A Scientist's Adventures in Postmodernism

Mario Markus

ABSTRACT

The author provides an account of his everyday experience as a physicist, which allows him to witness research on chaos as a science of convergence: the elite with the masses, the scientific disciplines with each other, modern physics with Giordano Bruno's philosophy, and science with mysticism and art. He also outlines how chaos theory displays postmodern features and dissolves the boundaries between the "two cultures."

Fifteen years ago, while working at the Max-Planck-Institut, I became interested in biorhythms, the endogenous, physiological clocks of organisms. I was fascinated by experiments performed in the 1960s with persons in isolation that showed that our daily clock is not 24 hours, but can range between 21 and 27 hours (with some exceptional cases of up to 48 hours) and only maintains at 24 hours with exposure to light and society [1].

At that time, I asked myself what would happen to a 21-hour-person on a 30-hour-planet. Would this person adjust, and if not, what else could happen? I decided to experiment, but instead of people I used brewer's yeast cells, which have a biorhythm period of about one minute. Instead of a planet with a different rhythm, I used a motorized syringe that periodically provided the yeast with a feeding solution. Yeast has lived symbiotically with humans for thousands of years, producing alcohol when we provide it with plants containing sugar. Depending on the amplitude and frequency with which I fed the yeast, the experiment yielded three types of results: (a) the yeast's alcohol production periods became entrained to the syringe feeding period as long as it did not vary greatly from the yeast's normal rhythm; (b) the two periods coincided; and (c) chaos, i.e. the yeast's alcohol production oscillated unpredictably. My colleagues would bet me one deutsche mark that alcohol production would rise above average within the next 60 seconds. Sometimes I won, sometimes I lost. At that time, it was the first laboratory demonstration of chaos in a biological system [2]. Nobel Prize–winner Ilya Prigogine was so fascinated with our experiment that he communicated our computer simulations of this phenomenon to the National Academy of Sciences in the U.S., which eventually published them [3]. On the basis of this work, the University of Dortmund conferred on me the "Habilitation," a kind of assistant professorship, in 1988.

A few years later I learned that my work represented the peak of banality: I had discovered a basic phenomenon in nonlinear science using an unnecessarily complicated and particular system. In fact, chaos appears in general when two oscillating systems (oscillators) compete, provided the equations governing them are sufficiently non-linear so that the oscillators do not simply overlap. Many observations of chaos in such coupled oscillators were reported in those years, including the double pendulum [4] and Saturn's rings [5]. With regards to the latter, a rock in the ring is subject to both its own endogenous rotation around Saturn (the period of which is defined by the distance) and to an external gravitational force imposed on it by the Saturn satellite Mimas. Like yeast, the rock's dynamics may become chaotic, leaving black, empty stripes at the orbits they would have if Mimas were not there.

VERTICAL PLURALISM

Before my academic fiasco became known in the university, I received a phone call from philosophy professor Friedrich Rapp in 1990, who asked me if I would like to give a talk on my work on chaos in the "Studium Generale" series in the university's auditorium. Since only four speakers are invited each semester, I did not hesitate to agree.

Two weeks later, I saw the posters announcing my talk in the cafeteria, but they made me chill with fear: they announced a "Studium Generale on Postmodernism," and I only vaguely knew what postmodernism was. I phoned Rapp, who said: "Take it as a

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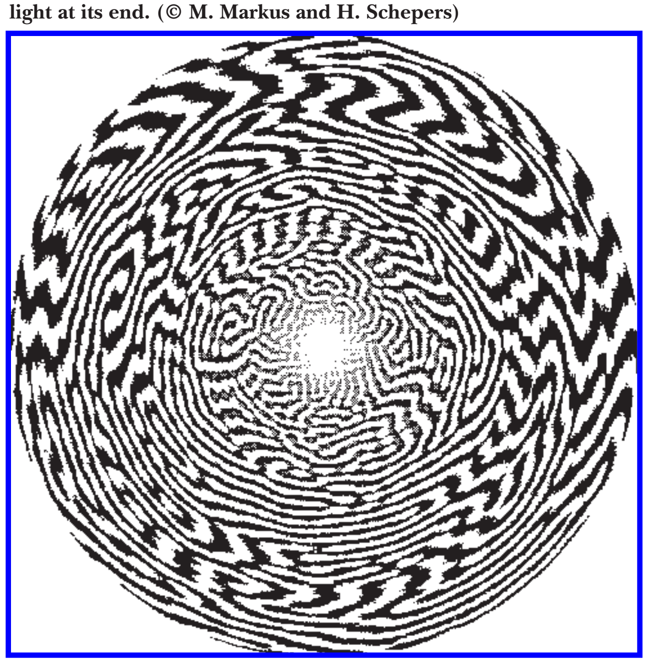
Fig. 1. M. Markus and H. Schepers, *Light at the End of the Tunnel*, computer simulation of a near-death experience as a self-organized structure in the visual cortex, 1992. This structure is caused by near-by activation and far-reaching inhibition due to lack of oxygen, and impresses in the subject the image of a tunnel with light at its end. (© M. Markus and H. Schepers)



