

Fractal visionary dies: Benoit Mandelbrot, 1924-2010

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School students throughout the world, if they have access to personal computers, will have probably been given programmes that produce beautiful and complex pictures called fractals. A simple Internet search will turn up thousands of computer images, discussion articles and mathematical explanations of fractals. The most famous of them, the image called the Mandelbrot set, was named after the man who carried out investigations in the 1960s, 1970s and 1980s at the IBM laboratories at Yorktown Heights in New York State.

Benoit Mandelbrot coined the word “fractal” in 1975 to describe the revolutionary approach to geometrical mathematics that he pioneered. From the time of the ancient Greeks, geometry, associated with the name Euclid, had studied a restricted range of objects—lines, circles, planes, cylinders and so on. In the nineteenth century, under the impact of new developments in physics, especially electricity and magnetism, mathematician scientists like Carl Friedrich Gauss and Bernhard Riemann extended geometry beyond Euclid into higher dimensions. They examined properties such as curvature that were often far beyond our daily experience. This was the type of geometry that Einstein could apply to his theories of relativity. Nevertheless, even these new geometries relate to things that are smooth and even “tame” in some sense.

Mandelbrot began looking at many different branches of science—turbulence in fluid mechanics and meteorology, price fluctuations in economics, the growth of cells in physiology, the clustering of galaxies, the shape of trees and plants—and realised that traditional smooth geometry was often at best a crude approximation. Even the scientific understanding of causal or regular laws of extension and motion that were combined with or expressed through chance fluctuations or “noise”, the basis of most branches of science, did not satisfy Mandelbrot.

Mandelbrot wanted to show that what often appeared to be wild or random fluctuations that did not obey the laws of statistics could in fact be explained by simple laws or rules. His fundamental idea was that of “self similarity.” To take a

famous example, when you examine a cauliflower, cut it in pieces and magnify a piece, you find it has a similar structure to the original cauliflower. Cut the piece up again and magnify the new tiny pieces, and they have the same structure again. This approach enables a geometry to be applied to things where it did not previously seem possible—to clouds, coastlines, mountains and so on.

Such an unusual and even iconoclastic view of the world can partly be explained by Mandelbrot’s biography. He was born to a Lithuanian Jewish family, his father a clothes merchant and mother a dentist. The Mandelbrots moved to Paris in 1936, fearing the spread of Nazism. During the war they moved south to Tulle in central France where Benoit had no formal education, living in constant threat of poverty and capture.

Largely self-taught, but with educated parents and refugee teachers around him, Mandelbrot developed a highly individual genius for geometrical mathematics. After the war, he passed the examinations to the elite Ecole Polytechnic in Paris and, after graduating, visited the California Institute of Technology. He received a PhD at Paris, and then went to the Institute for Advanced Study at Princeton under John von Neumann. In 1955 he returned to a post at the Centre National de la Recherche Scientific in Paris.

Mandelbrot was deeply unsatisfied with the postwar state of mathematics. In France, mathematics was dominated by Nicolas Bourbaki. This was not a single person (the name was taken from a French general) but the collective pseudonym for a group of top mathematicians whose names were kept secret. Bourbaki produced a series of textbooks, mainly during the 1950s and 1960s that attempted to give a foundation to the whole of mathematics that was rigorously based on axioms, and was set out in the driest and most austere manner imaginable, without a single diagram or picture. The number of mathematicians in the group was fixed, and they had to retire at the age of 50.

Bourbaki was a reaction against the much more intuitive approach to mathematics, stemming from Henri Poincare, that predominated in France earlier in the century. It was very much in tune with a formalist or structuralist zeitgeist that permeated many academic areas at this time. Not unreasonably, this outlook was seen to be heavily influenced by Stalinism, even

though many of its mathematical practitioners had no connection with the Communist Party.

