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Is Cognitive Science Usefully Cast as Complexity Science?

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Abstract

Readers of *TopiCS* are invited to join a debate about the utility of ideas and methods of complexity science. The topics of debate include empirical instances of qualitative change in cognitive activity and whether this empirical work demonstrates sufficiently the empirical flags of complexity. In addition, new phenomena discovered by complexity scientists, and motivated by complexity theory, call into question some basic assumptions of conventional cognitive science such as stable equilibria and homogeneous variance. The articles and commentaries that appear in this issue also illustrate a new debate style format for *topiCS*.

Keywords: Complexity; Cognition; Bifurcation; Nonstationary equilibria; Qualitative change

Complexity theory is a special branch of *chaos theory* or *nonlinear dynamical systems theory* distinguished by its emphasis on qualitative change. Chaos theory is a mathematical theory and has been applied successfully across a broad swath of natural phenomena—including climate change, dripping faucets, and the kinematics of living beings—basically anything that changes over time such that its next state is determined by its previous state and the rules that govern how states change over time. Complexity theory emphasizes the straw that breaks the camel's back—the incremental change in behavior, manner, and emotion that might lead from ''Are you busy tonight?'' to ''Let's get married!'' Complexity theory concerns how small local changes precipitate qualitative change in the behavior of a system. Much inspiration for thinking about qualitative change in this way came from ''far-from-equilibrium'' thermodynamics.

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Living systems generally express dynamics that are far from equilibrium. For example, when the average performances of children at different ages are compared, and these are compared across a life span of development (with the average performances of adults and the elderly), the estimated mean values change appreciably throughout the life span (as does the pattern of dispersion of measured values around the mean). Instead of measured values gravitating toward the stable average value of a stable equilibrium, development expresses nonstationary and unstable equilibria. As a consequence, the observed average values simply do not carry the same weight, by themselves, as they would to characterize stationary and stable equilibria. Stock market indices are nonstationary in the same way, expressing the ups and downs in economic developments of market systems (Taleb, 2007).

Most work in cognitive science has treated empirical data as though they do yield stable average values, with theoretical origins in stable equilibria. Please notice that the basis of the distinction between truly complex systems versus complicated behavior does not rest on whether an average can be computed—naturally, any collected set of measurements will have a mean value—only not all measured data gravitate toward stable mean values. Yet far and away the majority of laboratory studies in which cognitive and behavioral activities were measured have presupposed that the measured values do gravitate toward stable averages, and that task and cognitive effects are first and foremost discovered in the direction and magnitude of change between average values (however, cf. Ashby, Tien, & Balikrishnan, 1993; Balakrishnan & Ashby, 1991; Estes & Maddox, 2005; Luce, 1986; Maddox, Ashby, & Gottlob, 1998; Michell, 1999; Molenaar, 2008).

The empirical distinction at issue, then, is between the dynamics of stable equilibria and far-from-equilibrium dynamics—that is, whether a mean value's variance stays put or changes when more data are collected, and whether mean values provide sufficient and reliable information about the system under study. If mean values are not stable equilibria, then the empirical focus may shift to more reliable and informative aspects of a system's behavior, and theory development may explain these alternative aspects. Understandably, a shift of this consequence could require a scientist to make qualitative changes in the empirical methods employed and in the theoretical and conceptual tools brought to bear. Consequently, a shift to the theory and methods of complexity science would naturally require persuasive and motivating justification. This *topiCS* provides the forum for a contemporary debate about whether such justification yet exists.

From the perspectives taken in the target articles, this debate hangs on the observations already made about the character of qualitative change in human behavior and conscious experience—the coming into existence of a new insight in problem solving, the reorganization of mind and body after brain damage (Dixon, Holden, Mirman, & Stephen), the pragmatic choices for sensible speech (Gibbs & Van Orden), spontaneous qualitative change generally (Riley, Shockley, & Van Orden), and the qualities of phenomenology that suggest coupling among brain, body, and environment (Silberstein & Chemero). If these observations prove to be sufficiently general and reliable, they will motivate the alternative perspective, emphasizing the coordination of mind and body (synergies) in human activities instead of centralized cognitive control of behavior (Turvey, 2007). This emphasis on coordination stems from seeing the origins of qualitative change as a reordering or reorganization of how the mind and body interact—not a switch from one mental process to another, different, control process (Hollis, Kloos, & Van Orden, 2009).

The mathematical term for a qualitative change is *bifurcation*, which refers to the tipping point between different potential spontaneous reorganizations of a system's behavior. The corresponding term in physics is *phase transition*. Bifurcations can be local or global. On the one hand, when a person corrects his or her course of action on the way to an error, ending in the correct course of action after all (e.g., Spivey, 2007), we might call this a local bifurcation. On the other hand, when a person changes the overall strategy with which he or she approaches the same task, we might call this a global bifurcation (Stephen, Boncoddo, Dixon, & Magnuson, 2009; Stephen, Dixon, & Isenhower, 2009). Almost all of the empirical work in cognitive science conducted under the umbrella of complexity theory tests for the presence of the marker phenomena of bifurcations, the empirical flags of behavior that are predicted to occur near the tipping points of qualitative change (for a review, see Van Orden, Kloos, & Wallot, 2011).

