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Complexity and Information: Measuring Emergence, Self-organization, Homeostasis, and Autopoiesis at Multiple Scales

Concepts used in the scientific study of complex systems have become so widespread that their use and abuse has led to ambiguity and confusion in their meaning. We use information theory to provide abstract and concise measures of complexity, emergence, self-organization, homeostasis, and autopoiesis. The purpose is to clarify the meaning of these concepts with the aid of the proposed formal measures. In a simplified version of the measures (focusing on the information produced by a system), emergence becomes the opposite of self-organization, while complexity represents their balance. Homeostasis can be seen as a measure of the stability of the system. Autopoiesis can be measured as the ratio between the information produced by the environment over the information produced by a system. We use computational experiments on random Boolean networks and elementary cellular automata to illustrate the measures at multiple scales.