Abstract

The standard assumptions that underlie many conceptual and quantitative frameworks do not hold for many complex physical, biological, and social systems. Complex systems science clarifies when and why such assumptions fail and provides alternative frameworks for understanding the properties of complex systems. This review introduces some of the basic principles of complex systems science, including complexity profiles, the tradeoff between efficiency and adaptability, the necessity of matching the complexity of systems to that of their environments, multi-scale analysis, and evolutionary processes. Our focus is on the general properties of systems as opposed to the modeling of specific dynamics; rather than provide a comprehensive review, we pedagogically describe a conceptual and analytic approach for understanding and interacting with the complex systems of our world. With the exception of a few footnotes, this paper assumes only a high school mathematical and scientific background, so that it may be accessible to academics in all fields, decision-makers in industry, government, and philanthropy, and anyone who is interested in systems and society.

Law of Requisite Variety

- Given a fixed set of components with a fixed set of potential individual behaviors, the area under their complexity profile will be constant, regardless of the interdependencies (or lack thereof) between the components.
- Corollary: more efficient, larger-scale systems will necessarily possess less adaptability at smaller scales.

Generalization to Multiscale and Subdivided Systems

To be effective, each subset of a system must match (or exceed) at all scales the complexity of the environmental behaviors to which that subset must differentially react.

How do we understand complex systems?

Our understanding of all systems depends on universality: the existence of large-scale behaviors that do not depend on all the small-scale details. Standard approaches are predicated on mean-field theory, i.e. the assumption that such large-scale behaviors are simply the average of the small-scale details. But mean-field theory is just one example of universality.

Another example: all materials, regardless of their composition, allow for the propagation of sound waves. Sound waves cannot be understood as a property of the average behavior—in this case, the average pressure or density—of a material, since they arise from precisely the systematic correlations in the deviations from that average. Nor are they best understood by focusing on the small-scale details of atomic motion. Rather, the key to understanding sound waves is to recognize their multi-scale structure and to choose a model description accordingly.

More generally, understanding all the details of any complex system is impossible—there is just too much complexity at the smaller scales. It should not surprise us that complex systems are difficult to understand. Rather, it is surprising that we are able to understand any system at all, as even the simplest macroscopic systems contain trillions upon trillions of molecules.

We are able to understand such systems because of mean-field theory, in which the average behaviors of a system’s components are explicitly modeled and deviations of the components from this average are treated as statistically independent fluctuations. This standard approach works well for systems such as cars, buildings, and computers, but it is also widely applied to biological and social systems for which its assumptions do not always hold.

Complex Systems and Uncertainty

- Plans will always have unintended consequences; the key is to allow unintended consequences to work for rather than against the system as a whole.
- Systems can explicitly design only systems of lesser complexity since an explicit design is itself a behavior of the first system. However, systems that evolve over time can become more complex than their designers.
- The desire for direct control must therefore be relinquished in order to allow complexity to evolve over time.

Successful evolutionary processes generally do not consist of unbridled competition but rather contain both competition and cooperation, each occurring at multiple scales (e.g. sports, as illustrated above). With the multiscale structure, groups with unhealthy evolutionary dynamics are selected against, while groups with a healthy mix of competition and cooperation that benefits the entire group are selected for.