Editorial & Letters

EDITORIAL

In Celebration of AAAS

Concern for man himself and his fate must always form the chief interest of all technical endeavors ... in order that the creations of our mind shall be a blessing and not a curse to mankind.

–Albert Einstein

The reader of *Science* regularly encounters researchers from all walks of life in these pages. But he or she does not often read these researchers' personal views about science, much less the views of artists, politicians, religious leaders, and science fiction writers. Beginning with this issue (see page 812), *Science* is publishing a series of essays that explores the relationship among science, scientists, and the wider society. Over the next 9 months a rich assortment of viewpoints will be aired, forming a provocative, often contradictory, and consistently entertaining mosaic that illustrates just how deeply embedded in our culture science has become.

The inspiration for this series is the 150th anniversary of the American Association for the Advancement of Science. The original objectives of the Association, agreed to on 20 September 1848 in the Academy of Natural Sciences in Philadelphia by 461 charter members, were "by periodical and migratory meetings, to promote intercourse between those who are cultivating science in different parts of the United States; to give a stronger and more general impulse, and a more systematic direction to scientific research in our country; and to procure for the labors of scientific men, increased facilities and wider usefulness."

These objectives remain in place today and are met by a wide range of activities, including the ongoing program of AAAS meetings and the relationship with the journal *Science*, which AAAS has been linked with since 1900 and has owned since 1944. In addition, just as scientific progress has accelerated over the past century and a half, so the objectives of the Association have widened. Thus, the Committee on Science, Engineering, and Public Policy, established in 1973, took the lead in bringing science to political decision-makers, and in 1977, a new objective "to foster scientific freedom and responsibility" was introduced to help define the rights and obligations of scientists. These changes presaged a major current focus for the Association, namely promotion of the public understanding of science. Through the Directorate for Education and Human Resources, AAAS is involved in activities as diverse as science radio shows for children, joint projects with black church groups, media fellowships for science and engineering students, and Women in Science programs. Most recently, the realization that public understanding of science must be matched by scientists' understanding of the public led the Association to initiate a "conversation with the community" (see www.sciencemag.org/feature/data/aaasforum.shl/) to identify the key issues facing science and society, and meaningful ways to address them.

It is thus in keeping with the spirit of the organization that we have chosen to celebrate 150 years of the AAAS by exploring how the advancement of science—for better or worse—influences the nature of society. While this is not a direct tribute to the rich history of the Association (a retrospective analysis will be provided by a three-volume history to be published later this year), it does provide testament to the intellectual ferment that is an integral part of AAAS. The organizing committee consists entirely of *Science* staff, and, in keeping with the editorial policy of the journal, the series has been put together with complete editorial independence.

The essayists represent a broad mix. Many of them are scientists who have thought deeply and feel strongly about science's place in society. But we have striven to include the creative insights of a wide range of nonscientists too—members of the business community, teachers, journalists, philosophers, critics, and schoolchildren. In providing such diverse perspectives, it becomes impossible to give a truly comprehensive picture, and we apologize for the inevitable omissions. However, we are confident that the series will provide a vivid illustration of how the scientific endeavor is perceived today.

150th Anniversary Essay Committee*

**Richard B. Gallagher (Chair), Christine Gilbert, Barbara Jasny, Andrew Lawler, Elizabeth Pennisi, Linda R. Rowan, and Julia Uppenbrink*

LETTERS

Envisioning the future

Physicists hold forth on the frontiers of their fields—fractality and muon colliders (right). The genetics of how insulin signaling and longevity are related in a nematode are explored. And ending polio immunization is discussed by scientists considering international policy.

Is Nature Fractal?

David Avnir *et al.* (*Science*'s Compass, 2 Jan., p. 39) report on the high proportion of hasty claims of fractality in *Physical Review* journals and end by saying that "[t]his is the fractal geometry of nature." When assessing a field, other authors might not dwell so much on the statistics of implied and possible failures, but on the variety and quality of the best work. In the case of fractal geometry, it is outstanding.

As I have stressed (*1*, p. 3), fractals *are not* a panacea; they *are not* everywhere. But many investigations in numerous fields started with few decades of experimental data and later moved to many. For example, the fractality of metal fractures was reported (*1*, p. 461) over a few decades, and this produced the first appropriate measurement of roughness. E. Bouchaud has now confirmed fractality over five decades (*2*). In another example [references and discussion in (*1*), chapter 8], in 1963, Berger and I postulated the fractality of transmission errors on the basis of data ranging from seven to nine decades. Even in finance, my new multifractal model (*3*) covers data ranging from three to four decades. In a multitude of other instances, repeated analysis, based on abundant data and distinct methods, yields the same result, or a well-understood theory explains why upper and lower cutoffs are both unavoidable, or both.

