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Spontaneous Action Switch in Interaction between Robots with Prediction Error Minimization Mechanism

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This study demonstrates the emergent and spontaneous aspects of complex interactions between double cognitive agents by using the synthetic approach. Taking external causes meaning the uncertain environment into consideration, two small humanoid robots each of which is controlled by a hierarchically organized neural network model with prediction error minimization mechanism are able to switch among learned actions. The results show that the complex interactions between two agents can be accounted for by the simple computational principle of prediction error minimization.

1. Introduction

Interaction is a phenomenon existing in the society so that people are able to establish a relationship with others. Imagine that there are two children who continue playing by passing a ball to each other. During the interactive process, because of various internal causes (e.g. personal aim) and external causes (e.g. uncertain ball dynamics), forming interaction may be forcibly interrupted and then be shifted to deforming, and vise versa. The appearance of forming and deforming interaction occurs in an emergent and spontaneous way. This study speculates that the mechanism of prediction error minimization (PEM) is capable of realizing interaction whenever forming or deforming happens.

In the field of theoretical neurobiology, a Bayesian scheme called active inference succeeding in minimizing prediction error was able to simulate birdsong communication between synthetic songbirds [Friston and Frith, 2015]. In the context of robot learning, a robot equipped with a connectionist scheme could flexibly switch its ball handling actions based on the PEM [Noda et al., 2006]. In this scheme, a static vector called parametric bias (PB) was attached to a recurrent neural network (RNN) to represent a specific action pattern [Tani, 2003]. During action generation, the PB was dynamically determined by minimizing prediction error caused by uncertain ball dynamics.

In this study, we include double agents instead of one agent to achieve reciprocal interaction by using two small humanoid robots. Our speculation about the PEM is tested by taking irregular ball dynamics as the trigger to stimulate the shifting between forming and deforming interaction in a similar manner to the action switch in [Noda et al., 2006]. This study demonstrates the emergent and spontaneous aspects of bi-directional interaction through the PEM.

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2. Computational Model

This study utilizes a continuous time RNN (CTRNN) in which dynamics of context states are characterized by their time constant. In our CTRNN model, several context units are assigned as PB regarded as the specific case of context units whose time constant is infinite.

There were two phases for operating the computational model. In the action learning phase based on the PEM, the error between predicted and actual visuo-proprioceptive states was backward-propagated for optimizing network parameters. By means of gradient descent method, the parameters including the synaptic weight, bias, and PB were optimized in an off-line way. Each uniquely optimized PB was expected to represent a specific action pattern.

After the learning phase, two humanoid robots each of which was equipped with the trained CTRNN model were employed in the action generation phase. In accordance with the PEM mechanism, the determination of PB dynamics of double robots were mutually conducted in an online way by comparing the difference between predicted and actual visual states.

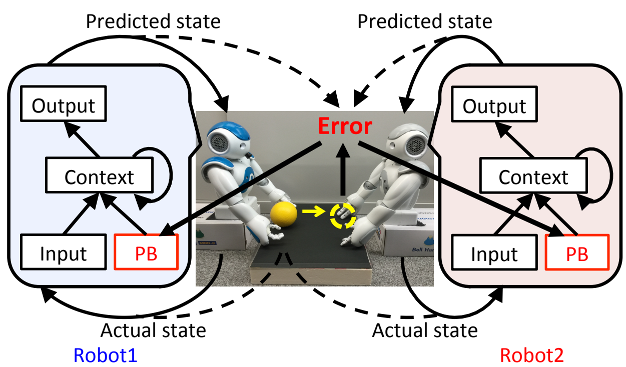

Figure 1: Structure of system. The solid-lines represent proprioception and the dot-lines represent vision.

3. Experimental Setup

To investigate the bi-directional interaction between cognitive agents, this study used two humanoid robots called NAO made by Aldebaran Robotics. Figure 1 illustrates the structure of system. Each robot was simultaneously controlled by the CTRNN model. In regard to dealing with forming and deforming interaction brought about by external cause, this study used a yellow ball as a manipulated object possessing the characteristic of uncertain dynamics which was the trigger of action switch. An experimenter directly taught four actions to a robot involving two pairs. One category was classified as the action that depended on the partner consisting of passing ball by right (R) and left (L) hand respectively. The other pair including self-playing ball (S) and attraction (A) could be self-existent so the simultaneity was low. While teaching process, the experimenter simultaneously recorded the time-series data of both joint angles (left and right four joints separately) as proprioception and ball position (x and y coordinate) as vision for the learning phase.

4. Results

Figure 2 shows the interactive results between the double robots which were respectively shown in blue and red line. Firstly, we could observe the coordinate phenomenon between the two agents while they were passing the ball to each other. This was regarded as the realization of forming interaction.

However, when the ball abruptly rolled to the unexpected position happening in approximate time step 760, the prediction error became greatly large and the interaction was deformed. To adapt to the unexpected situation, the dynamics of PB were optimized in the direction of minimizing the prediction error. Along with the change of external cause generated by the ball, the robots were able to spontaneously switch their actions by the optimized PB dynamics. Although we only show one possible case of action switches which is transition between left hand (L) and right hand (R) in Figure 2, the other cases also successfully switch to each other in the experiment.

After both the robots switch action by following the past learning experience, the prediction error was indeed minimized. The interaction was retrieved to well-organize and we were able to observe the correlation between the double robots again. From the results, we can know that the two robots mutually adapt each other and switch their actions which are relevant to unpredictable ball dynamics. Finally, the double agents were able to achieve bi-directional interaction thanks to the PEM mechanism.

5. Conclusion

The present study demonstrated the emergent and spontaneous aspects of interaction between the double agents by using two small humanoid robots. Through the PEM mechanism, the robots were able to switch their actions and adapted to the change of the ball. Currently this study

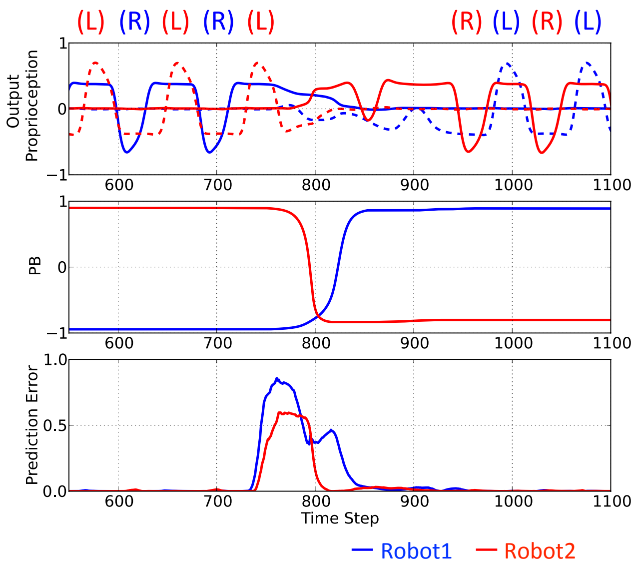

Figure 2: Interactive results between the double robots. The first panel extracts the results of proprioceptive output from eight dimension to two dimension. The solid-line represents elbowroll of right arm and the dot-line represents elbowroll of left arm. The second and third extract the information about one of two PB and that about one of two visual prediction error, respectively.

only includes the information of the ball position to deal with external cause generated by the manipulated object. Future work will take internal cause made by self-plan into account and increase the visual information of companion agent's movement to consider influence from partner.

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