Gernsbacher, M.A., & Faust, M.E. (1991). The mechanism of suppression: a component of general comprehension skill. *Journal of Experimental Psychology*, **17**, 245–262.
Karmiloff-Smith, A. (1979). Micro- and macrodevelopmental changes in language acquisition and other representational systems. *Cognitive Science: A Multidisciplinary Journal*, **3**, 91–117.
Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.
Kimberg, D.Y., & Farah, M.J. (1993). A unified account of cognitive impairments following frontal lobe damage: the role of working memory in complex, organized behavior. *Journal of Experimental Psychology*, **122**, 411–428.
Lapish, C.C., Kroener, S., Durstewitz, D., Lavin, A., & Seamans, J.K. (2007). The ability of the mesocortical dopamine system to operate in distinct temporal modes. *Psychopharmacology*, **191**, 609–625.
McClelland, J.L., & Kawamoto, A.H. (1986). Mechanisms of sentence processing: assigning roles to constituents of sentences. In J.L. McClelland & D.E. Rumelhart (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition* (pp. 272–325). Cambridge, MA: MIT Press.
Marcovitch, S., & Zelazo, P.D. (2008). A hierarchical competing systems model of the emergence and early development of executive function. *Developmental Science*, **12** (1), 1–18.
Miyake, A., Freidman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., & Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex 'frontal lobe' tasks: a latent variable analysis. *Cognitive Psychology*, **41**, 49–100.
Munakata, Y. (1998). Infant perserveration: rethinking data, theory, and the role of modelling. *Developmental Science*, **1**, 205–211.
Waltz, D.L., & Pollack, J.B. (1985). Massively parallel parsing: a strongly interactive model of natural language interpretation. *Cognitive Science*, **9**, 51–74.

DOI: 10.1111/j.1467-7687.2008.00774.x

Dynamic executives

Linda B. Smith

Department of Psychological and Brain Sciences, Indiana University, USA

This is a commentary on Marcovitch and Zelazo (2008).

Processes that drive change in behavior and processes that conserve against change are everywhere evident in the human cognitive system. Change in behavior emerges most fundamentally as a consequence of changing sensory input. New sensory events pull attention, internal activation, and behavior in new directions; however, new sensory events also activate memories of related events and in this way may pull the system toward past behavior. Stability is also a strong force in our cognitive system because the processes that constitute cognition endure in time and thus each new moment emerges out of and is often integrated with the just previous state of the system. The bringing of the past into the present is so ubiquitous in cognition – in priming, in memory interference, in assimilatory effects in perception, in generalization – that we often overlook the fundamentally perseveratory nature of even mature cognition. This 'perseveratory' aspect, this pull to the past, is, as William James (1890/1950) pointed out, also the foundation of the coherence of mind itself; and this perseveration, even by infants in the A-not-B task, is a significant developmental achievement in its own right (Clearfield, Dineva, Smith, Diedrich & Thelen, 2008).

The widespread interest in 'executive control' derives in part from the idea that something more – something *different* – is required to explain the task-specific and adaptive flexibility evident in mature human cognition. This is the main idea of the Hierachical Competing Systems Model (HCSM): the 'something special' is rule-like representations, reflection and consciousness. These certainly sound special, but would they seem so special if they were grounded in well-specified cognitive and neural processes? And, if they were so grounded, what would it mean about what is developing? Insights into these questions emerge not from considering how HCSM differs from competing process accounts, namely Munakata's (1997, 1998) latent-active memory account and Dynamic Field Theory (DFT; e.g. Clearfield *et al.*, 2008), but rather by considering what HCSM shares with those process-based accounts.

Munakata's account is built on the idea of two kinds of memories that operate at different times scales; the pre-switch task (searching at A) creates a longer-lasting, but latent memory, that is activated by the context cues post-switch and, thus, competes with the weaker transient memory for the new event (hiding at B). For younger infants, the reactivated latent memory wins out; for older infants, the transient memory is maintained and augmented through strong recurrent connections. Critically, these recurrent connections (linked to the activity of the

Address for correspondence: Linda B. Smith, Department of Psychological and Brain Sciences, Indiana University, 1101 East 10th Street, Bloomington, IN 47405, USA; e-mail: smith4@indiana.edu

prefrontal cortex) incorporate some form of intrinsic bistability (Munakata, 2001; O'Reilly, 2006). This yields a nongraded rule-like, go-no go, all-or-none) activation pattern. These nonlinear dynamics of the recurrent signal enable the system to select and pump-up a relatively weak signal (hiding at B, for example), enabling the more mature system to rapidly jump from some past state (searching at A) to a completely different one (searching at B).

