A unified theory of chaos linking nonlinear dynamics and statistical physics

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A fundamental issue in nonlinear dynamics and statistical physics is how to distinguish chaotic from stochastic fluctuations in short experimental recordings. This dilemma underlies many complex systems models from stochastic gene expression or stock exchange to quantum chaos. Traditionally, deterministic chaos is characterized by "sensitive dependence on initial conditions" as indicated by a positive Lyapunov exponent. However, ambiguity arises when applying this criterion to real-world data that are corrupted by measurement noise or perturbed nonautonomously by exogenous deterministic or stochastic inputs. Here, we show that a positive Lyapunov exponent is surprisingly neither necessary nor sufficient proof of deterministic chaos, and that a nonlinear dynamical system under deterministic or stochastic forcing may exhibit multiple forms of nonautonomous chaos assessable by a noise titration assay. These findings lay the foundation for reliable analysis of low-dimensional chaos for complex systems modeling and prediction of a wide variety of physical, biological, and socioeconomic data.

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