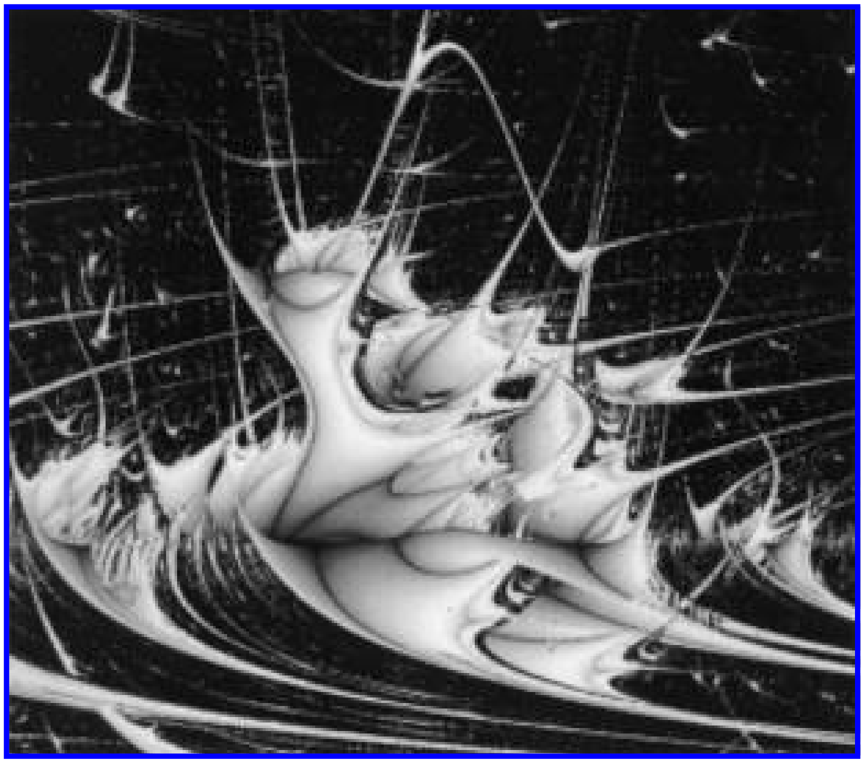
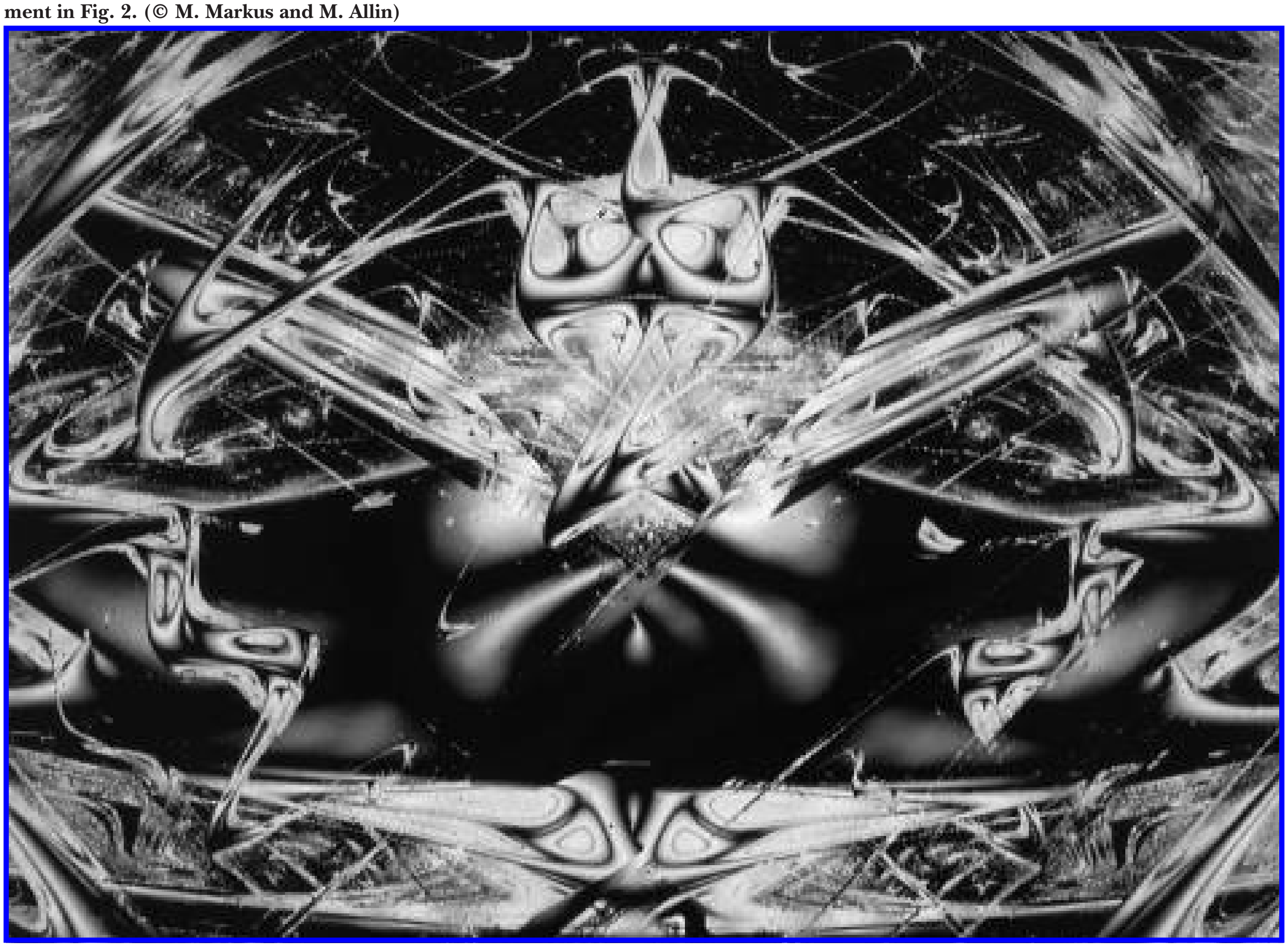