Those examples do not exhaust the usefulness of *careful* fractal modeling. Many claims that are questioned by Avnir *et al.* are best understood as unfortunate side effects of enthusiasm, imperfectly controlled by refereeing, for a new tool that was (incorrectly) perceived as simple.

Since 1983, Avnir has published extensively on data that cover one decade or less (*4*), and his claims of fractality have become widely known and disputed. This work is not mentioned in the article. It appears, then, that Avnir is withdrawing his earlier claims.

Benoit B. Mandelbrot
Department of Mathematics, Yale University, New Haven, CT 06520-8283 USA

References

1. B. B. Mandelbrot, *The Fractal Geometry of Nature* (Freeman, New York, 1982).
2. E. Bouchard, *J. Phys.* **C9**, 4139 (1997).
3. B. B. Mandelbrot, *Fractals and Scaling in Finance: Discontinuity, Concentration, Risk* (Springer-Verlag, New York, 1997).
4. D. Avnir, Ed., *The Fractal Approach to Heterogeneous Chemistry*, vol. 2 (Wiley, Chichester, UK, 1989); in *Handbook of Heterogeneous Catalysis*, G. Ertl *et al.*, Eds. (Wiley-VCH, Weinheim, Germany, 1997), pp. 598–614.

Avnir *et al.* turn the question of whether experimental power laws scale over many or few decades of length into a litmus test for well or poorly established fractals in nature. There are several problems with this viewpoint. Avnir and I have presented, *inter alia*, scaling ranges of less than a decade as fractals (*1*); I developed criteria to distinguish tentatively fractal power laws from crossover effects (*2*); in critical cases, he and I tested the fractal hypothesis extensively—and successfully—for consistency with all available data (*3*). Thus, the article leaves unmentioned Avnir's own contributions to what he classifies as "perhaps erroneous fractal label." It also leaves unmentioned that the discovery of fractals requires a lot more than fitting a power law through a set of points and asking how many decades of length it spans. To discredit limited scaling ("[t]he scaling range of experimentally declared fractality is extremely limited") panders to the skeptic; to allow that "the use of this label [fractal] may be acceptable" caters to the enthusiast; to state that "the question of fractality is … secondary" and "the label 'fractal' is not needed" says the issue is not important. One can't have it all three ways. To assess the fractality of nature, one can't just take a histogram of 96 power laws and compute the mean. It's too much like fitting a power law through a set of points.

Peter Pfeifer
Department of Physics and Astronomy, University of Missouri, Columbia, MO 65211, USA
E-mail:physpepf@showme.missouri.edu

References

1. D. Avnir, D. Farin, P. Pfeifer, *Nature* **308**, 261 (1984).
2. P. Pfeifer, *Applic. Surf. Sci.* **18**, 146 (1984).
3. ———, in *Fractals in Physics* (Elsevier, Amsterdam, 1986), pp. 47–53; P. Pfeifer, D. Avnir, D. Farin, *IVATO Adv. Study Inst.* **B258**, 215 (1991).
4. D. Avnir, D. Farin, P. Pfeifer, *New J. Chem.* **16**, 439 (1992); P. Pfeifer and K.Y. Liu, *Stud. Surf. Sci. Catal.* **104**, 625 (1997).

Response: Mandelbrot's reaction to the outcome of our analysis is uncalled for. Our papers (*1*, *2*) reported on the most comprehensive survey of experimental measurements of fractals done thus far. This survey allows one both to assess the abundance of fractals in various types of physical systems and to examine the dimensions and the scaling range of empirical fractals. The answer to the critical question of "the abundance of fractals" determines either their central relevance to all fields of natural sciences or their esotericity.

Mandelbrot's main point is that there are some examples of many decades of fractality, and he suggests that we simply were looking at the wrong data. However, the data we analyzed is not junk and cannot be dismissed: it comes from a prestigious set of journals in the physics community, and they represent beyond doubt the status of fractals in the natural sciences. The main problem is that the "best data," according to Mandelbrot's own criteria, is exceptionally rare, which at the very least raises the need for a serious reexamination of the explicit book-title claim (*3*). It is in order, then, to reexamine some of the best known experimental examples, beginning with the flag question of the whole field, "How long is the coast of Britain?" (*3*). The answer, given by Mandelbrot in (*3*) in terms of the original study of Richardson, is that various coastlines exhibit power-law behavior, spanning between one and two orders of magnitude, with an average of about 1.3 orders (conforming with the average we found in our survey). If these limited power-law correlations represent legitimate fractals according to Mandelbrot, then by the same token so are all of the 96 limited-range examples of fractals we analyzed.

