Introduction to special issue: “The potential contribution of computational modeling to the study of cognitive development: When, and for what topics?”

By: Stuart Marcovitch, Philip David Zelazo

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Abstract:

As our understanding of cognitive development becomes more sophisticated, and scientists explore how processes operating at many levels of analysis (cultural, social, cognitive, neural, and molecular) work together to yield complex cognitive skills, the need for computational approaches to the study of cognitive development is increasingly apparent.

Keywords: cognitive development | computational modeling | cognitive psychology

Article:

As our understanding of cognitive development becomes more sophisticated, and scientists explore how processes operating at many levels of analysis (cultural, social, cognitive, neural, and molecular) work together to yield complex cognitive skills, the need for computational approaches to the study of cognitive development is increasingly apparent. In addition to providing a way to model complex dynamic systems, productive computational approaches to cognitive development require the precise specification of theoretical assumptions, encourage the identification of key variables, and focus attention on the mechanisms of developmental change (Shultz, 2003). As with any model, these approaches can drive empirical research by generating novel (and often unexpected) hypotheses. As observed by Schlesinger and Parisi (2001), computational models have already advanced our understanding of development in the domains of physical knowledge (Dehaene and Changeux, 1989 and Munakata, 1998), numerical knowledge (Shultz, 1998 and Simon, 1998), classes and categories (Mareschal and French, 2000 and Quinn and Johnson, 1997), language (e.g., Plunkett and Marchman, 1991 and Rumelhart and McClelland, 1987), and motor control (Thelen, Schöner, Scheier, & Smith, 2001).

Despite the increasingly widespread recognition that computational approaches are required to capture the complexity of cognitive development, computational models are still perceived to be inaccessible to researchers who are not versed in the methodology. Readers tend to get bogged down in mathematical details, causing them to miss the important contributions that models can make to understanding developmental processes. In fact, if one argues that an advantage of computational modeling is the formalization of assumptions and process, it is important to explain in psychological – and not necessarily mathematical – terms how these assumptions relate to developmental theory, and it is our contention that this responsibility lies with the modelers.

The present special issue is devoted to assessing when and for what aspects of cognitive development, computational approaches are likely to be useful. By situating various computational approaches in their historical and epistemological contexts while focusing on their unique contributions to the understanding of cognitive development, this issue hopefully will serve as a "one-stop shopping experience" both for curious researchers who want to familiarize themselves with different computational approaches and for experts who want to examine the approaches more critically. Great care has been taken to minimize the computational details, yet enough details are provided for the interested researcher to get the flavor of the mathematics behind the models. We hope that the reader will be exposed to how computational approaches affect, and are affected by, the way we define and formalize our psychological constructs.

In the first article, *Schlesinger and McMurray* present a history of computational modeling in cognitive development and offer their perspective on what the future may hold for computational techniques. This is followed by a series of three articles that employ variants of connectionist models. *Chatham, Yerys, and Munakata* demonstrate how both successful and unsuccessful attempts at connectionist modeling can be used to advance developmental theory, focusing on cognitive flexibility in the Dimensional Change Card Sort. *Westermann and Mareschal* use empirical work in infant categorization to motivate their description of how connectionist models can simulate changes in the sizes of neural receptive fields, as well as account for dual memory processes where separable memory systems can learn at differential rates. *Shultz* reviews an impressive set of simulations using variants of the cascade correlation algorithm where the architecture of the model is not pre-specified but rather self-organizes to meet the demands of the input.

Understanding the process of self-organization is critical to developmental research, and is a primary focus of the dynamic systems framework. *Spencer, Austin, and Schutte* provide an excellent overview of the history of dynamic systems theory and how the modeling of embodied cognition has redirected the way that the field conceptualizes developmental change. *Simmering and Patterson* then apply Dynamic Field Theory to account for age-related changes in spatial cognition, leading to a precise theory of how to operationalize capacity limitations as well as the developmental mechanism responsible for the changes.

The last set of articles present unique approaches to computational modeling. *Dauvier, Chevalier, and Blaye*utilize procedures associated with generalized linear models to analyze trial-to-trial variability on children's trials on a task-switching paradigm. Using this technique, they identify five classes of children, each with their own distinct response patterns that inform us about their capabilities and strategy selection. *Ullman, Goodman, and Tenenbaum* introduce a symbolic algorithmic model in a Bayesian framework and demonstrate how it provides an alternative to connectionism that may capture children's sudden shifts of strategy use more reliably. Finally, *Halford, Andrews, Wilson, and Phillips* present a review of computational models related to relational knowledge, and offer insight into how the representation and manipulation of symbols can emerge from subsymbolic systems. This article presents an excellent demonstration of how different computational approaches, each of which might come up short as a full account for the phenomenon, can converge to increase our understanding of the development of relational knowledge.

This collection represents only a sample of contemporary approaches, but the selections have been carefully chosen to provide a meaningful overview and appreciation of the approach from experts known both for their modeling skills and for their theoretical and empirical contributions. Moreover, we hope that this special issue can inspire non-modelers to integrate what can be learned from computational models into their own theories, as well as inspire modelers to clarify how their models are benefitting, and are critical to, our understanding of cognitive development.

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Stuart Marcovitch*
University of North Carolina at Greensboro, United States

Philip David Zelazo
University of Minnesota, United States

*Corresponding author.
E-mail address: s_marcov@uncg.edu (S. Marcovitch)