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Maturational Biases and Encapsulation in Spatial Development

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Introduction

Most system designers of complex artificial systems explicitly/implicitly use a design principle, in which higher-level functions are composed of encapsulated lower-level modules. Modularity is seen as a necessary feature of large-scale softwere design. However, in human cognitive development, it is unlikely that there exists an executive function, analogous to a systems analyst, at work in the modularization of cognitive function.

In this research, we address the question: *If higher-level cognitive functions are organized based on encapsulated lower-level modules, how are these modules created in the course of development?* Elman (1993) suggested that a developmental increase in working memory capacity promotes encapsulation, and improves learning.

We claim that *maturational biases* such as body growth also promotes encapsulation. To elaborate upon this hypothesis, we have been using autonomous robots as the subject of cognitive development, and constructing computer programs by which robots can behave analogously to infants (Hiraki,Sashima and Phillips 1997; Hiraki,Sashima and Phillips in press). The following summarizes the result of a simulation focusing on the relationship between spatial development and changes of degrees of freedom (DOF) with body growth.

Simulation with Developmental Robot

A Computational Model of Spatial Development

Psychological experiments on children's development of spatial knowledge suggest experience at self-locomotion with visual tracking as important factors. Yet, the mechanism underlying development is unknown. We have proposed a robot that learns to *mentally track* a target object (i.e., maintaining a representation of an object's position when outside the field-of-view) as a model for spatial development. Mental tracking is considered as prediction of an object's position given the previous environmental state and motor commands, and the current environment state resulting from movement. Following Jordan and Rumelhart's (1992) forward modeling architecture, the system consists of two components: an inverse model of sensory input to desired motor commands; and a forward model of motor commands to desired sensory input (goals).

Stepwise and Non-stepwise growth

In order to get a understanding of the relationship between body growth and spatial development, we compared the robot under stepwise and non-stepwise conditions. In the stepwise development condition, we simulated three stages of a child's development of motor skills with the robot by varying its permitted actions (DOF). In stage 1, the robot is only permitted head rotation. In stage 2, the robot can rotate both head and body. Finally, in stage 3, the robot is also permitted self-locomotion, whereas in stages 1 and 2, locomotion was performed by an external agent. In the non-stepwise condition, the robot commenses training at stage 3 (i.e., all actions permitted).

Result

In each condition, the robots were tested on the "three cups" paradigm (where children are required to select the cup containing the hidden object under various movement conditions). The result showed that there was a faster decrease in error under the stepwise condition than under the non-stepwise condition in stage 3 for both forward and inverse models. The simulation results suggested that gradual growth of body might help spatial development by limiting degrees of freedom that infants must control.

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