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Post-Piagetian Constructivism for Grounded Knowledge Acquisition

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Piaget [1952] proposed a mechanism by which infants integrate experience into progressively higher-level representations, which he called "constructivism." According to constructivism, infants progress from simple to sophisticated models of the world by use of a "change mechanism" that allows the infant to build higher-level representations from lower-level ones. Constructivism is a powerful model of grounded knowledge acquisition that has been applied with considerable success [Drescher, 1991; Cohen, Atkin, Oates and Beal, 1997].

Constructivism, though, has long been criticized for its vagueness regarding the precise nature of the change mechanism. The lack of detail in this area has hampered the production of more powerful models of cognitive development, and has led some to suggest that the primitives of the infant's world model (such as solidity and causality) are innate [see Spelke, Brienlinger, Macomber & Jacobson, 1992]. However, recent studies of infant cognitive development [Cohen & Younger, 1984; Cohen & Amsel, 1998; Cohen, Amsel, Redford & Casasola, 1998] have provided strong evidence that these primitives are indeed acquired and, in doing so, they have shed light on the details of the change mechanism itself.

Cohen [1998] has integrated several of these studies to produce a set of principles that describe constructivist development using an information processing approach. Specifically, Cohen and Cashon [in press] postulate that infants organize stimuli into categories based on criteria such as frequency, invariance and co-occurrence. Moreover, infants then build higher-level representations by applying these criteria to lower-level representations. Given this work, it is now possible to implement a more accurate computational model of developmental cognition. In addition, these studies provide a body of empirical data against which developmental models can be tested.

The Constructivist Learning Architecture (CLA) is such a model. Based on the principles of constructivist learning described by Cohen and Cashon, CLA uses a hierarchy of Self-Organizing Maps (SOM) [Kohonen, 1997] to build representations of observed stimuli at progressively higher levels of abstraction. The SOM is already recognized as a useful tool for the development of categories. By connecting the SOMs hierarchically, higher-level representations can be built from the activation of lower-level representations. In this way, high-level representations can be built from raw stimuli, and all representations are ultimately defined in terms of the system's sensorimotor apparatus. The resulting representations are distributed, both laterally (within a layer) and hierarchically (across layers). Also, since all levels of processing are maintained throughout development, confusion at a higher level can be handled gracefully by falling back to a lower level. Finally, CLA's modular design makes it well suited for temporal and cross-modal knowledge acquisition. CLA has been used to replicate various studies from developmental cognition, like infants' acquisition of causality and word boundary detection. CLA has also been applied to autonomous robotic control by building a world model through interaction with the environment and using this world model to develop environment-appropriate behaviors and recover from sensor trauma.

Developmental cognition is a powerful model for grounded knowledge acquisition. The new discoveries coming out of developmental psychology are providing the details necessary to create a new generation of more accurate models of infant learning. Robots can use these models to generate the knowledge necessary for robust and sophisticated behavior. Indeed, the developmental approach can be employed in a wide variety of domains that would benefit from grounded representations, such as language and common sense reasoning. And by building models of developmental cognition, we can further understand the process of human learning itself.

Cohen, L. B. (1998). An information processing approach to infant perception and cognition. In *Development of Sensory, Motor, and Cognitive Capabilities in Early Infancy: From Sensation to Cognition*, G. Butterworth & F. Simion (Eds.) (pp. 277-300). East Sussex: Psychology Press.

Cohen, L. B & Amsel, G. (1998). Precursors to infants' perception of causality. *Infant Behavior & Development 21* (4), 713-732.

Cohen, L.B., Amsel, G., Redford, M. A., & Casasola, M. (1998). The development of infant causal perception. Chapter in *Perceptual Development: Visual, auditory and speech perception in infancy*, A. Slator (Ed.). London: UCL Press and Taylor and Francis.

Cohen, P. R., Atkin, M., Oates, T., & Beal, C. R. (1997). Neo: Learning conceptual knowledge by sensorimotor interaction with an environment. In *Proceedings of the First International Conference on Autonomous Agents*. 170-177.

Cohen, L. B. & Cashon, C. H. (in press). Infant object segregation implies information integration. *Journal of Experimental Child Psychology*.

Cohen, L. B. & Younger, B. A. (1984). Infant perception of angular relations. *Infant Behavior and Development, 7*, 37-47.

Drescher, G. L. (1991). *Made-Up Minds, a Constructivist Approach to Artificial Intelligence*. Cambridge: MIT Press.

Kohonen, T. (1997). *Self-Organizing Maps*. New York: Springer-Verlag.

Piaget, J. (1952). *The Origins of Intelligence in Children*. New York: International Universities Press. (Originally published 1936.)

Spelke, E. S., Brienlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*,Vol. 99, No. 4, 605-632.