Fig. 2. M. Markus and K. Kötter, *Lyapunov Orgy,* personal computer and laser printer, 1995. $x_{n+1} = g(x_n)$ if $x_n \geq 0.5$, or else $x_{n+1} = b\, g(x_n)$, where $g(x_n) = r_n \sin(\pi r_n) \sin(\pi x_n)$, $b = 0.9$, r_n: $A^2B^2\ A^2B^2 \ldots$ (© M. Markus and K. Kötter)

challenge to find out the parallels between your results and postmodernism." Actually, I got the impression that he did not know the parallels himself—he just had some intuition. So I looked for the definition of "postmodernism" in a new philosophy encyclopedia, but the text—unreadable to a layman in philosophy like me—oscillated between Heidegger, Lyotard and Bonito Oliva; I understood nothing. Luckily, it cited a work that promised to be fundamental and understandable to me. It was Leslie Fiedler's "Cross the Border—Close the Gap", a highly enlightening text in a highly unorthodox journal [6].

Fiedler's article is—among other things—both a take-off on such elitist writers as Marcel Proust and Thomas Mann and a tribute to such songwriters as Leonard Cohen, Frank Zappa and Bob Dylan. Fiedler's point is that some of the song lyrics of these artists reach both the literary elite and the masses—a typical postmodern feature, I learned—and therefore bridge the old abyss between an art for the educated and a sub-

Fig. 3. M. Markus and M. Allin, *A Chief from Cygnus,* personal computer and laser printer, 1995. A is shifted 1.5 units to the right of placement in Fig. 2. (© M. Markus and M. Allin)



art for the non-educated. Further reading taught me that there exist such things as postmodern cooking and postmodern tourism, but I found nothing on postmodern science, the subject I was supposed to talk about. This was until I realized that what Fiedler was describing had been happening for years in my department, where high school science students worked on chaos theory for their training during vacations: they sometimes got valuable scientific results within a short time in spite of their lack of expertise. This type of bridging between experts and laymen is particularly easy in chaos research both because most of this research takes place via patient, game-like experimentation at the computer and because a substantial part of chaos theory deals with the mesocosmos, i.e. the things that are directly detectable by our senses (such as clouds, flames and arrhythmic hearts). These things are certainly more conceivable than either the elitist microcosmos of the elementary particle physicists or the macrocosmos of the cosmologists.

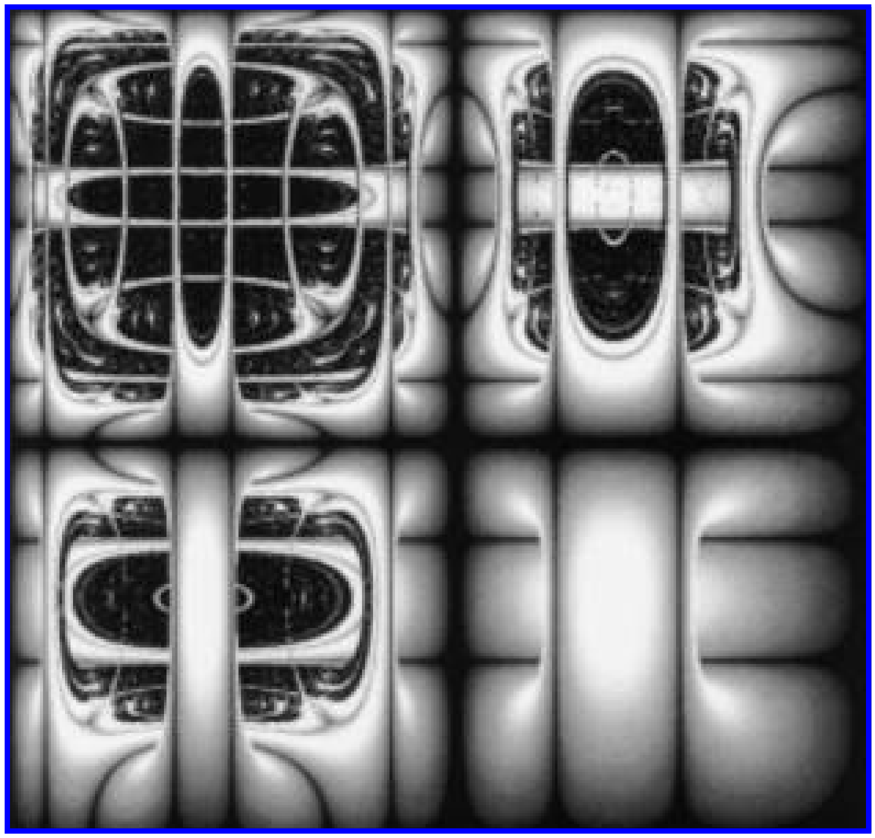


Fig. 4. M. Markus and K. Kötter, *Breathing Windows*, personal computer and laser printer, 1995. $x_{n+1} = r_n \sin(\pi r_n) \sin(\pi [x_n - b])$, b = 0.5, r_n: AB AB . . . (© M. Markus and K. Kötter)

HORIZONTAL PLURALISM

The above considerations led me to regard the vertical pluralism of the elite and the masses as a postmodern aspect of chaos theory. Later on, I felt that this vertical aspect should be complemented by another "crossing of the border and closing of the gap": namely, a horizontal, interdisciplinary pluralism, which we can associate with Bonito Oliva's "all territories of culture" [7]. This da Vinci–style pluralism had disintegrated more and more over the centuries; however, in non-linear science (to which chaos theory belongs) we are witnessing a new convergence. Nowadays, many conferences feature experts as far apart as astronomers and medical doctors speaking the same language [8]. A holistic, rather than a reductionist, attitude makes such a dialogue possible. By choosing examples from classical mechanics (the double pendulum), astronomy (Saturn's rings) and biology (yeast) to illustrate the emergence of chaos in coupled oscillators, I displayed a holistic attitude that entailed scrutinizing a whole system rather than reducing it to its details.

