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EDITORIAL

The role of complex systems theory in cognitive science

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This special issue contains a collection of papers from the 2013 conference of the Society for Complex Systems in Cognitive Science (SCSCS), held as a satellite of the Cognitive Science conference in Berlin in July of that year. The SCSCS is aiming to promote the use of complex systems theory (CST) in cognitive science. Occasionally, when cognitive scientists encounter complex systems theory, it is not at all clear that CST is actually relevant to cognitive science. Given that non-CST cognitive scientists are often accustomed to utilizing Donders' subtraction method in reaction-time, event-related potential, and fMRI paradigms in the attempt to isolate cognitive processes, the concepts and measures used by CST researchers, such as 1/*f* noise, chaotic attractors, and fractal scaling, simply do not seem capable of isolating, let alone measuring cognition. To be sure, such measures can reveal that a system's dynamics are recursively coupled across all time scales (e.g., brain, body, and world) and that such multi-scale dynamics cycle through a high-dimensional space of various states, none of which ever repeat. But while such multi-scale measures are all well and good, they just do not allow one to isolate cognition.

The above-mentioned reaction to CST leads to a minimum of two options. One is to ignore CST, commit to the idea that cognitive processes can be isolated from perceptual and action-oriented processes, and continue on as before. The second is to utilize CST methods and measures, and leave open the issue of whether or not cognitive processes can be isolated. The papers entailed in the current volume represent a strong vote in favor of the latter option. Speaking from the field of theoretical physics, Harald Atmanspacher proposes (*Contextual Emergence of Mental States*) that the emergence of mental states requires certain lower-level physical processes, as well as the presence of higher-level boundary constraints that provide a context within which mental properties can emerge. From this perspective, mental states are inherently context dependent. Thus, the idea of isolating them, measuring them, and assuming one is not measuring the overall context simultaneously, is somewhat misleading.

Continuing the idea of multi-scale dependence, David Alexander, Chris Trengove, and Cees van Leeuwen (*Donders is dead: Cortical Traveling Waves and the Limits of Mental Chronometry in Cognitive Neuroscience*) make the strong claim that the averaging methods utilized to generate subtractions across between-trial conditions in ERP and fMRI experiments actually constitute methodological artifacts derived from globally synchronous fields that emerge in within-trial evoked brain activity—what are known as traveling waves (TWs). Their analysis reveals that within-trial topography is better described by TWs than between-trial averages of phase. In conclusion, the authors assert that traditional, between-trial averaging methods underestimate the coherent motion of cortical fields, and any 'signal' entailed in brain dynamics might very well exist at this larger, global level.

As an additional alternative to the notion of 'signals' in brain dynamics, and what they might be, William Benjamin St. Clair and David Noelle (*Implications of*

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Polychronous Neuronal Groups for the Continuity of Mind) propose that cognitive activities such as concept formation are neurally represented in spatiotemporal patterns of neural spikes, called polychromous neuronal groups (PNGs). PNGs differ from vector space representations, which group conceptual states in the instantaneous firing rates of neurons. An advantage of PNGs is that they support graded, intermediate, and blended concepts while also avoiding the activation of such intermediate states during the transition between conceptual states. As a result, the conceptual spaces afforded by PNG representations do not entail the dynamic continuity obtained in vector space approaches and instead, although continuous in nature, nonetheless offer a means to change the activation of concepts discretely.

In addition to contributions that apply CST concepts and analyses to brain dynamics, others focus on higher-level, traditional psychological variables such action–perception coordination. Auriel Washburn, Charles Coey, Veronica Romero, Mary Lauren Malone, and Michael Richardson (*Interaction of Intention and Environmental Constraints on the Fractal Dynamics of Human Performance*) asked participants to complete manual tasks involving different levels of task constraints as well as varying degrees of voluntary and involuntary control. Results revealed variations in the structure of the participants' performance variability as a function of both intentional and task constraints. From these findings, the authors conclude that their CST approach measures the dynamical organization of the entire participant-task system. Such findings again challenge the notion that cognition, perception, and action constitute system functions that can be isolated and measured independently of the rest of the organism-environment system.

