$$P(i,a,j) = N(i,a,j) / N(i,a) \qquad (1)$$

Note that $N(i,a)$ is the frequencies of execution of the $rule(i,a)$, $N(i,a,j)$ is the frequencies of the transition to state j after executing the $rule(i,a)$.

Next, the identification of non-simple mind transition rule is described. Main problem is to decide a minimum length of the context. It is desirable to estimate an adequate length of the context during the model identification. As a heuristic method, all contexts (i.e. the complete sequence of guess results) of the game is stored, and each state has context length n as a parameter (initial value is n = 1, simple). If there is a state with a rule in which the state transition probability is not deterministic, the context length n is increased until each state transition probability becomes deterministic. This method is called *variable length context*. Contrast to it, the method in that a context length is fixed is called *fixed length context*.

III. Experiment

A. The Experimental task

Using the iterated mind reading game between a user and the agent in Chapter II as a task, two experiments to perform model identification of a user's mind transition rules when the agent guesses three kinds of user's minds are described.

In the experiment 1, the guess strategy of the agent is fixed to random during the user's model identification. The objective is to evaluate the degree of the consistency of the mind transition model of a user by comparing the first half of the identified model with the latter half of one.

In the experiment 2, the guess strategy of the agent is changed in the experiment. In the first half of it, the guess strategy is fixed to random to perform the model identification of a user. In the latter half of it, the guess strategy is changed to estimate a user's mind using the identified mind transition model in the first half if it. The objective is to evaluate the accuracy of the online model identification by the rate of right guess of the mind reading game.

B. The experimental method

First, the common conditions of two experiments are described. There are five subjects consists of four students and a teacher of our laboratory. Available minds of each user in the experiments are three kinds described as Fig.2 in Section II.C. The number of iterations of the game is 30, the first half of it is fifteen and the latter half of it is fifteen. Then the expected number of the games per mind is five in each half. The model for identification is the MDP model with context described in Section II.D and II.E. Next, the guess strategies of the agent used in the experiments are described. Note that in all strategies, the model is updated incrementally by the method in Section II.E by using the guess result.

random strategy: It always tells a random mind in any situation. It is the simplest action selection strategy as an exploration strategy for model identification.

model estimation strategy: It tells a mind that has the largest transition probability according to the faced situation by referring the identified model. Note that if the state is not explored yet, the random strategy is used.

Measured items are the identification result of mind transition rules for a user, and the number of right guesses of the mind reading game in each first half and latter half of the experiment. Next, set up conditions of each experiment are described.

B.1 the experiment 1: the evaluation of the consistency of mind transition rules for a user

The objective of the experiment is to evaluate the consistency of mind transition rules that a user used. Two kinds of identified models for the user with the first half of guess results and the latter half of them are compared.

- The guess strategy of the agent is the random strategy.
- The context length of the model is two and the fixed length context is used.
- The instruction to subjects is following; "Please select and input a nearest mind you feel. "

B.2 the experiment 2: the guess with online model identification

The objective of the experiment is to evaluate the improvement of the rate of right guess of the latter half of the mind reading game. In the latter half, the estimation of the guess is performed with the user's model identified in the first half of it. Additionally, questionnaires on the impressions for each subject according to the guess strategy change are performed.

- The guess strategies of the agent are in that the first half is the random strategy, and the latter half is the model estimate strategy.
- The context length of the model is variable length context in which the initial length is one.
- The instruction to subjects is following; "Please select and input a nearest mind you feel. Please cooperate with the agent that can guess your mind accurately."

C. The experimental results

C.1 The experiment 1: evaluating consistency of mind transition rules of a user

Fig.7 shows the comparison of the first half and the latter half of identification result of mind transition rules of three subjects within five. Note that each displayed state transition is only the transition that has the largest branching probability. First, mind transition rules are *individual* since each mind transition rules of three is different. Second, the mind transition rules used and explored in the game is partial against the whole model. The main reason is that the number of samplings of the experiment is about half of the number of rules in the whole model. It is only fifteen in each first half and latter half. Contrast to it, the number of state transition rules is 3x3x3 = 27 under three minds and the context length is two. Used mind transition rules of the subject is not the same between the first half of the experiment and the latter half of it. In time axis, it is partial. Third, the consistency of the mind transition rules of each user between the first half of the experiment and the latter half of it is described.

