An Interaction-Based Development of Human-Robot Joint Attention and Self/Other Cognition

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What makes us human? How do humans acquire cognitive abilities? Although these are fundamental questions many researchers have been addressing, no clear answers have been obtained yet. This talk presents our computational studies aiming to provide new understanding of human cognitive development by means of synthetic approaches. Two key issues we address are: (a) what inherent mechanisms enable robots as well as infants to learn and develop cognitive functions and (b) what environmental assists are necessary for their proper development.

Regarding (a), we suggest contingency learning as a core mechanism for cognitive development. Contingency P_i of the *i*-th event is defined as a conditional probability between the perceptual state S^i_t and the action A_t, i.e., $P_i = Pr(S^i_{t+1} \mid S^i_t, A_t)$, where t denotes time. For example, the visual state of our own body exhibits perfect contingency since it always produces the same state change in response to a certain motor command. In contrast, the body of other individuals produces lower contingency due to an influence of the context. Among various responses of others, however, social activities such as joint attention and language use produce relatively higher contingency than non-social behaviors, which becomes a clue for cognitive development. Regarding the issue (b), we suggest that caregivers' scaffolding plays an important role in facilitating infants' development. Caregivers are supposed to provide contingent reactions to infants so as to enable infants to learn to acquire social reactions. Relatively higher but imperfect contingency is important for infants to discriminate between self and others and to learn to achieve social interaction.

The above key idea has been verified in two case studies: First, a computational model for self/other cognition is presented. Our model makes a robot learn the sensorimotor coordination through experiences of body babbling with a caregiver. Our experiment demonstrates that spatiotemporal contingency in the sensorimotor coordination enables the robot to discriminate self from others. Our results further reveal that an improvement in the perceptual acuity of the robot leads to the emergence of mirror neuron system. Second, a neural network model for learning of joint attention is presented. Joint attention is a process to look at the same object that someone else is looking at. Our model enables a robot to learn to achieve joint attention by detecting higher contingency between the visual input (i.e., a face image of the partner) and the motor output (i.e., a motor command to shift the robot's gaze) even if no explicit reward is given to the robot. In both case studies, a caregiver plays an important role in providing social contingency to the robot.

The results are discussed in relation to recent findings about autistic spectrum disorders (ASD). It is suggested that ASD is characterized by a difficulty in learning sensorimotor contingency rather than in social interaction. Their hypersensitivity to prediction error prevents them from acquiring proper contingency for social interaction. The potential of our computational models to understand the mechanism of ASD is explained.