Fig. 5. M. Markus and B. Hess, *Fly Together*, personal computer and laser printer, 1988. $x_{n+1} = r_n x_n (1 - x_n)$, r_n: AABAB AABAB. . . (© M. Markus and B. Hess)

We see another example of horizontal pluralism in the simulation of patterns in the visual cortex under near-death conditions [9] (see Fig. 1). Hans Schepers and I carried out these computer simulations considering so-called active sites in the visual cortex (shown in black in Fig. 1) which emerge erratically, are amplified by positive feedback on themselves and activate nearby sites. In the case of low oxygen supply occurring in a near-death situation, the "active" sites inhibit regions farther away within a certain spatial range, preventing a further spread of activity. These inhibited regions are shown in white in Fig. 1. Erratic fluctuations of activity can be amplified only in regions that are sufficiently far from the inhibitory action. We achieved the pattern in Fig. 1 when we considered that connections between the cortex and the retina are such that Cartesian coordinates in the visual cortex (where the patterns are formed) are transformed in to polar coordinates in the retina, and it is this retinal pattern that is interpreted as a vision by the brain. How does this relate to horizontal pluralism? The mechanism of the retina is governed by the same principles that define leaf veins or pigmentation patterns on animal skins [10], except that activation in leaves and skins is caused by rapidly diffusing chemicals, while patterns in the visual cortex are caused by close-reaching neuronal synapses. I thus felt myself caught up in a "theoretical theology," in which we interpreted the oft-mentioned "tunnel with light at its end" [11] as something like mackerel or zebra stripes occurring in the brain.

Fig. 6. M. Markus and T. Kauch, *I Remember a Puppet*, personal computer and laser printer, 1998. $x_{n+1} = \exp(r_n/[\sin x_n + \cos x_n])$, r_n: $A^3B^3\ A^3B^3$ . . . (© M. Markus and T. Kauch)

The study of fractals also reflects the spirit of horizontal pluralism. Fractals look similar in small and large scales, seen in Julia and Mandelbrot sets or—most lucidly—in Jonathan Swift's fleas, whose own fleas are itched by their own flea-bitten fleas and so on. One studies fractals by employing the same methods used to study the surface of catalysts, reconstructed attractors from the sun's activity, or EEG-signals recorded during different mind states [12]. Horizontal pluralism via holism is also the essence of the theory of excitable media [13], which embraces systems as diverse as heart muscles, epidemics, aggregating amoeba, fertilized fish eggs and galaxy dynamics.

Surprises Contrary to Reason

I define a third postmodern aspect of chaos theory as "openness to surprises contrary to reason": the celebration of arbitrariness . . . reason as the Goddess of Modernism . . . and of the Age of Enlightenment [14]. Based on reason, humans have projected into the future through various ideological programs: the Reformation, the Counter Reformation, German idealism, Marxism and, in the natural sciences, Newtonism. I use the word "reason" here in the sense of "calculability". Newton's work aroused a claim for predictability that peaked with Pierre Simon de Laplace in 1776. Laplace envisaged an entity—later called the "Laplace Demon" (nobody envisaged anything quite like a computer at that time)—capable of calculating the past and future of the universe, provided we feed it with the positions and velocities of all particles of the universe, and, of course, with Newton's formulae. It follows from Laplace's thinking that if we were to include the particles in our brains, free will would become an illusion. Laplace's God is equivalent to the present state of the universe since it is the same thing we call "past," then "present" and then "future," because one may calculate one from the other. Laplace's God indeed just turns the pages of a book that is already written.

Contrarily, postmodernism abandons the idea of an historically structured and predictable world à la Isaac Newton or Karl Marx [15]. It is characterized by the acceptance of arbitrariness. Strangely, scientists have stubbornly stuck to calculability, although there are phenomena in front of everybody's eyes that have always resisted prediction: weather changes, the roulette wheel and horribly surprising insect plagues such as the forest-eating Gypsy moth in the U.S. Scientists have handled these phenomena by using statistics, a discipline that certainly appeared long before postmodernism; however, statistics are of no help in predicting singular events.

The first scientist who realized that Newton's equations may lead to unpredictable behavior was Henri Poincaré. He studied the problem of three interacting celestial bodies (such as in the previous example: Saturn, a ring's rock and Mimas) and showed that small perturbations in the initial conditions for the development of such a system may eventually overshadow the whole system. Poincaré remarked: "Unthinkably small subtleties in the croupier's arm may decide upon all my stake in the casino . . . These things are so bizarre that I cannot stand thinking about them" [16]. This was the birth of what was later called the science of chaos.