As the result of three subjects in Fig.7, there is no rule in that the state transition with maximum transition probability is different. It is supposed that mind transition rules of a user is consistent in the experiment 1. Note that almost mind transition rules are deterministic, so the small number of probabilistic rules reflects the unstableness of the regularity of a user.

C.2 The experiment 2: evaluating the accuracy of the guess of the agent with online model identification of a user

Fig.8 shows the number of right guesses of five subjects. It is the comparison between the first half the experiment and the latter half of it. In four subjects within five, the number of right guesses is increased in the latter half of the experiment.

The expected rate of right guess is 1/3 under the random strategy with three minds. It is nearly equal to the averaged rate of right guesses 5.6/15 in the first half of the experiment. Contrast to it, the averaged rate of right guesses 10.8/15 in the latter half of the experiment is much greater. Therefore, in the case of this cooperative task, it is possible to improve the accuracy the latter half of the task with online model identification. Next, results of the questionnaires of subjects after the experiment 2 are summarized. One subject C answered that intentionally he input the mind with regularity. Two subjects B and D answered that in the first half of the experiment, since the agent did not see the user's intention, the low rate of right guess much annoyed the user. Additionally, D answered that in the latter half of the experiment, he was able to cooperate with the agent since the reaction of the partner could be expected. These impressions of the subjects correspond to the interpretation of the experimental results as shown in Fig.8.

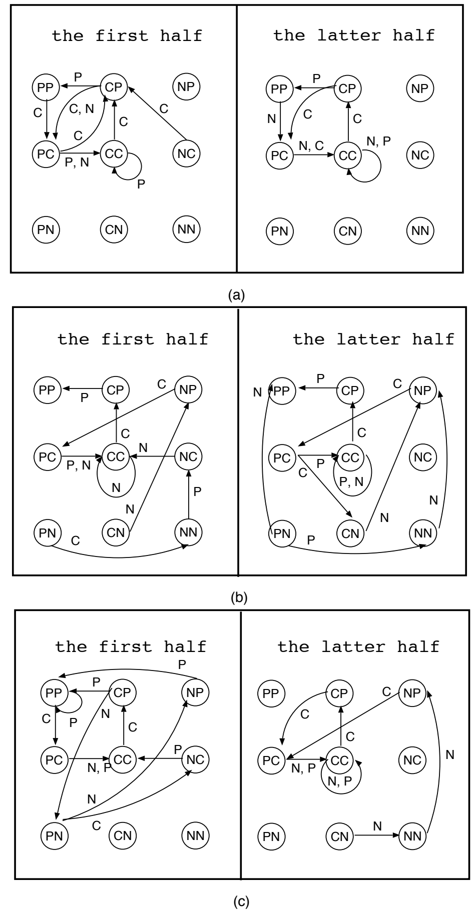

Fig. 7. modeling a simple mind transition rule

IV. Conclusions

This paper presented the online identification of the model for mind transition rules of a user using the mind transition sequence and its usage in the iterated mind reading game between a user and the agent. From the result of the experiment 1, the properties of the mind transition rules of a user used in the game are consistent, individual, almost deterministic and partial. From the result of the experiment 2, using online identification model, it is supposed that the guess accuracy can be improved without a disturbance to a user.

Future work is to introduce an adequate exploration strategy for the model identification. Then we have a plan to improve the adaptation ability and it's ac-

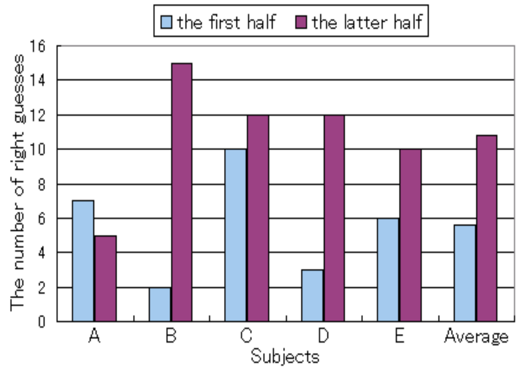

Fig. 8. The experimental result2: Comparison between the first half of the number of right guesses and the latter half of that by each subject

curacy through interactions by combining the model identification for mind transition rules in this paper with the leaning of mind mapping.

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