

Avalanche theory in rice

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By patiently dropping grains of rice, in the experiment reported on page 49 of this issue, Frette *et al.*¹ put to the test some features of 'self-organized criticality' (SOC), a purported generic mechanism for the common occurrence of fractals, $1/f$ -noise and power-law distributed events. Although SOC is frequently observed in numerical simulations, controlled experiments on granular media have at best provided ambiguous results. Some piles of sand relax by big avalanches (of the order of the system size), whereas the statistics of avalanches in others can be fitted to different distributions. Depending on the shape of their rice grains, Frette *et al.* obtain both types of behaviour: small aspect ratios (short, fat grains) lead to large avalanches, larger ones (longer grains) lead to a power-law distribution for avalanche sizes — the signature of self-organized criticality.

A common exercise in elementary physics is to estimate the typical value of some quantity by dimensional analysis. Yet there exist many phenomena that are effectively scale-free, with possible values that span several orders of magnitude. Fractals — geometrical entities whose fluctuations repeat in self-similar fashion from the smallest to largest distances² — have been invoked to characterize natural shapes from coastlines to clouds. Possibly related manifestations of self-similarity in the time domain are the broad-band noise observed in electrical

circuits, and the fluctuations in time of the flow of rivers, or light from quasars. One model of this so-called $1/f$ -noise relies on the incoherent superposition of signals from oscillators with a wide (scale-free) distribution of frequencies f . Power-law distributions also seem to characterize the size (strength) of many natural catastrophes: avalanches, mass extinctions and stock-market crashes, to name but a few. The Gutenberg–Richter law, which relates the number of earthquakes to their magnitude, is a prominent example³.

Why are scale-free phenomena so frequent in nature? In 1987, Bak, Tang and Wiesenfeld⁴ introduced the idea of self-organized criticality as a possible answer. They used the analogy of a pile of sand gradually built up by the addition of single grains. Once the pile has reached a critical slope, addition of further grains may cause avalanches, while the overall pile fluctuates around this 'angle of repose'. In the idealized sand pile, modelled on the computer, avalanches of all sizes occur at this stage, with a probability distribution that is scale-free (a power law).

The initial claims of SOC as the underlying link between fractals, $1/f$ -noise and power-law distributed events naturally excited the imagination of a broad spectrum of scientists. Currently, the principle is applied more modestly to explain power-law distributions of events (avalanches) observed in some slowly

driven systems. Earthquakes, forest fires and rainfalls are just some of the diverse phenomena that have been suggested to show SOC.

As the original theory was cast in terms of avalanches on a sand pile, granular systems have been a prime target in the experimental search for SOC. But the behaviour of real sand is complex, showing a variety of slip, slide and roll motion not usually incorporated in the simple dissipative computer models. Some piles relax in large avalanches where a top layer of sand slides away⁵, and even though a spectrum of avalanche sizes is observed in other experiments^{6,7}, the limited range of data makes a convincing identification of SOC difficult.

Frette *et al.* set out to do the definitive experiment on this subject, and they have carried out the task with great patience and care. They do their experiment on grains of rice, which they find to be less subject to slipping and rolling than are sand grains, and hence closer to the dissipative limit studied numerically. (This is especially true for long-grain rice, with its larger aspect ratio.) They accumulate sufficient statistics to distinguish between a power-law distribution in one case (long grains) and a stretched exponential in another (more spherical grains). The occurrence of both behaviours in the same experiment is valuable, and allows the authors to provide possible reasons for distinct relaxation dynamics by appealing to the relative importance of inertia and friction. Although this explanation is not new, here it is clearly demonstrated.

Whether or not SOC is indeed a useful model (and the debate is not yet settled), it has certainly generated broad excitement. The new experiment provides the best evidence so far for the occurrence (sometimes, but not always) of power-law distributed avalanches in granular media. The continuing challenge to both theorists and experimentalists is to go beyond observation of power-law distributed events to the identification of the exponent and demonstration of its universality in different systems — that is, to go from qualitative to quantitative agreement. □

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