DFT also proposes an internal all-or-none pattern of activation that feeds back on itself, creates an all-or-none decision and that sustains itself even after the stimulus that triggered the activation is removed (see also Clearfield *et al.*, 2008; Dineva, 2005). In DFT, new sensory inputs and memories for past goals and activity feed into a decision field. Several potential targets (both A and B, for example) can be represented simultaneously as sub-threshold peaks in the decision field. If the activation in any region of the field pierces a threshold, cooperative interactions within the field are set to work. These processes of local excitation and global inhibition create a single self-sustaining target that through lateral inhibition suppresses competitive targets (Schöner and Dineva, 2007). What older infants in the A-not-B task have, that younger children do not, is activation levels generated by the newer event (hiding at B) sufficient to pierce the threshold for generating the cooperative interactions within the field.

The similarities between Munakata's account and DFT are obvious (though there are finer points of clear disagreement as well; see Spencer & Schoner, 2003). But might 'reflection' as posited by HCSM just be another name for recurrence or self-sustaining activation, and might 'rule-like conceptual representations' just be another name for bistability or all-or-none patterns of activation? Are all three kinds of theories converging on the same fundamental ideas about what generates flexibility – a nonlinearity in interacting patterns of activation that can cause the system to jump – given some new appropriate sensory input such as a hiding at B – to a new state? If so, what does this mean about just what is developing?

HCSM posits that experience in specific task domains strengthens the quality of representations and the processes that modulate those representations. Three further observations support this idea. First, simulation and empirical findings within the DFT framework show that even the immature system can generate self-sustaining activation as long as the threshold for local excitation and lateral inhibition is pierced (see Clearfield *et al.*, 2008). Second, the developmental trend in the A-not-B task – from perseveration to shifting – is seen over and over again throughout development. All that changes is the developmentally relevant task. For example, the three models considered here may also be applied to the developmental changes in executive function as seen in a selective attention card-sorting task between 3 and 5 years of age (Zelazo, Müller, Frye & Marcovitch, 2003; Morton & Munakata, 2002). Apparently, hiding an object at a new location is too weak a signal to generate self-sustaining activation (in the face of past searching at a different location) in an 8-month-old, but instructions to sort cards by color is too weak a signal (in the face of recent sorting by shape) to generate self-maintaining activation in 3-year-olds. Finally, a recent model by Rougier, Noelle, Braver, Cohen and O'Reilly (2005) of PFC functioning consistent with the latent-active framework of Munakata shows how *expertise* with the task cues that signal a new goal creates less graded, more selective and more all-or-none internal activations that then orchestrate a rapid jump in the system as a whole.

Notice if these ideas are right, then executive control is *not* fundamentally different from the push and pull of sensory cues as they activate memories of related past events; all that is different is the dynamics of that activation.

References

Clearfield, M., Dineva, E., Smith, L.B., Diedrich, F., & Thelen, E. (2008). Cue salience and infant perseverative reaching: tests of the dynamic field model. *Developmental Science*, **11**, 890–904.

Dineva, E. (2005). Dynamic field theory of infant reaching and its dependence on behavioral history and context. PhD thesis, Institut für Neuroinformatik & International GraduRuhr-Universiät-Bochum, Germany.

James, W. (1890/1950). *The principles of psychology*. New York: Dover Publications.

Marcovitch, S., & Zelazo, P.D. (2008). A hierarchical competing systems model of the emergence and early development of executive function. *Developmental Science*, **12** (1), 1–18.

Morton, J.B., & Munakata, Y. (2002). Active versus latent representations: a neural network model of perseveration, dissociation, and decalage. *Developmental Psychobiology. Special Issue: Converging method approach to the study of developmental science*, **40** (3), 255–265.

Munakata, Y. (1997). Perseverative reaching in infancy: the role of hidden toys and motor history in the AB task. *Infant Behavior and Development*, **20** (3), 405–416.

Munakata, Y. (1998). Infant perseveration and implications for object permanence theories: a PDP model of the AB task. *Developmental Science*, **1** (2), 161–184.

Munakata, Y. (2001). Graded representations in behavioral dissociations. *Trends in Cognitive Sciences*, **5** (7), 309–315.

O'Reilly, R.C. (2006). Biologically based computational models of high-level cognition. *Science*, **314** (5796), 91–94.

Rougier, N.P., Noelle, D.C., Braver, T.S., Cohen, J.D., & O'Reilly, R.C. (2005). Prefrontal cortex and flexible cognitive control: rules without symbols. *Proceedings of the National Academy of Sciences of the United States of America*, **102** (20), 7338–7343.

Schöner, G., & Dineva, E. (2007). Dynamic instabilities as mechanisms for emergence. *Developmental Science*, **10** (1), 69–74.

Spencer, J.P., & Schöner, G. (2003). Bridging the representational gap in the dynamic systems approach to development. *Developmental Science*, **6**, 392–412.

Zelazo, P.D., Müller, U., Frye, D., & Marcovitch, S. (2003). What do children perseverate on when they perseverate? *Monographs of the Society for Research in Child Development*, **68** (3), Serial No. 274.