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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 36(36)

ISSN
1069-7977

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Publication Date
2014

Peer reviewed

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Abstract

In an interactive decision-making process like a face-to-face consultation (a situation in which subjective information can be obtained), we dynamically change the emphasizing points during the interaction in which an adviser provided new information and subjective interpretations. In previous work, we proposed and evaluated a method to dynamically estimate emphasizing points (DEEP) but the method only included the intrinsic emphasizing points of each person. In this study, we investigated the effect of extrinsic subjective interpretations of the adviser in interactive decision-making. We used tightly controlled Embodied Conversational Agents (ECAs) as the adviser to evaluate the effect. We conducted an experiment that compared the results of interactive decision-making with two types of ECAs: a facilitative agent who provided subjective opinions to realize divergent and convergent processes in decision-making and an estimation agent who only provided proposals that reflected the emphasizing points of each participant. As a result, we can confirm that the facilitative agent increased the participant's satisfaction of interaction with the ECA, the naturalness of ECA's interaction, and the impression of decision-making process. In addition, we developed a concept called the "Bubbling intention." We think the concept is useful to design human-agent interaction.

Keywords: verbal and nonverbal behavior; human-agent interaction; decision-making support.

Introduction

We seldom make important decisions without information from outside sources. Nowadays we can readily obtain information from the internet and various publications. On the other hand, subjectively interpreted information is still important in decision-making. In this case, the information is obtained from friends, experts, and other trusted sources. One of the reasons why we place significance on it is that it helps us to interpret those factors that we consider and emphasize to reach an appropriate decision. There are many factors which influence decision-making. We implicitly focus on some of the factors and make a decision based on the focused factors. We call these factors "emphasizing points."

In an interactive decision-making process like a face-to-face consultation (a situation in which subjective information can be obtained), we dynamically change the emphasizing points during the interaction as a consequence of facing new information and subjective interpretation. We also change our interpretations of these points and the relationships between them. For example, in travel planning, we have to consider factors such as place, a hotel, budgets, members, schedule and what to do in the travel. We often make such plans interactively with friends and travel agency staff. In this case, the subjective information given by these parties includes a reasonable emphasizing points from a different perspective.

In previous studies (Ohmoto, Kataoka, Miyake, & Nishida, 2011; Ohmoto, Miyake, & Nishida, 2012; Ohmoto, Kataoka, & Nishida, 2013), to support interactive decision-making, we proposed a method to dynamically estimate emphasizing points (DEEP) based on verbal reactions, body movements, and physiological indices. To evaluate the method, participants interacted with Embodied Conversational Agents (ECAs), which implemented DEEP and a comparative method. Using ECAs, we could strictly control the verbal and nonverbal expressions of the agent, which could affect the participants' decision-making. In those studies, we found that the dynamic estimation of emphasizing points was helpful for the participants in the decision-making process. The estimated emphasizing points reflected in the proposals helped to the decision-making in the given task because the emphasizing points were important intrinsic factors for their appropriate decision-making. In other words, the DEEP supported their decision-making by being aware of the intrinsic emphasizing points. On the other hand, subjective information is also helpful when people must considered many factors for the decision-making. The subjective interpretations of the emphasizing points are extrinsic and they provide different perspectives to interpret the factors we have to consider and emphasize to reach an appropriate decision. The extrinsic subjective interpretations can support decision-making.

One of the methods to conduct smooth and effective

decision-making using subjective opinions is "facilitation." The facilitator mediates between participants during the communication process (Reagan-Cirincione, 1994). The facilitator can support the social and cognitive processes, allowing participants to focus their attention on the more substantive issues in the decision-making process (Schuman, 1996) and ultimately reach the most appropriate solution (Khalifa, Kwok, & Davison, 2002). For the facilitation, the facilitator subjectively interprets participants' emphasizing points based on the most important arguments of each participant and then controls the communication process.

A conversation is divided into some "zones" depending on the contents. The facilitation process includes a divergent zone, convergent zone and others (Kaner, 2007). We have previously analyzed facilitation processes and facilitating behavior, and have identified that the process changes from divergent discussion to convergent discussion (Ohmoto, Toda, Ueda, & Nishida, 2010). Especially in the convergent zone, the facilitator subjectively summarizes the discussers' opinions and limits the direction of the discussion. We assume that we can effectively support interactive decision-making based on extrinsic subjective information by applying the facilitation process to interactive decision-making. For example, a counselor in interactive decision-making provides subjective opinions, such as "I think that's good," to move into the convergent zone of the decision-making interaction.

