

Harter, D., Graesser, A. C. and Franklin, S. P.(2001). Bridging the gap: Dynamics as a unified view of cognition. *Behavioral and Brain Sciences*, 24(1):45-46.

Bridging the gap: Dynamics as a unified view of cognition

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Abstract: Top-down dynamical models of cognitive processes, such as the one presented in this article by Thelen et al., are important pieces in understanding the development of cognitive abilities in humans and biological organisms. Unlike standard symbolic computational approaches to cognition, such dynamical models offer the hope that they can be connected with more bottom-up, neurologically inspired dynamical models and provide a complete view of cognition at all levels. We raise some questions about the details of their simulation and about potential limitations of top-down dynamical models.

A useful top-down dynamical model should not only simulate what is already known to be the case empirically but should also take the lead in identifying potentially illuminating patterns of simulated data for future testing and experimentation. With this in mind, we built a quick computer simulation of Thelen et al.'s model and were intrigued by what we found. We start this commentary by sharing some of these observations.

In the model presented by Thelen et al., the h control parameter sets a resting level for the field that in effect controls the amount of interaction exhibited among the sites of the field. By varying the resting level of the field, the model displays behavior that is largely driven by its inputs on one extreme, to a self-sustaining mode where sites excite and inhibit one another and can sustain activation when it is no longer present as input (sect. 5.1.3). The results presented for the critical B trial (sect. 6.1.4, fig. 12) show that without the self-sustaining excitation in the non-cooperative regime, the history of past performance soon overrides the specific input of the hiding event and the A site is selected. In the cooperative regime meant to simulate more mature infants, the self-sustaining activation of the field causes it to successfully remember the specific input through the delay so that the model predicts a selection at site B. However, it appears that in the simulations, at least for a value of $h=-6$, the activation peak will not decay rapidly enough to predict perseverative reaching for delays of 5 seconds or longer for these more mature infants. But there is more to this story than merely fussing about whether the model's parameters predict the appropriate behavior.

We have questions about the predicted patterns of behavior as a function of varying the values of h . Are there resting field values in which the self-sustaining activation of the sites is not sustained indefinitely, but can eventually decay once the specific input is no longer present. That is to say, is there a change in the behavior of the model, from $h=-12$ to $h=-6$, such that at some values the cooperative regime only lasts for a limited amount of time. Are there values of h where a combination of cooperative and non-cooperative regimes are observed during a single simulated run of the experiment. Or does the model in effect switch from one mode of behavior to another at some value of h (e.g. an abrupt bifurcation). Without this domain of a mixed regime of cooperative and non-cooperative behaviors, it becomes unlikely that manipulation of the resting field level effectively captures the maturation of infant performance, since such performance is characterized by a rapidly increasing ability to tolerate delay (among other effects) during the critical phase of development.

From our own explorations of the model, it does appear that there exists a region of the resting field control parameter that exhibits a mixture of cooperative and non-cooperative behavior. This area of the h

parameter is very small and shows rapid change from a completely non-cooperative regime to a completely cooperative one. Interestingly enough, the rapid area of change that we observed would presumably be expected if the model does capture some aspects of real development. This area (and not at $h=-6$) more appropriately represents 12 month old infant's performances. Regimes dominated by cooperative behavior, like $h=-6$, represent an ability of short term memory to cue behavior towards the correct location for an indefinite amount of time; this is representative of very mature adult performance. But there is also an area of mixed characteristics that represents a very exciting region of the model; very small changes in the levels of the specific, task and memory input will cause disproportionate nonlinear changes in the predicted behavior and capabilities to tolerate delay. It remains to be seen how well predictions from studying the model in this region will correlate to actual observed behavior and make predictions of unseen effects.

Such questions about the effectiveness of various control parameters to capture the processes of maturation do illustrate the limitations that such top-down dynamical models have in providing satisfying explanations of cognitive phenomenon. Clark, who calls such models "pure" dynamical models, puts it thusly:

"... these 'pure' models do not speak directly to the interests of the engineer. The engineer wants to know how to build systems that would exhibit mind-like properties, and, in particular, how the overall dynamics so nicely displayed by the pure accounts actually arise as a result of the microdynamics of various components and subsystems." (Clark 1997, pg. 120)

In spite of this limitation with dynamical models, they do offer an exciting alternative to standard computational models of cognition. It has always been difficult to imagine how the dynamics of action and motor processes could be connected to disembodied, context free models such as those studied in traditional computational approaches (Hendriks-Jansen 1996). Dynamics as the language of cognitive processes does seem to offer hope as a unified model, where the dynamics of groups of neuronal elements give rise and organize into higher levels of dynamical description. Top-down dynamical models, such as this one, do seem to offer a clearer path towards a future synthesis of all levels of explanation of cognition. Neurologically inspired, bottom-up, dynamic embodied models, such as those proposed by Edelman and Freeman (Edelman & Tononi 2000; Edelman 1987; Freeman 1999; Skarda & Freeman 1987) exhibit top-down dynamical behavior of the type presented here by the authors. We are convinced that a synthesis of all levels of cognitive explanation through a language of dynamics and embodiment offers the appropriate viewpoint of cognition.

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