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# How Nature Works: The Science of Self-organized Criticality

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late fluid percolation through porous media, or the growth of dendrites and skeletal crystals by "diffusion-limited aggregation." Those who still doubt the scientific potential of fractal studies should read the articles on these two subjects by Feder and Jössang, and by Meakin and Fowler, in the second volume: if these articles do not convince them, then they have probably already aquired a severe case of fractal blindness. Fractal objects ("strange attractors") also appear in the state space of low-dimensional chaotic dynamic systems, but according to Bak and Chen (first volume, p. 233) "The belief that there may be a connection between low-dimensional chaos and fractals is without mathematical foundation." Instead, Bak (see next review) believes strongly that the most common cause of natural fractal objects, including sand avalaches, earthquakes, and many other geological phenomena, is a multidimensional dynamic state poised on the edge of chaos (or catastrophy), which he calls "self-organized criticality."

## How Nature Works: The Science of Self-organized Criticality

Per Bak
*Copernicus (Springer-Verlag)*
*New York, 1996, 212 p., US$27.00*

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Per Bak is a physicist at Brookhaven, with a sceptical view of scientific institutions, and a low opinion of many of his fellow scientists, apparently especially of geophysicists:

> ... (who) often show little interest in the underlying principles of their science. Perhaps they take it for granted that no general principles apply, and that no general theory...can exist. (p.81)

This book is about a general theory to explain the existence of power laws, like the Gutenberg-Richter law relating the number of earthquakes $N(m)$ with a magitude great than some value $m$

$$N(m) = am^{-b}$$

A log-log plot of $N$ against $m$ is a straight line with a slope of $-b$. Alternatively, one might plot the magnitude of earthquakes against time: taking a power spectrum of this time series would reveal that the variance in earthquake magnitude was proportional to the frequence ($f$) raised to some negative power ß. Time series with this type of spectrum are said to show "$1/f$" noise, and have been commonly observed in many fields. $1/f$ noise can be simulated by random walks, and the extended phenomenon was called "fractional Brownian motion" by Mandelbrot and Wallis. One of their pioneer papers about this has been reprinted in the first of the two volumes edited by Barton and LaPointe, and reviewed above. Power laws and $1/f$ noise are now generally thought to be characteristic of fractal objects.

Bak has developed a general theory to explain power laws and $1/f$ noise (and more generally, the complexity of nature): he calls this theory "self-organized criticality" (SOC). Bak argues that complex systems, with many degrees of freedom, that are driven far from equilibrium by the application of some extrinsic but possibly steady force tend

> ...to evolve into a poised "critical" state, way out of balance, where minor disturbances may lead to events...of all sizes... The state is established solely because of the dynamic interactions among individual elements of the system: the critical state is *self-organized*. (p.1-2).

Bak's model for such a system is a sand pile, continually fed by sand added grain by grain (but randomly) close to the apex.

Cellular automata (computer) models of such a system show that it builds up to a critical state, after which avalaching takes place. The timing and size of the avalanches, however, are quite unpredictable, and do not show any natural periodicity; instead, the power spectrum of the time series shows 1/f noise, and the number and size of the avalanches are related by a power law (real sand piles are not as satisfactory, in this respect, as computer ones: see Anita Mehta, ed., Granular Matter, published by Spinger-Verlag, 1994). In Bak's book, he extends the sand-pile model to: earthquakes, cotton prices, extinctions, landscape geometry and evolution, coupled pendulums, turbidite deposition, volcanic eruptions, pulsars, solar flares, evolution (including punctuated equilibria), the brain, and traffic jams. Perhaps you think this ambitious? I can only say that I know of several other published applications that he has omitted.

Most of the topics considered at length in this book are part of the earth sciences; earthquakes, landscape, sedimentation, evolution, and extinction are the major topics. The style is for the most part autobiographical, alternately entertaining and irritating, and at the *Scientific American* level. Bak argues for an approach to complex systems that is necessarily abstract and statistical. He claims that

> ... we must learn to free ourselves from seeing things the way they are!... If... we concentrate on an accurate description of the details, we lose perspective. A theory of life is likely to be a theory of a process, not a detailed account of utterly accidental details of that process... (p.10)

For most geologists, this approach may be one that they have never seriously considered.

My recommendation: read this book, and decide for yourself how valid the approach is. At the very least, it is entertaining to read a book by a physicist who does not believe that meteorite impacts cause extinctions!

## The Geology of South Australia: Volume 1. The Precambrian

Edited by J.F. Drexel and A.J. Parker
*South Australia Geological Survey*
*Bulletin 54*
*1993, hardbound, 242 p., A$75.00, + A$20.00 overseas surface postage and packaging*

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This attractive volume provides an up-to-date overview of the Precambrian geology of South Australia (an Australian state roughly comparable in size to British Columbia). Volume 2 will cover the Phanerozoic geology. As mentioned in the introduction, the book is designed to provide the reader with a comprehensive regional account of the products of sedimentation, deformation, metamor-