The purpose of this study is to investigate how the interaction process during the transition from divergent to convergent discussion, which includes providing extrinsic subjective information, affects the decision-making process and the impression of the process. To test this, we used ECAs because it is difficult for human agents to achieve rigorously controlled interactions with participants. Specifically, we conducted an experiment that compares the results of interactive decision-making with two types of ECAs: a facilitative agent that provided subjective opinions to implicitly reduce divergent opinions from different perspectives and to encourage convergent process in decision-making, and an estimation agent that only provided proposals that reflected the emphasizing points of each participant. Both of the ECAs implemented DEEP. This means that the facilitative agent supported the decision-making using intrinsic and extrinsic factors.

Overview of DEEP

In an earlier study (Ohmoto et al., 2011), we introduced the DEEP method, based on verbal reactions, body movements, and physiological indices from an interaction.

Estimation of Emphasizing Points

The degree of emphasis is rated on a scale from zero to five. The rating is changed based on the following three factors in interaction between human and a system with DEEP.

- **Verbal reactions**
  Either of the following two reactions occurs.
  - Listed words appear in answers or demands.
  - The participant provides backchanneling phrases, which express acknowledgement, surprise, or understanding, such as "ah," "oh," "aha," "I see," and "I understand."
- **Body movements**
  The participant repeatedly nods three times or more.
- **Physiological indices**
  Either of the following two responses occurs. (refer to (Lin, Omata, Hu, & Imamiya, 2005; Nakazono, Hada, Ataka, Tanaka, & Nagashima, 2008)).
  - Skin conductance response (SCR) increases more than 10% compared with resting levels.
  - Low-frequency/high-frequency (LF/HF) value (electrocardiograph measurement) is more than 6.0.

Verbal reactions, body movements, and physiological indices, are used as criteria for determining when a new factor is discovered and should be emphasized, and for determining when a user's degree of emphasis of a particular factor increases or decreases.

Rules for changing estimated emphasizing points during interaction A DEEP system explains the proposals and the estimated emphasizing points change depending on the participant's responses.

- **Discovery of a new factor to be emphasized**
  Verbal reactions, body movements, and physiological indices are the criteria for determining when a new factor is discovered and should be emphasized. When any one of the three criteria appears during interaction, the system decides that the factor should be slightly emphasized, and increases the degree of emphasis from zero to two. When any two or all three criteria are present, the system increases the emphasis from zero to three.
- **Increasing or decreasing degree of emphasis**
  Verbal reactions, body movements, and physiological indices are used as criteria for determining when a user's degree of emphasis of a particular factor increases or decreases. When any one of the three criteria appears, the system decides that the factor should be emphasized, and increases the emphasis of the factor by one.

  When there are physiological reactions, but no verbal reactions and body movements, the system decides that the factor should be emphasized less, and decreases the emphasis of the factor by one.

Rules for changing estimated emphasizing points from active demands The system asks whether or not a user has any demands. From the user's response, the system determines what the user's demands are and what changes there are to the emphasizing points. The system accepts keywords which are expected words in advance to express emphasizing points, demands, and basic words necessary to capture demands in the user's responses. Words that are not expected to be included in answers are ignored.

- **Discovery of new factors to be emphasized**
  When the emphasis degree of the discovered factor is zero, the system increases the degree of emphasis from zero to three.

- **Increasing or decreasing degree of emphasis**
  When the emphasis of the discovered factor is greater than zero and the system decides that the factor should be increased, the system increases the degree by one. When the system decides that the emphasis of the factor should be decreased and the degree is greater than zero, the system decreases the degree by one.

Selecting the next step based on DEEP results

According to the criteria mentioned above, changes to a user's emphasizing points are estimated after the proposals are given and data are collected from the user's reactions and responses. After the estimation, the next two proposals are selected based on the estimation results.

The next proposals are selected using a table of orthogonal arrays prepared in advance. Orthogonal arrays are a special set of Latin squares, which can be used to estimate main effects using only a few experimental runs. From the table, the proposal that most satisfies the user's emphasizing points is selected. When many proposals in the table can satisfy a user's emphasizing points, a proposal is selected according to predefined rules. For example, the system selects a nearest proposal in convergent process bacause the system knows which factor is important. The distances of the proposals are calculated by cosine similarity.