As another application of CST principles to investigating action–perception systems, Arkady Zgonnikov and Ihor Lubashevsky (*Bistable dynamics of noise-driven activation in human intermittent control*) asked participants to engage in a virtual stick-balancing task. The results revealed that the statistical properties of the stick motion (as controlled by the participant) were non-Gaussian, practically identical for all participants, and remained roughly the same as the task difficulty varied. The authors assert these results, which were only revealed via the use of CST techniques, might allow us to better understand human behavior in a wide variety of tasks.

In addition to the above-mentioned perception–action applications, other contributors apply CST techniques to traditional cognitive functions such as memory and decision-making. In regard to the former, Janelle Szary, Chris Kello, Rick Dale, and Theo Rhodes (*Collaborative recall: Interactive memory foraging*) conceptualize memory retrieval as being similar to animal foraging behavior in which one searches the memory landscape for target items. A comparison of individual and group data revealed that while the number of recalled items was similar, the dynamics underlying the production of the items were different, with groups and individuals generating different mixes of convergent and divergent processes.

As regards decision-making, Simon Frisch, Maja Dshemuchadse, Max Görner, Thomas Goschke, and Stefan Scherbaum (*Unraveling the sub-processes of selective attention: Insights from dynamic modeling and continuous behavior*) investigated the selective attention dynamics that lead to biases in information processing toward goal-related stimuli. Using dynamic neuronal field models that focus on evaluating the continuous evolution of behavior over time, they tested whether the goal-related bias was due to the amplification of goal-related information, or the inhibition of distracting information. They found evidence supporting the presence of amplification, yet found none supporting the notion of inhibition. And again, this finding was uncovered via the use of CST techniques that model neural dynamics as being recursive and multi-scale. As a result, these data serve as yet another empirical challenge to the idea that cognitive processes can be isolated from perception and action process, and measured independently.

Finally, we present the research of contributors who apply the CST framework to social interaction. Drew Abney, Alexandra Paxton, Rick Dale, and Christopher T. Kello (*Movement dynamics reflect a functional role for weak coupling and role structure in dyadic problem solving*) asked participants to engage in a cooperative construction task. Via the use of cross-recurrence quantification analysis, which looks for multi-scale predictabilities in the unfolding dynamics of ongoing behavior, the authors discovered that groups whose body movements were loosely coupled performed better on the task. The analysis was also able to identify leader–follower dynamics in the data. This dependence between the dynamics of moving bodies was uncovered via the use of CST (i.e., cross-recurrence quantification analysis) techniques. Given the multi-scale dependence inherent to such data, it seems difficult if not impossible to isolate the cognitive processes entailed therein.

In the final contribution (*Semantic network mapping of religious material: Testing multi-agent computer models of social theories against real-world data*), Justin E. Lane utilizes Semantic Network Analysis (SNA) to investigate the semantic networks that underlie the use of religious concepts. He reports evidence for scale-free, small-world network properties in which there exists strong correlations between a concept's centrality in the conceptual network and its frequency of use. The author then goes on to propose a new multi-agent model of doctrinal ritual behavior.

Across all of the above-mentioned contributions, researchers are measuring variables as they unfold in real-time, and attempting to discern if the changes that occur from moment-to-moment can be treated as independent events, or actually constitute states of change that are irreducibly nested within smaller and larger states of change. And given that the measured dependent variables increase in scale across the papers (i.e., from traveling waves, to perception–action cycles, to semantic networks), it seems difficult to believe that a level will emerge within the midst of all of this multi-scale dynamical change, which can be isolated from all other levels and referred to as cognition. Does this mean there is no such thing as cognition? We think not. Rather, it seems we should perhaps conceptualize cognition, perception, and action as nested levels of dynamic coordination, what Jordan (2003, 2013) has referred to multi-scale event control. While such a multi-scale, contextually contingent approach to cognition will require a massive reorganization of how we interpret the results of cognitive science, it will simultaneously rid us of age old arguments regarding whether or not a given process or dynamic should be labeled as perceptual or cognitive. Given that more and more data indicate the processes we measure in cognitive science are actually multi-scale, recursive, and contextually emergent, whether or not we label them as perceptual or cognitive appears more and more to have to do with flavor than data.

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