Framing the debate between computational and dynamical approaches to cognitive science

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Abstract: van Gelder argues that computational and dynamical systems are mathematically distinct kinds of systems. Although there are real experimental and theoretical differences between adopting a computational or dynamical perspective on cognition, and the dynamical approach has much to recommend it, the debate cannot be framed this rigorously. Instead, what is needed is careful study of concrete models to improve our intuitions.

Dynamical ideas are slowly but surely beginning to filter into cognitive science and there are signs that they may fundamentally transform the field. Because some of these ideas appear to challenge basic assumptions of a traditional computational perspective, it is hardly surprising that there is growing debate about the relative roles of computational and dynamical ideas in cognitive science. As with many ideological disputes, this debate is often marked by acrimony, misunderstanding, and outright dismissal. The goal of van Gelder's target article is to convince the skeptics that there is a substantive empirical claim behind those who seek to apply the concepts and mathematical tools of dynamical systems theory to the analysis of cognitive systems. Although I am extremely sympathetic to this overall goal and I applaud van Gelder for his valiant attempt to clarify the issues, I fear that his strategy gets him into more trouble than is strictly necessary to defend the dynamical approach.

Having the distinction between computational and dynamical systems turn on whether or not the state space and the time set of a system are "quantitative" simply does not work. The integers over which digital computers operate are nothing if not quantitative, and metrics can certainly be defined on integer spaces. In addition, dynamical systems can easily be defined over discrete state spaces (e.g., cellular automata), and computational descriptions of the symbol sequences generated by discretizing the output of continuous dynamical systems can be used to characterize their complex dynamical structure (Crutchfield 1994). Finally, what about analog computers, on which van Gelder's definitions are strangely silent? Sections 6.2 and 6.3 try to address some of these difficulties. For example, van Gelder insists that in a dynamical system distances must bear some "systematic relationship to system behavior" (sect. 6.2.2, para. 4). But how can you tell whether a system is bouncing around its state space because its dynamics are chaotic or because its behavior is based on nonmetrical "formal properties"? Although van Gelder would like to dismiss such concerns as mere nit-picking, it seems to me that they fatally undermine the very coherence of his nature hypothesis. As mathematical formalisms, both computation and dynamics are sufficiently broad that there is no empirical fact of the matter about which kind of system a cognitive agent *is.* Unfortunately, the debate cannot be framed with the mathematical precision to which the nature hypothesis aspires.

What the debate between computational and dynamical approaches to cognitive science is really about is which is the most insightful, explanatory, penetrating, and parsimonious stance to take toward a cognitive agent. There are very real conceptual, mathematical, and experimental consequences of adopting a dynamical versus a computational perspective on cognition. A computational approach is concerned with how an agent extracts, represents, stores, and manipulates information about its situation. In contrast, a dynamical approach is more concerned with the way in which the interaction between an agent's intrinsic dynamics and the dynamics of its body and environment unfolds into an observed trajectory of behavior with particular stability properties.

A dynamical perspective offers several potential advantages over a computational one. First, it explicitly incorporates the temporal dimension of cognition. Second, a dynamical perspective provides a broader theoretical playing field, because by making fewer a priori commitments, it demands an account of theoretical entities (e.g., representation) that a computational perspective simply takes for granted, and it encourages the consideration of alternatives to such entities. Third, it very naturally incorporates the growing realization that the behavior of an embodied and situated agent must be seen as arising from the ongoing interaction between its nervous system, its body, and its environment (Clark 1997). [See also Clark & Thornton: "Trading Spaces" *BBS* 20(1) 1997.] Fourth, it provides a natural language for reconnecting cognition with the brain processes that support it, with the noncognitive behavior that humans also exhibit, and with the "mere" adaptive behavior of simpler animals. Thus, it may provide a better framework for understanding the emergence of cognition in development and evolution. For all of these reasons, a dynamical framework holds the promise of providing a unified theoretical framework for the cognitive sciences. In contrast, the traditional computational approach to cognition can be almost fully characterized by the long list of things that are "somebody else's problem."

The claim that a dynamical perspective is the better one to take is essentially van Gelder's knowledge hypothesis. My only problem with the knowledge hypothesis is that it is not a genuine scientific hypothesis, at least not in the traditional sense of making an empirically falsifiable claim. At issue here are not experimentally testable predictions, but rather competing intuitions about the sort of theoretical framework that will ultimately be successful in explaining cognition. Simply put, computational and dynamical approaches make different pretheoretical bets about what features of cognition are more fundamental, about what sorts of mathematical models and tools will be most applicable to these features, and about how they will eventually fit together into an overall explanatory framework.

I certainly agree with van Gelder that this debate will only be resolved (or dissolved) by empirical investigation. Any battle between computational and dynamical ideologies must be fought on a case by case basis, grappling with the real experimental data on particular cognitive behavior. Indeed, as van Gelder has reviewed at length elsewhere (Port & van Gelder 1995), this battle is already being joined in many areas of cognitive science. In the meantime, I think that the careful study of concrete examples is more likely to clarify the key issues than abstract debate over formal definitions. In particular, the design and analysis of idealized model agents holds great promise in this regard (Beer 1997), and such work is beginning to engage cognitively interesting issues (Beer 1996). Such models can serve not only as intuition pumps (Dennett 1980), but also as the experiment pumps and mathematics pumps that advance us toward a unified theory of the mechanisms of adaptive behavior. There is nothing like studying birds or trying to build an airplane to cut to the heart of the debate about what can and cannot fly.

Why the dynamical hypothesis cannot qualify as a law of qualitative structure

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Abstract: Van Gelder presents the dynamical hypothesis as a novel law of qualitative structure to compete with Newell and Simon's (1976) physical symbol systems hypothesis. Unlike Newell and Simon's hypothesis, the dy-