A Facilitative Decision-making Support Agent

We used MMDAgent (*MMD Agent*, n.d.) as the interface for a facilitative decision-making support agent. MMDAgent is a toolkit for building voice interaction systems, and includes Julius, Open J Talk, and a number of other systems. We developed a control system that received inputs from MMDAgent (recognized voice data) and Polimate (LF/HF data and SCR data) and sent outputs of motion and speech commands to MMDAgent. The inputs for the facilitative agent were automatically captured, with the exception of the data related to verbal meanings, such as whether a user's utterance was positive or negative and whether the user's utterance was a question, because we could not robustly determine them automatically in real-time. We call the agent control method using manual inputs as a WOZ (Wizard of Oz) method. The agent automatically generates verbal and nonverbal behavior that had been previously designed, with the exception of the answers to the questions.

Method to control divergent and convergent processes in an interaction

The facilitative agent supports the user's decision-making during the interaction. The agent uses social signals for active listening and teaming to control divergent and convergent processes in the interaction. The used signals are the frequency of providing a new proposal, recommendation from the agent, mimicry of nodding motions, and utterances.

- **The agent's behavior in the divergent process**
  The agent provides a small nod once in reaction to the user's utterance. The frequency of providing a new proposal is low. The agent provides a new proposal after she explains three emphasizing points. The furthest proposal from the previous one is selected as a new proposal. The degree of emphasis decreases if the emphasizing point is not explained in the previous proposal.

- **The agent's behavior in the convergent process**
  The agent provides two nods in reaction to the user's utterance. The frequency of providing a new proposal is high. The agent provides a new proposal after she explains one emphasizing point, which is a recommendation. The nearest proposal to the previous one is selected as a new proposal. The degree of emphasis decreases only when the emphasizing point is refused in the previous proposal.

- **The rules to switch between the divergent process and convergent process**
  The agent starts the interaction with a divergent process. The agent switches from the divergent process to a convergent process when she detects the following situations:
  - There are more than three emphasizing points, with a degree of emphasis of more than one, and the degree of emphasis does not change during the interaction.
  - The user offers a convergent opinion such as "I want to see like this one" and "I want to determine."

- **The emphasizing points of the agent**
  The agent has the same set of emphasizing points for the decision-making. The emphasizing points and the degree of emphasis are the subjective opinions of the agent. The emphasizing points are set to the values of the recent proposal at the time when the agent switches from the divergent process to the convergent process. This means that the agent searches the neighbor of the last proposal of the divergent process during the convergent process. The degree of emphasis decreases when the emphasizing point is clearly refused by the user.

Experiment

The purpose of this experiment was to investigate how the interaction process during the transition from divergent to convergent, which includes providing extrinsic subjective information, affects the final goal of the decision-making and impressions of the process. In the experiment, to strictly control the verbal and nonverbal expressions, we used two types of agents: a facilitative agent who provided subjective opinions to realize divergent and convergent processes in decision-making and an estimation agent who only provided proposals that reflected the emphasizing points of each participant. We

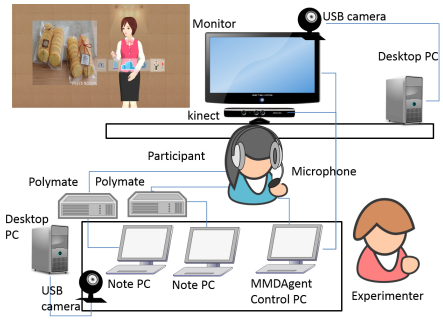

Figure 1: The experimental settings.

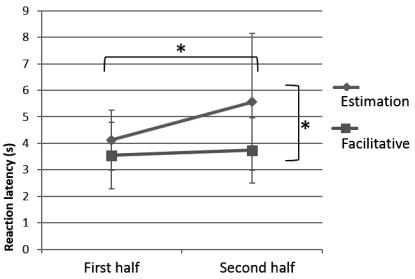

Figure 2: Means and the results of the t-test for reaction latency.

explained the facilitative agent in the previous section. The estimation agent is similar to the agent used in previous studies. The estimation agent is implemented DEEP method. The agent can dynamically estimate emphasizing points of a participant but it cannot control divergent and convergent process. Here, we analyze the reaction behavior of participants and questionnaire responses.

Task

Participants were asked to design gift-wrapping for a valentine present. The participants did not know what was appropriate gift-wrapping. The participants interacted with the agent to design the gift-wrapping. We identified 30 factors that the participants considered when they designed the wrapping. We expected that the emphasizing points would change during the interactions and the participants would take advice from the agent because they tried to predict what the receiver of the gift would like.

Experimental settings

The experimental setting is shown in Figure 1. The participant sat in front of a monitor displaying the ECA. The experimenter sat out of view of the participant and entered the stimuli via a WOZ interface. The kinect captured the nodding motion of the participant. Polymate was used to measure SCR and the electrocardiogram.

