nature insight

Complex systems

Cover illustration
A computer simulation of the ground displacement due to the 1992 Landers earthquake — an example of one of the many systems that show complex dynamical behaviour. (Image: D. Massonnet/ CNES/SPL.)

The science of complexity, as befits its name, lacks a simple definition. It has been used to refer to the study of systems that operate at the 'edge of chaos' (itself a loosely defined concept); to infer structure in the complex properties of systems that are intermediate between perfect order and perfect disorder; or even as a simple restatement of the cliché that the behaviour of some systems as a whole can be more than the sum of their parts.

Notwithstanding these difficulties over formal definition, the study of complex systems has seen tremendous growth. Numerous research programmes, institutes and scientific journals have been established under this banner. And the new concepts emerging from these studies are now influencing disciplines as disparate as astronomy and biology, physics and finance. The richness of the field and the diversity of its application lends itself naturally to the Insight format, although our choice of themes to review is necessarily somewhat eclectic.

We begin by considering systems in which the microscopic properties and processes can be immensely complex and seemingly noisy, yet on larger scales they exhibit certain classes of simple behaviour that seem insensitive to the mechanistic details. On page 242, Sethna *et al.* show that the seemingly random, impulsive events by which many physical systems evolve exhibit universal — and, to some extent, predictable — behaviour. Shinbrot and Muzzio on page 251 offer a different perspective on noise, describing how order and patterns can emerge from intrinsically noisy systems.

We then shift our focus to systems where both the properties of the individual components and the nature of their interactions are reasonably well understood, yet the collective behaviour of the ensemble can still defy simple explanation. On page 259, Debenedetti and Stillinger show how recent theoretical progress on describing the dynamics of systems of many identical interacting particles — in the form of a multidimensional 'energy landscape' — is shedding light on the age-old phenomena of supercooling and glass formation. And for extensive networks of simple interacting systems, Strogatz shows on page 268 how network topology can be as important as the interactions between elements.

But complex systems do not always lend themselves to such easy (if qualitative) categorization. For example, the many complex rhythms encountered in living organisms arise not just from intrinsic stochastic or nonlinear dynamical processes, but also from their interaction with an external fluctuating environment. Yet, according to Glass on page 277, decoding the essential features of these rhythms might ultimately be of benefit to medicine, even in the absence of a simple mathematical interpretation.

As should be clear from these articles, the science of complexity is in its infancy, and some research directions that today seem fruitful might eventually prove to be academic cul-de-sacs. Nevertheless, it seems reasonable to suppose that the general principles emerging from these studies will help us to better understand the complex world around us.

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