With a potentially chaotic system—such as the oscillating yeast, a mechanical device or an insect population—it is important to know which externally imposed conditions make the system behave chaotically and which render it predictable. We have found a comfortable way of visualizing this, exemplified here in Figs. 2 through 9 (other examples are given in [17]; technical details are found in the Appendix). The coordinates of these figures correspond to control parameters, i.e. externally imposed conditions. Within the lighter regions appearing in the figure foregrounds, the system is predictable; within the darker figure backgrounds, it is chaotic. A team of students and colleagues conducted the long search of parameters, windowing, axes-scaling and grey-shadings (or colors) in these diagrams (see the figure captions). A larger collection of these kinds of figures that was exhibited in several countries garnered an award in Chile—not by scientists, but by a society of art critics. That surprising event only extends horizontal pluralism beyond its scientific status as a postmodern aspect of chaos theory into an even broader realm in which pictorial art is bridged to scientific activities: C.P. Snow's "two cultures" merge [18].

In order to account for the artistic input of the type of imagery we have created, one may invoke the work of fine art photographers: "They capture a slice of the real world from their personal viewpoint" [19]. In fact, just as a photographer chooses among infinite motifs and then alters light and contrast, we choose among infinite formulae and parameters and then alter axes scaling, windows and colors, seeking to create an atmosphere that will convey a message to viewers. Also relevant is the concept of the "controlled accident," which has led to the comparison of computer-generated pictures with the paintings of Jackson Pollock [20]. As Timothy Binkley noted, "The computer rises from the sea of postmodern culture . . . as a wily sorcerer . . . that commands an intriguing repertoire of artistic resources" [21]. A more elementary and more critically exposed analogy is the kaleidoscope, which David Brewster exuberantly presented as a source of art in the nineteenth century [22].

Fig. 7. M. Markus and M. Woltering, *Lady Marble*, personal computer and laser printer, 1995. $x_{n+1} = b \sin^4 (x_n - r_n)$, b = 2.4, r_n; $A^2B^2\, A^2B^2$ . . . (© M. Markus and M. Woltering)

The overwhelming development of computers has generated a boom in chaos studies. Unfortunately, many of its results are only of dubious use (for example, the finding that outbreaks of measles and mumps in New York and Baltimore between 1928 and 1963 had characteristics of chaos [23]). On the other hand, some highly useful results appeared in the clinical domain. One example is Rolf-Dieter Hesch's finding (at the Medizinische Hochschule Hannover, Germany) that parathormone oscillations of healthy persons are chaotic and that these oscillations become more and more predictable as osteoporosis develops in a patient [24]. There are more examples like this in medicine, including electrocardiogram analyses and the development of implantable defibrillators to control chaotic heart rhythms. Considering all these efforts, what have we learned about the predictability of conditions like the weather? The routine is to collect the data from about 10,000 weather stations (plus some satellites and balloons) and get predictions for about three days. Chaos theory allows us to estimate that a prediction 11 days in advance would require 100 million stations, and a prediction one month in advance, 10^{20} stations all over the world—that is, one station on every 5 mm^2 of earth and water. Clearly, there is no feasible solution, and the Laplace Demon is in agony. Even more aggravating is the estimation that in order to process the data for a two-month prediction, one would need a computer that has more processing elements than there are atoms on earth. Furthermore, no presently conceivable computer speed would render any results before the two months are over. We can definitively kill the Laplace Demon (more precisely, the meso- and macroscopic Demon [25]) with a more lucid example than the weather: balls colliding on a billiard table. Humans can learn to predict the last angle of a 3-ball carom. Any advanced physics student can calculate how amazingly fast unpredictability increases with the number of balls. A computer programmed to predict the outcome with 9 balls would have to consider the gravitational forces of objects around the table. For 49 balls (the number of balls in the German lottery sphere), the gravitation of the whole Milky Way is involved. For 56 balls one would have to consider the influence of an electron 20 billion light years away, at what some would call the "edge of the universe." Undoubtedly, a computer exists that is able to consider all these influences. It is an analogue computer: the universe itself. Only the universe can predict what will happen within it. As a philosophical layman, I am deeply amazed by a number of developments of our concept of the world and its knowledge. In 1586, Giordano Bruno published his "Figuratio Aristotelici Physici Auditus," in which he rebelled against the predominance of Aristotelianism and wrote that God is the universe, which drives itself. The main difference between this stance and my statement above on the self-predicting universe is that Bruno was burned for his position. In 1687 (101 years later), Isaac Newton—free from Aristotelianism—published his "Philosophia Naturalis Principia Mathematica," the seed of what would become Newtonism. Another 101 years later, in 1788, Newtonian science reached its peak with the publication of Joseph-Louis Lagrange's "Mécanique

Fig. 8. M. Markus and K. Kötter, *Yesterday's Windows*, personal computer and laser printer, 1998. $x_{n+1} = b \sin(x_n) \sin(r_n x_n)$, b = 1.2, r_n: $A^3B^2\ A^3B^2 \ldots$ (© M. Markus and K. Kötter)

Analytique," contemporaneously with Laplace's Demon. In 1889 (yet another 101 years later), our view of the world changed with Poincaré's work on the three-body problem, "Les Méthodes Nouvelles de la Mécanique Céleste," the seed of chaos theory. And still another 101 years later, in 1990, I received a phone call from Friedrich Rapp, which via Fiedler's article finally led my worldview to encounter that of Giordano Bruno.