Participants

The participants in this experiment were 20 Japanese college students (all female). They did not know about gift-wrapping. The participants were divided into two groups: one interacted with the facilitative agent and the other with the estimation agent. The reason why the participants were females was that there was motivation gap for the gift-wrapping task between males and females.

Procedure

After a brief explanation of the experiment, the experimenter began the experiment, and the recording of the video and physiological indices. The participant repeatedly asked questions about the proposal and considered the proposals provided by the ECA until one of the proposals satisfied the participant. At the conclusion of the experiment, the participant completed a questionnaire regarding evaluations of the interaction process.

Results of participants' reaction analyses

Reaction latency To investigate whether participants attentively listening proposals by the ECA, we extracted a reaction latency for each participant. The reaction latency was defined as the time from the end of the utterance of the agent to the start of the participant's reaction. We expected that most of participants listened the proposals in the early part of the interaction but they became gradually less responsive to the ECA as they understood the task and proposals. Reaction latency data thus were divided into first half and second half in the middle of each experiment. We conducted a t-test to compare the data from the facilitative agent group with the data from the estimation agent group. The results are shown in Figure 2.

In the first half of the interaction, there is no significant difference between the reaction latency in both group. In contrast, there is a significant difference in the second half. In addition, there is a significant difference between the reaction latency in the estimation agent group in the first half and that in the second half.

We interpreted these results as follows. When the participant interacted with the estimation agent, she carefully thought about the proposal in the second half of the interaction. As the participant had already obtained a lot of information from the agent in the first half, she did not pay any further attention to the interaction with the agent. In contrast, when the participant interacted with the facilitative agent, she actively interacted with the agent in the second half. As the participant regarded the subjective opinions of the facilitative agent as helpful information, she continuously interacted throughout the whole interaction. Therefore, we can confirm that subjective information was helpful in interactive decision-making.

Changing emphasizing points To investigate whether the control of divergent and convergent processes influences participants' emphasizing points, the participants chose emphasizing points that they changed during the interaction at the

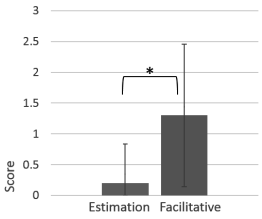

Figure 3: Means and the result of t-test of the number of the changed emphasizing points.

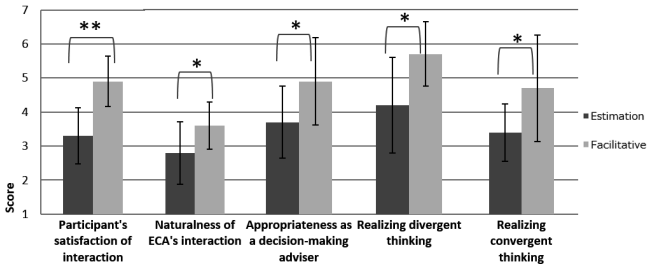

Figure 4: Means and the result of Wilcoxon signed-rank tests on the questionnaires.

end of the experiment. We then calculated the number of changed emphasizing points for each participant. We conducted a t-test to compare the number in the facilitative agent group with that in the estimation agent group. The results are shown in Figure 3.

The number in the facilitative agent group was significantly higher than that in the estimation agent group (t=-2.63, $p<0.05$). It seems that there were fewer changes in the facilitative agent group because the facilitative agent provided similar proposals in the second half of the interaction. We discuss this further below.

As the results of the reaction latency analysis have shown, the participants in the estimation agent group carefully considered the proposal in the second half of the interaction. It would seem that as they made their decision only based on intrinsic emphasizing points, they could not recognize changes to the emphasizing points. Similarly, the participants in the facilitative agent group did not recognize some changes because the total number of the changes reported by them was small. However, in the facilitative agent group, the agent provided extrinsic subjective opinions. Therefore, they could explicitly recognize some of the changes.

Questionnaire results

To investigate the impression of the decision-making process with ECAs, the participants answered three rating questions on the ECA's behavior using a seven-point scale. The scale was presented as seven ticks on a black line without numbers, which we scored from 1 to 7. And we conducted Wilcoxon signed-rank tests on each questionnaire result. The results are shown in Figure 4. We performed a Wilcoxon signed-rank test to each data of the questionnaire.

