A Formalism for Multiscale Structure in Complex Systems

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We develop a general formalism for representing and understanding structure in complex systems. We take the view that a system’s structure is captured in the pattern of information-theoretic dependencies among components. To allow for flexibility in the way information is quantified, we introduce axioms for information functions, of which Shannon entropy and Kolmogorov complexity are two well-known examples. From this axiomatic starting point, we develop useful indices of complex-system structure, providing a sound basis for the complexity profile of Bar-Yam and also introducing a new measure, the marginal utility of information. Using simple examples, we show how these indices capture intuitive ideas about structure in a quantitative way. Our formalism also sheds light on a longstanding mystery: that the mutual information of three or more variables can be negative. We discuss applications to complex networks, gene regulation, the kinetic theory of fluids and multiscale cybernetic thermodynamics.