Development of Self-Cognition through Imitation Behavior

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Abstract
We conducted a simulation experiment focused on the development mechanism of self-consciousness using a neural network structured by consciousness modules that we had developed called Module of Nerves for Advanced Dynamics (MoNAD), and succeeded in presenting a system relevant to the development of self-cognition and self-consciousness. This system can suppress, through learning, “imitation behavior as a result of the cognition of another” in response to a “behavior of avoiding pain after feeling the pain by oneself,” and can “formulate” the cognition of oneself. These study results may be highly suggestive of the development of self-consciousness. In this paper, we describe the theoretical basis for the development of the self-cognition of our system, and discuss the experiment and observations.

Keywords: consciousness, Neural Network, MoNAD, self-cognition, Imitation Behavior

1 Introduction

We focused on the development process of self-consciousness. Since self-consciousness can be defined as the “ability to be aware of oneself,” we may assume that self-cognition, i.e., “cognition of oneself,” has a meaningful connection with self-consciousness. In addition, according to the above-mentioned past studies, it is likely that there is a close relationship between the “development of cognition of oneself” and “imitation behavior.” From all this, we set up a hypothesis that imitation behavior causes the “cognition of oneself” and self-consciousness to develop.

2 Structure of conscious system

Our study used consciousness modules called Module of Nerves for Advanced Dynamics (MoNAD) (Takeno, 2011). In our previous research, MoNADs were implemented to structure an advanced conscious system in which a “conscious robot is aware of itself” (Takiguchi and Takeno, 2012).
3 Conscious system of “imitation behavior” and “pain”

For the purpose of the present study, the conscious system was designed so that the three subsystems cooperate with each other as an independent conscience to perform a “reasonable” behavior. In this context, the Association Subsystem has to learn the coordination capability for both the Reason Subsystem and the Emotion & Feelings Subsystem. By “reasonable,” we mean that the total disadvantage (pain) is decreased in the system.

Figure 1 shows the conscious system developed in the present study. A circle indicates a MoNAD. This conscious system enables imitation behavior. Imitation behavior implies seeing a behavior performed by another and repeating that behavior by oneself. Also, in the present study, a limit on the amount of movement exists for the imitation behavior and pain is recognized when this limit is reached.

The system starts with the information from the input section (Fig. 1 (a)), the Reason Subsystem constantly requests the imitation behavior, and MoNAD module IB recognizes the object to be imitated and MoNAD module Ac outputs the imitation behavior (Fig. 1(e)). On the other hand, the Emotion & Feelings Subsystem functions to recognize pain. When pain is sensed, it outputs a behavior to avoid the pain (f). When recognition of the object to be imitated and the perception of pain occur simultaneously, the perception of pain is given priority. This behavior rule is created by simulating the biological reflex behavior by an innate rule against pain.

The Association Subsystem converts the “recognition of pain in the Emotion & Feelings Subsystem” (Fig. 1(h)) into a signal (Fig. 1(g)) to suppress the “imitation in the Reason Subsystem” (Fig. 1(e)). This process means to coordinate the Reason Subsystem and the Emotion & Feelings Subsystem.

In the beginning of the present study, however, MoNAD module As of the Association Subsystem randomly initializes the weight for the connection between neurons in the constituent neural network, thus hampering the proper conversion from the recognition of pain to the imitation behavior suppression.
signal. Therefore, if pain and the imitation object are recognized at the same time, a conflict arises between the two recognitions in the conscious system.

Because the recognition of pain is an “awareness of oneself” and the recognition of the imitation object is an “awareness of another,” this conflict can be regarded as a mixed condition of an “awareness of oneself” and an “awareness of another.” When the Association Subsystem coordinates this conflict condition and, as a result, the imitation behavior is suppressed, it can be said that the “awareness of oneself” gets preference over the “awareness of another,” and the “awareness of oneself” is more “formulated.” By “formulation,” we mean a clear distinction between the “awareness of oneself” and the “awareness of another.” Formulating one’s own recognition promotes the development of an “awareness of oneself.”