- **Participant's satisfaction of interaction with the ECA**
  Participants answered how satisfied they were with the interaction with the ECA. In this experiment, the "satisfaction" means that the participant felt pleasure in the intaraction with the ECA. As a result, the facilitative agent provided significantly more satisfactory interactions than the estimation agent ($z = 3.5$, $p < 0.001$).

- **Naturalness of ECA's interaction**
  Participants answered how natural the sequence of proposals was. As a result, the facilitative agent provided significantly more natural interactions than the estimation agent ($z = 2.3$, $p < 0.05$).

- **Appropriateness as a decision-making adviser**
  Participants answered how appropriate the ECA was as a decision-making adviser. As a result, the facilitative agent provided significantly more appropriate than the estimation agent ($z = 2.0$, $p < 0.05$).

- **Realizing divergent thinking and convergent thinking**
  Participants answered how useful the proposals by the agent were for divergent thinking and convergent thinking. Wilcoxon signed-rank tests shows that the facilitative agent was significantly more useful for divergent interactions and convergent interactions than the estimation agent (divergent: $z = 2.5$, $p < 0.05$; convergent: $z = 2.0$, $p < 0.05$).

The results show that the interaction process with the facilitative agent was better than that with the estimation agent. This suggests that the convergent interaction process, where subjective opinions are expressed, produces a better impression of the interaction process. Of particular interest is the result stating how useful the agent's proposals were for divergent thinking. This means that the convergent process contributed to divergent thinking. We consider that one of the reasons for this result is that the participants felt they finished searching the whole of the problem space by switching from the divergent process to the convergent process.

Discussion

In this study, we evaluated a facilitative agent who provided subjective opinions to realize divergent and convergent processes in decision-making, and found that this led to higher scores for participant satisfaction regarding ECA interactions, the naturalness of ECA's interaction, and impressions of the decision-making process. From the results of the reaction analyses and questionnaires, we confirmed that the participants who interacted with the facilitative agent recognized the divergent thinking process more explicitly than those who interacted with the estimation agent. From these results and those of our previous studies, we have developed the following concept on decision-making and intention. The decision

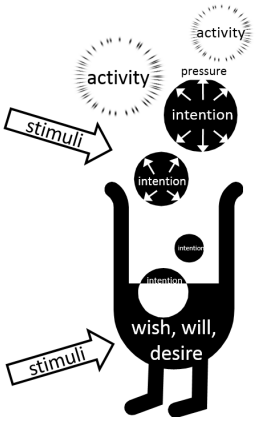

Figure 5: Bubbling intention.

or intention is extemporarily shaped, based on the underlying and ambiguous wish (which is one of the sources of the decision and intention) through the interaction. Figure 5 shows the concept. There are wishes, wills, and desires at the bottom of the human mind. When a stimulus is applied, then the decision or intention is produced as an ambiguous bubble. After the bubbling intention is produced, the bubble explodes as an activity because of an extrinsic stimulus (e.g., a partner's behavior or new information) and intrinsic pressure (e.g., reflection of one's own activity).

We can explain the results of this study from the perspective that the decision is extemporarily shaped by extrinsic stimulus and intrinsic pressure. For example, in the case of the results of the reaction analyses, the participants did not receive extrinsic stimulus, especially in the second half of the interaction when they interacted with the estimation agent. It took a long time to recognize their own emphasizing points and shape their decision; therefore, the reaction latency grew longer and they could not recognize the changes in the emphasizing points. Regarding the results of the questionnaires, the participants could clearly recognize the divergent thinking, which was intrinsic pressure, because switching from the divergent process to the convergent process was triggered by extrinsic stimuli provided by the facilitative agent.

From a different perspective, the concept means that we do not need to precisely estimate the inner states (e.g., emphasizing points, emotions, and intentions) of communication partners during natural communication. This can be used for the design of interaction artifacts like the facilitative agent.

Conclusion

In this study, we investigated the effect of the divergent and convergent interaction process in interactive decision-making. We used Embodied Conversational Agents (ECAs) to evaluate the effect because it is difficult for human agents to achieve tightly controlled interactions with participants. We conducted an experiment that compared the results of interactive decision-making with two types of ECAs: a facilitative agent who provided subjective opinions to realize divergent and convergent processes in decision-making and an estimation agent who only provided proposals that reflected the emphasizing points of each participant. The facilitative agent supported decision-making by intrinsic and extrinsic factors. As a result, we can confirm that the facilitative agent increased the participant's satisfaction with the ECA interaction, the naturalness of ECA's interaction, and the impression of decision-making process. In addition, we developed a concept called the "Bubbling intention." We think the concept is useful to design human-agent interaction so we will develop an ECA with the concept.

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