

*Lyapunov Exponents: A Tool to Explore Complex Dynamics*. In simple terms, a Lyapunov exponent is derived by considering two close-by initial conditions in a system's state space. If the behavior is chaotic, the state-space trajectories originating from those initial conditions will diverge exponentially, at least for a while. The exponent that gives the rate of that divergence is a Lyapunov exponent, named after Russian mathematician Aleksandr Mikhailovich Lyapunov, who introduced the concept in his 1892 PhD thesis. Most systems have more than one Lyapunov exponent: Indeed, there is one for each of the state-space dimensions. For a system exhibiting chaotic behavior, at least one of the exponents is positive.

Authors Arkady Pikovsky and Antonio Politi are two distinguished and well-known researchers in the field of nonlinear dynamics and complex systems. *Lyapunov Exponents* details how to determine the exponents for various dynamical models, including discrete-time, continuous-time, deterministic, and stochastic models, that are applicable to both simple systems with only a few degrees of freedom and complex systems with many degrees of freedom. The authors base their analyses on models that have been thoroughly studied in the field of nonlinear dynamics. But they emphasize that many of the results are independent of the underlying system details.

If Lyapunov exponents could be used only to characterize the divergence of nearby trajectories, it would hardly be worthwhile to devote an entire book to them. However, Lyapunov exponents also allow for the determination of other dynamical-system characteristics, including dynamical entropy, fractal dimensions, and system synchronization. Those connections are discussed clearly and comprehensively in *Lyapunov Exponents*. The authors end the book with a chapter devoted to short descriptions of how Lyapunov exponents help us understand the dynamics of Anderson localization, billiards models, transport coefficients, escape rates, molecular dynamics simulations, Lagrangian coherent structures in fluids, celestial mechanics, and quantum chaos.

The methods for extracting the values of the Lyapunov exponents from actual experimental time series data are discussed in only one section of the book. The practical difficulty is that for most

experimental data, we do not know the number of degrees of freedom in advance. That information, like the Lyapunov exponents themselves, needs to be extracted from the data. Given the limited data of any time series and the contamination of that data by experimental noise, there are many ways for the data analysis to go wrong. It would have been helpful if the authors had provided a more detailed guide through the muddy swamp of data analysis.

I was surprised to find that the authors did not mention an interesting connection between how Lyapunov exponents change at "the edge of chaos" and certain thermodynamic features near critical points. For example, near the onset of chaotic behavior following a sequence of period-doubling bifurcations, a positive Lyapunov exponent shows a universal power-law dependence on a parameter, exactly paralleling the behavior of an order parameter as a function of temperature at a critical point in a thermodynamic system.

Although *Lyapunov Exponents* assumes a readership with a basic knowledge of nonlinear dynamics, it should be required reading for anyone seriously engaged in the quantitative analysis of the dynamics of complex systems.

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