**Fig. 2  Structure of MoNAD “As” in the Association Subsystem**

The Association Subsystem As is sent a teacher signal to the cognitive representation section (Fig. 2 (e)) and the output section (Fig. 2 (f)) at intervals of 1 Ut to perform learning by back-propagation. Here, 1 Ut is one unit time, i.e., the time elapsed from the input until the output section and cognitive representation are determined by calculation processing. The rule of the teacher signal generation is as follows:

The teacher signal for cognitive representation (Fig. 2 (e)) is expressed as follows:

\[
t_{rec} = \begin{cases} 1.0, & \text{if} \ (rec_{Pa}[0] > Lm \ or \ rec_{Pa}[1] > Lm \ or \ ssu_{As} > Lm) \ and \ (Max(rec_{IB}) > Lm) \\ 0.4, & \text{else} \end{cases}
\]  

Where, the item \(B_M[k]\) indicates the cognitive representation section (Fig. 2 (e)) when \(B = rec\), the behavior representation section (Fig. 2 (c)) when \(B = beh\), and the somatic sensation section (Fig. 2 (d)) when \(B = ssu\). \(k\) is the value of \(k\)-th bit in the bit pattern defined by \(B_M\). \(M\) indicates any one of MoNAD As, Pa, and IB. For example, \(rec_{Pa}[0]\) indicates the value of the 0th bit in the cognitive representation (Fig. 2 (b)) in Pa.

The meaning of this equation is as follows: The teacher signal \(t_{rec}\) for the cognitive representation (Fig. 2 (e)) in As is set to 1.0 when the following conditions are satisfied: the information of the 0th bit of cognitive representation (Fig. 2 (b)) in Pa exceeds \(Lm\) (i.e., pain is perceived on the right side), OR
the information of the 1st bit of cognitive representation (Fig. 2 (b)) in Pa exceeds the value $Lm$ (i.e., pain is perceived on the left side), OR the somatic sensation value in As exceeds $Lm$ (i.e., suppression signal is sent from As to Ac before one unit time (1 Ut) has elapsed in the MoNAD), AND the maximum value of cognitive representation (Fig. 2 (a)) in IB exceeds $Lm$ (i.e., object to be imitated is provided). Otherwise, the signal is set to 0.4. In this experiment, we set 0.7 to $Lm$.

Also, the teacher signal for the output section (Fig. 2 (f)) in As is expressed as follows:

$$
tgt_{out} = \begin{cases} 1.0, & \text{if } (rec_{Pa}[0] > Lm \text{ or } rec_{Pa}[1] > Lm \text{ or } beh_{As} > Lm) \\ 0.4, & \text{else} \end{cases} \quad \cdots(2)$$

This equation means that the teacher signal $tgt_{out}$ for the output section (Fig. 2 (f)) in As is set to 1.0 when the information of the 0th bit of cognitive representation (Fig. 2 (b)) in Pa exceeds $Lm$ (i.e., pain is perceived on the right side), OR the information of the 1st bit of cognitive representation (Fig. 2 (b)) in Pa exceeds $Lm$ (i.e., pain is perceived on the left side), OR the behavior representation (Fig. 2 (c)) in As exceeds $Lm$ (i.e., imitation behavior of Ac is expected to be stopped). Otherwise, the teacher signal $tgt_{out}$ is set to 0.4.

4 Experiment

We mounted our developed conscious system on a quasi-robot on the simulator to conduct our experiment. As an assumption for this experiment, the quasi-robot, i.e., the subject of the conscious system, is forced to perform an imitation behavior only in the same direction.
We let the quasi-robot perform an imitation behavior triggered by sight and induce it to reach its movable limit (Fig. 3 (c1) or (c2)). When the movable limit is reached, pain is generated and the robot performs a reflective avoidance reaction (Fig. 1 (f)). In this instance, the pointers are fixed on the display (Fig. 3 (b1) or (b2)) to let the imitation behavior continue in the same direction. The pointer can specify the direction of the imitation behavior. As a result, the robot repeats the pain avoidance and imitation behavior. In this experiment, the imitation behavior moves to the right, and pain is generated on the right side when the robot detects the limit of its movement on the right side (Fig. 3 (c1)). Note that the robot is opposite to the object being imitated, and accordingly the left and right sides are reversed. Although the robot performs a reflective avoidance behavior and moves to the left (Fig. 1 (f)), the imitation behavior is performed to the right again because the pointer is always in the same direction (Fig. 3 (b1)) and pain is generated again on the right side of the robot.