On the other hand, the world is not only made of unpredictable phenomena. As mentioned in the Appendix, diagrams such as those in Figs. 2 through 9 can be drawn for any physical system. The technical devices or biological functions that make the world reliable operate in the regions of predictability (pictured as the lighter regions in the image foregrounds). On the other hand, we know that such wonderful things as orange trees and the human brain resulted via selection from unpredictable fluctuations. Similar scenarios are found in the development of ideas. Hans Jensen, who taught me theoretical physics in Heidelberg, enjoyed recounting how he got the idea for his nuclear shell model (in which the particles inside the nucleus behave similarly to the electrons surrounding that nucleus): he was watching dancers going round in a carnival after he had been brooding fruitlessly over huge amounts of spectroscopic data. He was awarded the Nobel prize.

Although the interplay of unpredictability (as creative drive) with predictability (for functional reliability) has indeed been recognized by scientists (especially evolutionary biologists), I am not sure that sociologists have learned from this dissolution of a black-or-white mentality. In fact, the modernist or postmodernist paradigm has been subject to severe political discussions. A. Hill made his position clear in 1987 [26]: "Modernism was largely Left, Postmodernism . . . is largely Right, if not covertly Fascist." Note that postmodernism became exceptionally fashionable around 1990, after the dissolution of the Eastern bloc. When Russia suffered a severe crisis that affected the rest of the world, Marxist Terry Eagleton got much publicity with his book, *The Postmodern Illusion* [27], which has induced newspaper headlines such as "The Postmodern Game is Over" and "The Postmodern Swindle." This attitude, however, has not been omnipresent [28].

The reader may be expecting from me some formula that would implement in politics a fruitful interplay between planned and unplanned economic models. But as a scientist, I will not dare to suggest operating instructions. However, I can offer a phenomenological description of such an interplay by using the newly "en vogue" mathematical theory of "Class 4" behavior [29]. This is also called "the edge of chaos" and corresponds to "spatio-temporal on-off intermittency" in continuous systems. "Class 1" means stagnation; "Class 2," periodicity; "Class 3," chaos; and "Class 4," the unpredictable alternation of chaos and order. There exist, indeed, physical and biological systems that endogenously display Class 4 behavior, which has been regarded as essential for the development and survival of living systems [30]. However, no matter to what degree we accept a general relevance of Class 4 systems, the problem remains: the predictability-unpredictability transitions are again unpredictable. Thus, we may be closer to understanding what is going on, but farther away from knowing what to do next. Therefore, any attempt at a modern-postmodern parliament will probably itself be postmodern.

Figure 1 represents an example of self-organization in the human brain cortex. Being the simulation of a "vision," this figure also puts us closer to the mystical wandering through the last tunnel in *The Rise to the Empyreum* by Hieronymus Bosch [31]. To be honest, though, I suspect myself of having influenced our choice of the parameters for Fig. 1 so that it may capture the atmosphere of Bosch's masterpiece, or maybe of Doré's illustrations of Dante's paradise-vision. I certainly did exert such an influence in Fig. 9, having other works of Bosch in mind. Considering that all of this figure strictly transmits a scientific message, I felt once more deeply involved in a dissolution of the "two cultures."

APPENDIX

We obtained Figs 2 through 8 and Fig. 9a with the iterative equations that are given in the captions, according to the following procedure.

Any point on a figure has an abscissa A (horizontal distance from the left edge) and an ordinate B (vertical distance from the lower edge). I will take Fig. 7 as