It was not suggested in (*1*) or (*2*) that many-orders fractal objects do not exist. However, one must use an extremely fine sieve to search through the scientific literature for a meager handful of examples. Even this handful is, in many cases, problematic. Let us take, for instance, Mandelbrot's metal fracture study (*4*), cited in his comment and cited also by Marder (*5*) and by Kalia *et al.* (*6*) as a classical example. The four orders of magnitude, shown in figure 1 of (*4*), are in fact only two orders. This is due to the method used there to extract the fractal dimension, namely the perimeter-area relationship. The yardstick used in this type of resolution analysis is of area units, and not the relevant linear extent. This leads to an artificial doubling of the number of decades. Another classical example for a many-orders physical fractal has been Lovejoy's report on the fractality of clouds (*7*), also determined from perimeter-area relations. Again, the six orders shown in figure 1 of that reference are actually only three, for the same reason, as is indeed stated in the text. Even these three decades are composed of two different experiments (radar data sensitive to rainfall and satellite pictures of clouds), covering each about two orders of magnitude, with some overlap. The other two examples mentioned by Mandelbrot are temporal self-affine trails. As stated in (*2*), such trails fall outside the domain of our discussion, because the time axis can be extended at will. Moreover, the eight cases in (*1*) and (*2*) with a scaling range extending beyond two decades are dominated by spatial self-affine fractals, such as sections of rough surfaces and fronts (*8*). This further lowers the average number of decades in isotropic self-similar fractals. As in temporal self-affine trails, an experiment leading to spatial self-affinity can in principle start with as long a front as desirable and is thus not limited in scaling range.

In conclusion, it appears that the limited-range empirical fractals (*9*) are the dominant justification for "the fractal geometry of nature." Rather than sweeping them under the carpet as "bad data," their limited range should be carefully studied and understood. An intriguing and fundamental question that remains open is, Why are these limited-range fractals so common?

Ofer Biham, Ofer Malcai
Racah Institute of Physics, Hebrew University, Jerusalem 1904, Israel
Daniel A. Lidar
Racah Institute of Physics, Hebrew University, and Department of Chemistry, University of California, Berkeley, CA 94720, USA
David Avnir
Institute of Chemistry, and Lise Meitner Minerva Center for Computational Quantum Chemistry, Hebrew University, Jerusalem
Email: biham@13.flounder.fiz.huji.ac.il

References and Notes

1. O. Malcai, D, Lidar, O. Biham, D. Avnir, *Phys. Rev.* **E56**, 2817 (1997).
2. D. Avnir, O. Biham, D. Lidar, O. Malcai, *Science* **279**, 39 (1998).
3. B. B. Mandelbrot, *The Fractal Geometry of Nature* (Freeman, San Francisco, 1982).
4. ———, D. E. Passoja, A. J. Paullay, *Nature* **308**, 721 (1984).
5. M. Marder, *Science* **277**, 647 (1997).
6. R. K. Kalia, A. Nakano, A. Omeltchenko, K. Tsuruta, P. Vashishta, *Phys. Rev. Lett.* **78**, 2144 (1997).
7. S. Lovejoy, *Science* **216**, 185 (1982).
8. See also P. Daguier, S. Henaux, E. Bouchaud, F. Creuzet, *Phys. Rev.* **E53**, 5637 (1996), although an explicit fractal dimension is not mentioned.
9. The usefulness and authenticity of the limited range empirical fractals, which is a central theme in (*2*), is not addressed by Mandelbrot. Thus, there is no cause for alarm that "Avnir is withdrawing his earlier claims." On the contrary, not only does Avnir stand behind the usefulness of the many limited-range fractals he, P. Pfeifer, and their many co-workers have found over the years, but he continues to detect them and reported recently on a method of controlling the effective small-angle x-ray scattering surface fractality of modified silicas [C. Rottman, G. S. Grader, Y. De Hazan, D. Avnir, *Langmuir* **12**, 5505 (1996)].

Muon Collider

Alexander Hellemans (News, 9 Jan., p. 169) conveys the physics of muon colliders to an admirable extent, and I agree with much of what is said in his article. I am an advocate of working on muon collider research and development (R&D), and I am even a sub-spokesman for the collaboration, for which Robert Palmer of Brookhaven National Laboratory is the spokesman. However, because of the context of certain quotes, the article conveys an inaccurate impression of some of my views.

Although I am working hard to make it a reality, I would not say, for example, "We can build a Higgs factory." My view is that the option is very attractive, but must receive strong funding support from the U.S. Department of Energy and strong R&D commitment from the community if we are to know that such a machine is a viable option at