

Dynamical Systems and Chaos

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Review of dynamical systems

PART

I

The laws of nature and many natural phenomena can be understood through cause-effect relationships, where the evolution of a system depends on its current state and governing rules. These relationships are expressed in the universal language of mathematics—through equations, functions, and deterministic or stochastic rules. The dynamical systems framework provide a powerful framework for modeling such behavior across disciplines, from physics and biology to economics and engineering.

Whether studying the motion of planets, the spread of diseases, neural activity, or climate patterns, dynamical systems reveal how complex behavior emerges from simple interactions. By analyzing differential equations, iterative maps, or network dynamics, we uncover patterns, stability, chaos, and predictability in nature. The multidisciplinary nature of dynamical systems highlights the unity of scientific inquiry, demonstrating how mathematical principles underlie diverse real-world phenomena.

1 Dynamical Systems

Definition 1.1. A dynamical system can be described as a collection or set of time dependent state variables \mathbf{S}

$$\mathbf{S}(t) = \{X_1(t), X_2(t), \dots, X_n(t)\}$$

that evolves with time according to a *specific known deterministic rule* \mathbf{f} , such that

$$S(t) \xrightarrow{\mathbf{f}} S(t + \tau)$$

This **deterministic** rule \mathbf{f} corresponds to a set of operations or procedures that allows to calculate the state of a system at time $t + \tau$ from the knowlodge of its state at time t .

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¹ With some additional sidenotes