For example, Wagenmakers, van der Maas, and Farrell discuss the use of catastrophe theory, which is one source of the empirical flags used by complexity scientists. Complexity theory has knit these empirical flags together with the empirical flags articulated in thermodynamics to characterize criticality, symmetry, and metastability. Criticality concerns the general implications of tipping points; symmetry generalizes what it means that a system can entertain more than one option, simultaneously, for reorganization; and metastability concerns the consequences for dynamics of simultaneous multiple options for reorganization.

This melding of mathematics and physics into a more coherent understanding of qualitative change was one mark of progress during the last half of the 20th century, giving a more comprehensive and exacting expression of qualitative change. The target articles all draw on predictions derived from mathematical expressions of qualitative change, the theoretical basis for the work described. What remains at issue, however, as the commentators clarify, is whether the corroboration already discovered by complexity scientists is sufficient to engender a sea change in how we go about cognitive science. We invite you to consider the kinds of evidence that the target articles illustrate and, if you haven't done so already, please join this discussion down the line.

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References

Ashby, F. G., Tien, J.-Y., & Balikrishnan, J. D. (1993). Response time distributions in memory scanning. *Journal of Mathematical Psychology*, *37*, 526–555.

Balakrishnan, J. D., & Ashby, F. G. (1991). Is subitizing a unique numerical ability? *Perception & Psychophysics*, *50*, 555–564.

Dixon, J. A., Holden, J. G., Mirman, D., & Stephen, D. G. (2011). Multifractal dynamics in the emergence of cognitive structure. *Topics in Cognitive Science*.

Estes, W. K., & Maddox, W. T. (2005). Risks of drawing inferences about cognitive processes from model fits to individual versus average performance. *Psychonomic Bulletin & Review*, *12*, 403–408.

Gibbs, R. W., & Van Orden, G. (2011). Pragmatic choice in conversation. *Topics in Cognitive Science*.

Hollis, G., Kloos, H., & Van Orden, G. (2009). Origins of order in cognitive activity. In S. J. Guastello, M. Koopmans, & D. Pincus (Eds.), *Chaos and complexity in psychology: The theory of nonlinear dynamical systems* (pp. 206–241). New York: Cambridge University Press.

Luce, R. D. (1986). *Response times: Their role in inferring elementary mental organization*. New York: Oxford University Press.

Maddox, W. T., Ashby, F. G., & Gottlob, L. R. (1998). Response time distributions in multidimensional perceptual categorization. *Perception & Psychophysics*, *60*, 620–637.

Michell, J. (1999). *Measurement in psychology. A critical history of a methodological concept*. Cambridge, England: Cambridge University Press.

Molenaar, P. C. M. (2008). On the implications of the classical ergodic theorems: Analysis of developmental processes has to focus on intraindividual variation. *Developmental Psychobiology*, *50*, 60–69.

Riley, M. A., Shockley, K., & Van Orden, G. (2011). Learning from the body about the mind. *Topics in Cognitive Science*.

Silberstein, M. & Chemero, A. (2011). Complexity and extended phenomenological-cognitive systems. *Topics in Cognitive Science*.

Spivey, M. J. (2007). *The continuity of mind*. New York: Oxford University Press.

Stephen, D. G., Boncoddo, R. A., Dixon, J. A., & Magnuson, J. S. (2009a). The dynamics of insight: Mathematical discovery as a phase transition. *Memory & Cognition*, *37*, 1132–1149.

Stephen, D. G., Dixon, J. A., & Isenhower, R. W. (2009b). Dynamics of representational change: Entropy, action, and cognition. *Journal of Experimental Psychology: Human Perception and Performance*, *35*, 1811–1822.

Taleb, N. N. (2007). *The black swan*. New York, NY: Random House.

Turvey, M. T. (2007). Action and perception at the level of synergies. *Human Movement Science*, *26*, 657–697.

Van Orden, G., Kloos, H., & Wallot, S. (2011). Living in the pink: Intentionality, wellness, and complexity. In C. A. Hooker (Ed.), *Philosophy of complex systems, volume 10: Handbook of the philosophy of science* (pp. 629–672). Amsterdam: Elsevier.

Wagenmakers, E.-J., van der Maas, H. L. J., & Farrell, S. (2011). Abstract concepts require concrete models: Why cognitive scientists have not yet embraced nonlinearly-coupled, dynamical, self-organized critical, synergistic, scale-free, exquisitely context-sensitive, interaction-dominant, fractal, interdependent brain-body-niche systems. *Topics in Cognitive Science*.