Mandelbrot, who always had a highly visual and experimental approach to mathematics, was very unhappy in France in the 1950s. He complained that he “loathed and feared” Bourbaki. He had a close personal connection with Bourbaki since his uncle, Szolem, was one of the founders of the group when it was a club of like-minded mathematicians in the 1930s. Szolem fled Paris during the war but returned as a professor at the University of Paris after the war and worked on the Bourbaki volumes. He told his nephew that “geometry has been dead for nearly a century” [1] and suggested he could work instead on a largely forgotten area of mathematical analysis in a paper by Gaston Julia, one of Poincare’s students. Benoit was not impressed, though the knowledge he gained about iterative sequences of complex numbers turned out to be central to fractal theory, and the student of fractal pictures will recognise the name Julia.

Escaping the stifling atmosphere of Bourbaki, Mandelbrot moved permanently to the US, taking a post at IBM’s research centre. This gave him the freedom to research into many areas—linguistics, aeronautics, engineering, physiology, economics, and so on, including also the history of science and the study of recondite areas of mathematics. Even here he did not escape the prevailing hostility to a materialist philosophy that had permeated mathematics and led mathematicians to see their formalistic world as somehow above and apart from reality. Mandelbrot takes a quote from Marshall Stone, then top mathematics professor at Harvard:

“While several important changes have taken place since 1900 in our conception of mathematics and in our points of view concerning it, the one which truly involves a revolution in ideas is the discovery that mathematics is entirely independent of the physical world....”

Mandelbrot strongly disagreed, insisting that the vitality of mathematics depended on applications to the real world. At IBM, he was able to investigate mathematics applied to many areas, “to retain permanently the ‘infantile sensibility’ I enjoyed as an adolescent” he wrote. The remark was provoked by the response of a mathematician who described his “mathematical sensibility” as being “rather infantile and somewhat dull.” This reaction, explains Mandelbrot, “echoes my uncle’s opinion.”

At IBM, Mandelbrot was able to use computers in a new way that has since become central to many branches of science. “I made them [the computer and computer graphics], not a tool to be called on only if needed, but a constant and integral part of my process of thinking,” he wrote.

Many scientists reacted against Mandelbrot’s intrusion into the fields in which they were experts. As James Gleick points out, “He was always an outsider, taking an unorthodox approach to an unfashionable corner of mathematics, exploring disciplines in which he was rarely welcomed, hiding his

grandest ideas in efforts to get his papers published, surviving mainly on the confidence of his employers at Yorktown Heights.” [2] His defensive approach made other scientists regard him as “prickly,” explains Gleick.

Over the decades, Mandelbrot’s ideas have become incorporated into a new mathematical area called chaos theory and are now widely respected. It has to be said, however, that so far fractals and chaos theory have relatively rarely been directly applied to science or engineering, even when chaotic motion is observed or fractal dimensions calculated. The mathematical rules used by Mandelbrot and even those further developed in chaos theory are often too simple to be of immediate application to real world situations. But computer modelling has entered the mainstream of many branches of science, and consequently fractal or chaotic phenomena can often be seen in computer graphics output. Their most ubiquitous application is in computer games programming and film making.

Philosophically, Mandelbrot’s ideas, and the chaos theory that has developed from them, help to challenge the widespread bias against determinism among intellectuals. Determinism as applied to history is far richer and more complex than determinism in physics. But even in physics, Newton’s laws of motion can be applied to phenomenon such as the asteroid belt of our solar system and produce chaotic results of enormous complexity. The equations that were developed by the nineteenth century physicists Navier and Stokes, which are completely deterministic, can now be seen to give rise to the chaotic motion seen in turbulent fluid flow. Mandelbrot’s life and work has helped to widen and enrich our understanding of determinism in ways that are only just beginning to be realised.

[1] Mandelbrot’s Introduction to *Fractals for the Classroom: Part One*, by Heinz-Otto Pietgen, Harmut Jürgens, Dietmar Saupe, Springer, 1992.

[2] *Chaos*, James Gleick, Penguin, 1988.



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