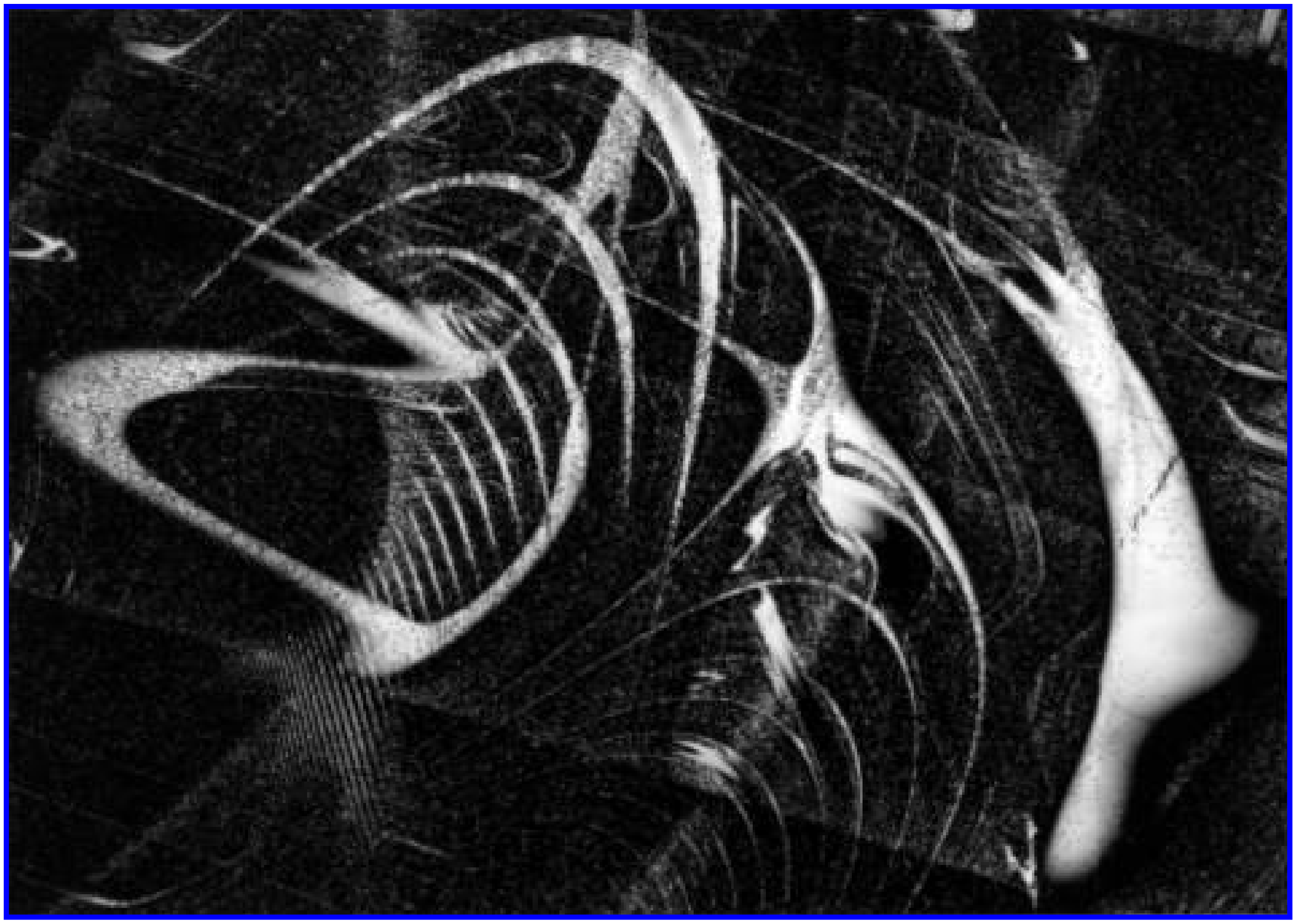


Fig. 9. (a, top) M. Markus and T. Kauch, *The Harp and the Ear*, personal computer and laser printer, 1998 [Abscissa A is shifted 0.5 units to the left of placement in Fig. 6]. (© M. Markus and Tobias Kauch). (b, bottom left and bottom right) Parts of *The Gardens of Lust*, by Hieronymus Bosch (© Museo del Prado, Madrid. All rights reserved.)

an example for the explanation; the other figures are done analogously. We start with $n = 1$ and set $x_1 = 0.5$. Using the iterative equation $x_{n+1} = b \sin^4(x_m + r_m)$, we calculate x_2 from x_1: $x_2 = b \sin^4(x_1 + r_1)$ with $r_1 = A$ (b is always set to 2.4), then x_3 from x_2: $x_3 = b \sin^4(x_2 + r_2)$ with $r_2 = A$, then x_4 from x_3 with $r_3 = B$, then x_5 from x_4 with $r_4 = B$, and so on. Note that r_n follows the periodic sequence AABB AABB . . ., which is written as A^2B^2 A^2B^2 in the figure caption. In this way we obtain a sequence $x_1, x_2, x_3, \ldots, x_n, \ldots$ These x_n values are inserted in the derivative dx_{n+1}/dx_n, which is calculated analytically from the iterative equation. We then calculate the so-called Lyapunov-Exponent λ by taking the average of the algorithm of the absolute value of dx_{n+1}/dx_n. (The first 200 values are not considered, in order to allow transients to die away; the average is then taken over the next 1,000 values. Taking more values does not significantly alter the results.) Finally, a grey value is assigned to the point of the figure defined by the considered values of A and B. Chaos, i.e. unpredictability, is indicated by $\lambda > 0$ and painted black. Periodicity, i.e. predictability, is indicated by $\lambda < 0$, grey levels changing here from black to white as λ increases. The procedure just described is done for each of 1000×1000 points (differing in A and B) in the figure. The other figures differ from Fig. 7 by the iterative equations and by the r_n sequences, as indicated in the captions. Calculations were performed with a workstation, but any personal computer would do the job. The grey levels on the plane defined by A and B were plotted with a laser printer. Note that the processes described here can be related to the dynamics of biological populations, with A and B corresponding to conditions in alternating periods of time, such as summer and winter [32]). Similar figures can be drawn for any systems in nature; one can use differential instead of iterative equations and any control parameters instead of A and B. Note that the quantity λ is obtained by a statistical average and the figures are therefore predictable; the figures tell us under which conditions there is chaos, but they tell us nothing about single unpredictable events occurring during a chaotic process.

Acknowledgments

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References and Notes

1. L. Rensing, *Biologische Rhythmen und Regulation* (Stuttgart, Germany: G. Fischer, 1973).

2. M. Markus, D. Kuschmitz and B. Hess, "Properties of Strange Attractors in Yeast Glycolysis," *Biophys. Chem.* **22**, No. 1–2, pp. 95–105 (1985).

3. M. Markus and B. Hess, "Transitions Between Oscillatory Modes in a Glycolytic Model System," *Proc. Natl. Acad. Sci. USA* **81**, No. 14, 4394–4398 (1984).

4. R.B. Levien and S.M. Tan, "Double Pendulum: An Experiment in Chaos," *American J. Phys.* **61**, No. 11, 1038–1044 (1993).

5. H.G. Schuster, *Deterministic Chaos* (Weinheim, Germany: VCH-Verlag, 1989).

6. L.A. Fiedler, "Cross the Border—Close the Gap," *Playboy* (Dec. 1969) pp. 151–258.

7. D.J. Cox, "The Tao of Postmodernism: Computer Art, Scientific Visualization and Other Paradoxes," *Leonardo* Supplemental Issue *Computer Art in Context* (1989) pp. 7–12. See also N. Zurbrugg, "Postmodernity, Métaphore manquée, and the Myth of the Trans-avant-garde," *Leonardo* **21**, No. 1, 61–70 (1998)

8. M. Markus, S. Müller and G. Nicolis, eds., *From Chemical to Biological Organisation* (Heidelberg, Germany: Springer, 1988). See also A. Holden, M. Markus and H. Othmer, eds., *Nonlinear Wave Processes in Excitable Media* (New York: Plenum, 1991).

