Computational Explorations of Cognitive Development

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Issues in Development

Many of the problems of children's cognitive development have been difficult and longstanding. Among these are issues of how children represent knowledge, whether stages exist, and how children achieve transitions between stages. Despite a century of scientific evidence on child development, comprehensive theoretical understanding of these issues has remained elusive. Part of the reason is that the problems of psychological development are too complex for traditional verbal theories of development. Nonetheless, it has become clear in recent years that considerable leverage on these problems can be gained by applying computational modeling, particularly using artificial neural networks. This is because computational modeling is a good way to capture complex processes, neural networks capture developmental phenomena in a natural way, and successful models can be examined in detail to discover insights into the phenomena that they simulate (Shultz, 2001).

Modeling with Constructive Networks

My colleagues and I use connectionist modeling to explore some of the key issues in psychological development. Much of our modeling is done with a constructive connectionist algorithm called cascade-correlation that allows networks to grow as they learn (Fahlman & Lebiere, 1990). Network construction is important because it is doubtful that evolution has prepared humans for all of the learning problems that they encounter. Growth by recruitment of hidden units is also consistent with contemporary evidence on neurogenesis and synaptogenesis in the service of learning.

Domains and Phenomena Covered

Cascade-correlation has been applied to a variety of developmental phenomena including the balance scale, conservation, seriation, personal pronouns, discrimination-shift learning, habituation of attention, concept acquisition, and concepts of velocity, time, and distance (Shultz, 2003). The simulations clarify a number of longstanding developmental issues such as knowledge representation, representation change, stage sequences, transition, the possibility of constructivism, the presence of perceptual effects in cognitive tasks, emergence of non-normative rules, and the trajectory of development.

Some Principal Findings

Neural networks possess a natural ability to simulate rules and exceptions, contradictory tendencies, and a variety of perceptual effects – a decided improvement over both classical verbal theories and rule-based models. Issues of knowledge representation cannot be isolated from issues of developmental transition – successful models must show how transitions connect successive stages. Contrary to what is commonly assumed, neural networks actually generalize more effectively than do rule learners when the rules and connection weights are learned from the same examples.

It is possible to reinterpret and integrate Piaget’s theory and a range of contemporary theories of developmental transitions within a constructive neural-network approach. Many verbally formulated transition mechanisms are inherent or emergent features of constructive networks and not independent causes of developmental transitions. Constructive networks offer a firm computational foundation for psychological constructivism and a clear distinction between development and learning. Constructivism is computationally coherent within networks that recruit new computational resources. Learning refers to quantitative change within a given cognitive structure, and development refers to qualitative change of a cognitive structure.

Developmental change, whether physical or psychological, consists of repeated series of spurts and plateaus which become more frequent with increasing density of observations. Particular orderings of psychological stages (identified initially by plateaus) can be traced to either general mechanisms involving growth in computational resources or domain-specific biases in the typical environments of specific developmental tasks. The mysterious notion of developmental precursors can be analyzed in terms of patterns of connection weights that are easy to train, and thus ready to learn, even if not currently performing at a high level.

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