Introduction

Most cognitive scientists are in the business of formulating models of cognitive phenomena. Historically, most of these models have fallen under one of two dominant conceptual frameworks: symbolicism and connectionism. More recently, the new conceptual stance of dynamicism has been advanced as an alternative to the symbolic and connectionist schemas. Supporters of this dynamical conception have sought to motivate its acceptance as a viable new paradigm by articulating the ways in which it differs from, and is more useful than, the symbolic and connectionist perspectives. The case for distinguishing the dynamical hypothesis from symbolicism has been fairly straightforward; the case for distinguishing it from connectionism has been considerably less so. The problem in this latter case is that connectionism and dynamicism are based on similar ideas and mathematical underpinnings. As a result, an interesting discussion has come to the fore: what is the proper relationship between connectionism and dynamicism?

Two interesting storylines have developed following the emergence of this discussion. In one storyline, the relationship between connectionism and dynamicism has been disputed somewhat contentiously by philosophers, with arguments rooted primarily in theoretical concerns. At the same time, practicing cognitive scientists have been applying ideas from the two conceptual frameworks in the design of novel empirical studies and the formulation of new models. Based on their empirical work, these scientists have chimed in to the "connectionism vs. dynamicism" dispute with insights about how the relationship between the two conceptions plays out in practice.

In this paper I begin by exploring the two storylines described above. First, I examine the debate regarding how dynamicism and connectionism relate to one another as general cognitive theories. Next, I look at what empiricists and modelers consider to be the practical consequences of the similarities and differences between the two perspectives. I then conclude by assessing how all three of the conceptual frameworks for cognition currently in vogue – symbolicism, connectionism, and dynamicism – may be mutually supportive and synergistic as cognitive science moves forward.

Connectionism and Dynamicism in Theory

As mentioned above, the dynamical movement has been met with considerable resistance in its efforts to establish sovereignty from connectionism. In this section, various arguments from this theoretical debate are laid out.

Dynamicism subsumes connectionism

The general strategy employed by dynamicists to deal with connectionism is to accommodate the connectionist conception as a subset within their more general framework, though with the strong caveat that connectionist models miss the mark in several important ways (van Gelder; van Gelder & Port, 1995). Clearly, dynamicists are obliged to make room for connectionism within their proposal to model cognition as systems of differential equations; connectionist models are nonlinear dynamical systems par excellence. However, dynamicists wish to separate their agenda from connectionism on the basis of two principles: (1) most connectionist models violate several of the more specific constraints imposed by dynamicism; (2) there is more to the dynamicist project than models of the connectionist variety.

Dynamicism restates connectionism

Numerous arguments have been offered as reproofs to the dynamicist position presented above; arguments seeking to clarify the dynamicist portrayal of connectionism, and arguments criticizing non-connectionist dynamical work.

In response to the criticism regarding connectionism's treatment of time, connectionists make note of the fact that the models they study are continuously evolving in nature (Eliasmith, 1996; Munakata & McClelland, 2003). A lack of emphasis on temporal dynamics in connectionist models should not be confused with a fundamental shortcoming in the ability to deal with continuous temporal evolution. In fact, connectionist models exist which deal convincingly with tasks like sensorimotor coordination and rhythmic behaviors (Churchland and Sejnowski, 1992). Therefore, the apparent inability to take time seriously in connectionism is solely an artifact of a lack of emphasis by connectionist modelers on temporally contingent behaviors, and not an inherent shortcoming in the approach.

The dynamicist arguments regarding representation and computation have by far been the points of greatest contention for critics of the dynamical movement (Clark & Toribio, 1994; Bechtel, 1998; Eliasmith, 1996). Most criticisms of the dynamicist's rejection of representation seem to boil down to the same argument: dynamicists are employing an incorrect and overly restrictive notion of representation. In essence, it seems that what dynamicists are seeking to reject are *explicit* representations, in the sense of the discrete symbolic units that form the basis for the symbolic conception of cognition. This rejection is by no means a new idea; the rejection of explicit representations was one of the hallmarks of the connectionist movement. In fact, critics argue, dynamicists can only reasonably be arguing against explicit representations, for otherwise dynamicism falls into the same trap that was the undoing of the behaviorist movement (Eliasmith, 1996). Dynamicism will most likely involve serious revisions to the standard concept of representation, putting emphasis on its fluid and dynamic nature. What remains to be seen though is whether this conception of representation will differ fundamentally from the somewhat radical form of representation still being grappled with in connectionism. However, at the very least it seems that the dynamicist criticism of connectionism on representational grounds does not hold water.

Finally, the criticism of connectionist models as being mostly disembodied is taken as warranted, but again with the observation that it only addresses an issue regarding the kinds of problems that connectionist models have been applied to thus far, and not a serious attack on the framework's potentialities (Bechtel, 1998). With consideration of the full space of possible connectionist models, it seems easily conceivable that models could be constructed to interface dynamically with their environments.

In addition to redressing the criticisms of connectionism advanced by dynamicists, connectionists have also rebuked the models chosen by dynamicists to serve as exemplars for their new theoretical movement (Eliasmith, 1996, 1997). The motivation for these rebukes has been to show that – contrary to the claim of a purported theoretical revolution – dynamicism does little more than restate the ideas which sparked connectionism's onset. The suggested problem with the new dynamical models, as

exemplified by the "decision field theory", is their reliance on collective parameters. As noted above, one of the central tenets of the dynamical framework is to offer low-dimensional models of cognitive behavior. For this reason, dynamical modelers must identify certain macroscopic states of a system and frame their model around the time evolution of those states, with the restriction that the states should be observable. These macroscopic states are termed collective parameters. The concern raised by critics is that it is typically unclear how these collective parameters map on to any underlying mechanistic units in the cognitive system. The obvious contrast here is between the symbols in symbolicism and the processing units in connectionism, on the one hand, and the collective parameters of dynamicism on the other. In the former case, both systems provide well-defined units which behavior can be traced back to; in the latter case, no such backtrace is possible. For this reason, connectionists claim that these new kinds of dynamical models don't provide any insight as to the underlying mechanisms of cognition, and thus do not constitute meaningful cognitive models. If these arguments are taken at face value, it seems that the dynamicist movement has done no more than to restate the worldview of connectionism.

Reconciling dynamicism and connectionism

From both sides of arguments presented, there seems to be a general consensus that connectionism fits to a large extent within the dynamical framework. As a result, the argument between connectionism and dynamicism seems to revolve mainly around the new class of models put forth by dynamicists, the class of models exemplified by the "decision field theory" framework. The question of import is whether or not these new models are sufficient as cognitive models. Weighing in on this issue, Bechtel (1998) draws a critical distinction between two kinds of explanation which seems to largely reconcile the two conceptual frameworks. The distinct that Bechtel makes is between *covering law* explanations and *mechanistic* explanations.