9. M. Markus, "Hallucinations: Their Formation in the Cortex Can Be Simulated by a Computer," in *Worlds of Consciousness,* M. Schlichting and H. Leuner, eds. (Berlin: VWB-Verlag, 1995) pp. 131–140.

10. J.D. Murray, *Mathematical Biology* (Berlin: Springer, 1989).

11. S. Grof, *Beyond Death: The Gates of Consciousness* (London: Thames and Hudson, 1980).

12. See Markus, Müller and Nicolis, eds. [8].

13. See Holden, Markus and Othmer, eds. [8]. See also M. Markus and B. Hess, "Isotropic Cellular Automaton for Modelling Excitable Media," *Nature* **347**, No. 6288, 56–58 (1990); and M. Markus, G. Kloss and I. Kusch, "Disordered Waves in an Homogeneous, Motionless Excitable Medium," *Nature* **371**, No. 6496, 402–404 (1994).

14. D.J. Cox places the beginning of modernism at the turn of the century and its peak during the first half of the twentieth century [7]. Zurbrugg [7], more precisely, places modernism between the 1880s and the 1930s and postmodernism afterwards. On the other hand, Umberto Eco's work suggests that each epoch has its own postmodernism. Jürgen Habermas sets modernism at the Age of Enlightenment, while Peter Koslowski regards the Age of Enlightenment as one of many modernistic "projects." See also P. Koslowski, *Die Postmoderne Kultur* (Munich: C.H. Beek, 1987).

15. Zurbrugg [7].

16. H. Poincaré, *Wissenschaft und Methode* (Berlin: Teubner, 1914).

17. J. Rössler, M. Kiwi, B. Hess and M. Markus, "Modulated Non-Linear Processes and a Novel Mechanism to Induce Chaos," *Phys. Rev. A* **39**, No. 11, 5954–5960 (1989). See also M. Markus, "Chaos in Maps with Continuous and Discontinuous Maxima," *Computers in Physics,* 481–493 (Sept./Oct. 1990); and M. Markus and B. Hess, "Lyapunov Exponents of the Logistic Map with Periodic Forcing," *Comp. & Graphics* **13**, No. 4, 553–558 (1989).

18. C.P. Snow, *The Two Cultures* (Cambridge, United Kingdom: Cambridge Univ. Press, 1993).

19. Cox [7].

20. C.A. Pickover, "How to Design Textures Using Recursive Composite Functions," *Leonardo* **22**, No. 2, 219–222 (1989).

21. T. Binkley, "The Wizard of Ethereal Pictures and Virtual Places," *Computer Art in Context, SIGGRAPH '89 Art Show Catalogue,* Supplemental Issue of *Leonardo* (1989) pp. 13–20.

22. N. Gray, "Critique and a Science for the Sake of Art: Fractals and the Visual Arts," *Leonardo* **24**, No. 3, 317–320 (1991).

23. M. Markus, "Are 1D-Maps of Any Use in Ecology?," *Ecol. Modelling* **63**, No. 1–4, 243–259 (1992).

24. R-D. Hesch, "Gesundsein und Kranksein," *Futura* 1/88, 23–27 (1998).

25. The Laplace Demon had certainly been defeated already by quantum physics. This branch of physics, however, describes the atomic realm and stays in that realm except for its effects on some mesoscopic (e.g. spectroscopical experiments) or Gedanken-experiments (like Schrödinger's cat). One may say: quantum physics killed demons that were discovered long after Laplace. At a meso- or macroscopic level, the Laplace Demon is not questioned by quantum physics.

26. A. Hill, "About the Immediate Future of Modern Art," *Leonardo* **20**, No. 4, 349–352 (1987).

27. T. Eagleton, *Die Illusion der Postmoderne* (Stuttgart, Germany: Metzler, 1998).

28. K.H. Bohrer and K. Scheel, eds., *Postmoderne. Eine Bilanz* (Stuttgart, Germany: Klett-Cotta, 1998).

29. S. Wolfram, *Theory and Applications of Cellular Automata* (Singapore: World Scientific, 1986). See also M. Markus, I. Kusch, A. Ribeiro and P. Almeida, "Class 4 Cellular Automata Simulating Diverse Physical Systems," *Int. J. Bifurcation and Chaos* **6**, No. 10, 1817–1827 (1996); and I. Kusch and M. Markus, "Mollusc Shell Pigmentation: Cellular Automaton Simulations and Evidence for Undecidability," *J. Theor. Biol.* **178**, (1996), pp. 333–340.

30. Two popular science books on this subject have found serious resonance in such first class journals as *Nature* and *Science*. These books are R. Lewin, *Complexity: Life at the Edge of Chaos* (New York: McMillan, 1992) and M.M. Waltrop, *Complexity: the Emerging Science at the Edge of Order and Chaos* (New York: Simon & Schuster, 1992). Both books were reviewed in L.G. Harrison, "Aspirations in Santa Fe," *Science* **259**, No. 5093, 387–388 (1993); and I. Stewart, "Nature's Semantics," *Nature* **361**, No. 6412, 507 (1993).

31. See Zurbrugg [7].

32. Rössler, Kiwi, Hess and Markus [17].

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