Metaphysical and Epistemological Issues in Complex Systems

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A number of metaphysical and epistemological issues are raised by the investigation and behavior of complex systems. Before treating some of these issues, a characterization of nonlinear dynamics and complexity is given. With this background in place, some myths about chaos and complexity will be discussed first. Although some claim that chaos is ubiquitous and many take the signal feature of chaos to be exponential growth in uncertainty (parameterized by Lyapunov exponents), both of these myths turn out to be highly misleading. They give rise to rather surprising further myths that chaos and complexity spell the end of determinism and predictability. But when we see that Lyapunov exponents, at least in their global form, and measures for exponential divergence of trajectories only apply to infinitesimal quantities in the infinite time limit, these myths vanish. Instead, the loss of linear superposition in nonlinear systems turns out to be one of the crucial features of complex systems. This latter feature is related to the fact that complex behavior is not limited to large multi-component systems, but can arise in fairly simple systems as well. Moreover, the lack of linear superposition in complex systems also has implications for determinism, predictability, confirmation, causation and reduction and emergence in nonlinear dynamics.

After defining determinism's crucial features, the impact of nonlinearity on these features will be discussed including, briefly, the potential impact of quantum mechanics. Some have argued that chaos and complexity lead to radical revisions in our conception of determinism, namely that determinism is a layered concept (e.g., Kellert), but such arguments appear to turn on misunderstandings of determinism and predictability and their subtle relations in the context of nonlinear dynamics. When the previously mentioned myths are removed, the relationship among determinism, predictability and nonlinearity can be seen more clearly, but still contains some surprising features.

The mathematical modeling of physical systems requires us to make distinctions between variables and parameters as well as between systems and their boundaries. These distinctions become problematic in the context of complex systems, where linear superposition is lost and such systems can be exquisitely sensitive to the smallest of influences. Such features raise questions about our epistemic access to systems and models in the investigation of complex systems. Furthermore, these features of our nonlinear mathematical models are problematic for standard approaches to confirming such models. We typically rely on the faithfulness of our mathematical models for our confirmation of their efficacy in capturing behavior of target systems, but when the models are nonlinear and the target systems complex, faithfulness turns out to be inadequate for these standard confirmation practices. Furthermore, there are ramifications here for the use of nonlinear models in the development and assessment of public policy.

Along with these epistemological issues, nonlinearity and complexity raise questions about some traditional metaphysical topics like the identity and individuation of complex systems, along with their levels of dynamics, and causation in such systems. While most metaphysicians focus on the "upward" flow of efficient causation from system components to system behavior as a whole, interlevel relationships in the dynamics of complex systems like convecting fluid present plausible examples of a "downward" flow of causation constraining the behavior of system components. Such behavior also raises questions about the nature of laws in complex systems as well as what self-organization principles might be at work.

The issues of identity and causation in complex systems leads naturally to a discussion of reduction and emergence in complex systems. In roughest outline, the received view on reduction maintains that properties and behavior of systems as a whole are completely determined by or explainable in terms of the properties and behaviors of its parts, ontological and epistemological claims, respectively; the received view on emergence denies one or both of these claims. The property of linear superposition plays an interesting role in the concepts of resultant and emergent forces in such systems. However, the loss of superposition and the possibilities for holism and constraining causation leads to the need to possibly consider an alternative to the received views.