In summary, as shown in the lower part of Fig. 3, the robot repeats the process of the imitation behavior (by moving to the right) “①” and of the immediate avoidance behavior in response to the generated pain (by moving to the left) “②”. In brief, the robot is in vibrational state. In this state, we observed the variation of the robot behavior and the change within the robot affected by the above-mentioned learning of the Association Subsystem.

5 Experimental Result

![Progress of Learning in As (750 to 880Ut)](image)

**Fig. 4 Progress of learning in As (750 to 880 Ut)**

Explanation of figure: ①in\textsubscript{As}[1]: state transition of pain to right side, ②out\textsubscript{As}[0]: output of imitation suppression signal, ③in\textsubscript{As}[2]: state transition of imitation object

The result of the experiment is as follows. Figure 4 is a diagram which shows the progress of learning in the Association Subsystem during the experiment. Figure 4 ①indicates the input from the state transition of pain on the right side (neuron unit in Fig. 2 (b)), and Fig. 4 ②indicates the output of the imitation suppression signal (Fig. 2 (f)), and Fig. 4 ③indicates the recognition of the imitation object (input from Fig. 2 (a)).
In this experiment, after 750 Ut, the cognitive representation of pain appears in the robot’s Emotion & Feelings Subsystem (i.e., the $\text{rec}_{\text{Pa}}[1]$ (Fig. 2 (b)) approaches 1.0), and the information is sent to the input section $\text{in}_{\text{As}}[1]$ in the Association Subsystem from Pa. At this moment, as stated earlier, the quasi-robot is in a state of repeated imitation behavior and pain (Fig. 3 (lower part)). The pain on the right side $\text{in}_{\text{As}}[1]$ indicates its state (Fig. 4 (1)).

As the pain and cognition are repeated, the system proceeds with the learning of As. Then the value of the control signal from As to AC $\text{out}_{\text{As}}[0]$ gradually increases (Fig. 4 (2)), $\text{out}_{\text{As}}[0]$ exceeds 0.8, and Ac controls the imitation behavior from IB (in the vicinity of 850 Ut).

After 850 Ut, the imitation output from Ac (Fig. 1 (e)) stops. Thereafter, although the imitation object is continuously recognized, the imitation behavior is always held in suspension. This is because it is anticipated that the imitation behavior in this state may cause the recognition of pain, according to the learning rule of equations (1) and (2).

At that moment, with regard to pain in the right direction $\text{in}_{\text{As}}[1]$, the repeated pain when moving to the right has already stopped due to the avoidance behavior output from Pa (Fig. 1 (f)). Therefore, it is possible to say that, after 850 Ut, as a result of the learning of As, the robot outputs the behavior by giving priority to “recognition of oneself through pain” rather than to the “recognition of another through imitation.”

6 Conclusion

In the experiment in the present study, the conscious system had to learn under the conflicting condition of the imitation of the Reason Subsystem (i.e., the projection of another to oneself) and the request of the Emotion & Feelings Subsystem to avoid pain. As a result, our conscious system prioritized the behavior related to its own pain sensed by the Emotion & Feelings Subsystem and suppressed the imitation behavior by means of the coordination with the Association Subsystem MoNAD. This means that the recognition of oneself became formulated. The formulation of self-cognition is relevant to the distinction between oneself and another, and plays an important role in the development of self-awareness.

In conclusion, our system using the MoNAD consciousness modules succeeded in learning the formulation of self-cognition while developing awareness by means of imitation, especially the imitation of others.

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