

obituaries

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Benoit Mandelbrot

For many of us, our introduction to the world of Benoit Mandelbrot, who died of pancreatic cancer on 14 October 2010 in Cambridge, Massachusetts, starts with a strange, beetle-like shape that looks nothing like anything we have ever seen in nature and yet looks remarkably natural! Referred to as the Mandelbrot set, it was generated by Mandelbrot in 1980 as an artificial shape that captures the essence of natural patterns such as trees and clouds. Several years earlier he had introduced the term “fractal” to describe how natural patterns repeat at finer and finer magnifications to build the intricate scenery that surrounds us. Mandelbrot will be best remembered for his epic book *The Fractal Geometry of Nature* (W. H. Freeman, 1982), which changed the way that many of us view the mathematical structure of the world.

Although Mandelbrot invented the term in 1975, he didn't actually discover fractals. In the late 19th and early 20th centuries, scientists such as Karl Weierstrass, Helge von Koch, Waclaw Sierpiński, and Giuseppe Peano explored the exotic consequences of building complexity from fractal shapes. However, they saw no connection between their mathematical creations and the physical world around them. Mandelbrot criticized such pure geometry as being “cold and dry.” His interests were instead closer to those of Ralph Elliott, who in 1938 showed that the temporal patterns in stock market variations repeat over different time scales. Mandelbrot extended his own explorations of the stock market to show that similar repetitions occur in other temporal patterns, such as the rise and fall of the Nile River. His broadening horizons triggered a thirst for understanding the complexity of physical phenomena rather than the cleanliness of pure mathematics.

Similarly, he fired new life into Lewis Fry Richardson's investigations of geographical patterns from the early 1950s. Richardson's hypothesis declared that the probability of two coun-



Benoit Mandelbrot

tries going to war was related to the length of their shared boundary. But his ability to confirm that idea was frustrated by the fact that the boundary lengths quoted in the literature varied with measurement resolution. Richardson's death soon after left Mandelbrot to promote Richardson's findings in his first famous work, 1967's *Science* article “How Long Is the Coast of Britain?” Mandelbrot explained the resolution dependence by picturing the coastline as a set of patterns recurring at increasingly fine scales. A depressing consequence of the coastline fractality for Richardson's model is that a boundary's infinite lengths would lead to infinite probability of conflict! Luckily, we escape that conclusion for physical fractals because their patterns die out at a fine-scale limit, in this case set by the sand's graininess.

Mandelbrot's inspiration for defining fractals was therefore one of unification. He needed an umbrella term to highlight the similarities between the earlier mathematical fractals and his increasing list of scale-invariance observations in natural systems. He likened his contribution to that of creating a language from previously existing words. However, the expansive scope of *The Fractal Geometry of Nature*, along with the plethora of experiments that it in-

spired, fueled a sometimes bitter debate within the sprawling fractals community. Battle lines were drawn over the magnification range required for declaring fractality, with some purists believing that it should be reserved for the infinite scaling of mathematical patterns. The debate was exacerbated by surveys of physical fractals showing that the largest pattern was typically only a factor of 25 bigger than the smallest. Wisely, Mandelbrot refused to insert a minimum magnification range into his definition; he declared that fractality should be judged simply by whether it is a “useful description” for understanding the physical system over the observed range.

The emphasis on usefulness was a crucial factor in Mandelbrot's ascendancy to godfather status in the fractals community. He delighted in discussing links between an object's fractal structure and its functionality—whether it be the light-harvesting capacity of trees, the electrical connectivity of neurons, or the wave-dispersing properties of coastlines. A related factor was his reliance on visualization. As a boy, he saw chess games in geometric rather than logical terms, and he shared his father's passion for maps. That bias toward geometry permeated through to his mathematical career. In particular, Mandelbrot relished the diversity of visual complexity; he noted that “a very simple formula explains all these very complicated things.”

Mandelbrot was born on 20 November 1924 in Warsaw but fled Poland with his family in 1936 and settled in France. After attending the École Polytechnique from 1945 to 1947, he received his master's in aeronautics from Caltech in 1948 and returned to France to earn a PhD in mathematics from the University of Paris in 1952. Mandelbrot described himself as a “fish out of water” in his early career environment of French abstract mathematics, and his blend of usefulness and visualization

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found a welcoming home when he moved to IBM's Research Center in Yorktown Heights, New York, in 1958. At IBM and later at Yale University he pushed the cross-disciplinary horizons of his research. Mandelbrot took heed of C. P. Snow's 1959 book *The Two Cultures and the Scientific Revolution* (Cambridge University Press), which served as an early warning of an emerging division between the arts and the sciences. Using fractals as a universal language, Mandelbrot built bridges across that divide for more than 50 years. Francis O'Connor, a prominent art theorist who studies Jackson Pollock's fractal paintings, recently declared that Mandelbrot's promotion of nature's mathematical structure represents a huge leap in the theory of aesthetics. O'Connor concluded that "Mandelbrot ought to be mourned by more than the scientific community."

Through the years, fractals researchers from many disciplines received surprise phone calls during which Mandelbrot's cheery voice offered support for their pursuit of his legacy. Sadly, we will all miss those calls.

Richard Taylor
 University of Oregon
 Eugene

Allan Rex Sandage

Allan Rex Sandage, who died of pancreatic cancer on 13 November 2010 in San Gabriel, California, was one of the greatest astronomers of the 20th century. He gave the first reliable size of the universe—seven times larger than the estimate by his mentor, Edwin

Hubble—and the first reliable age of the universe. Among his many honors were the 1991 Crafoord Prize and the 2000 Gruber Cosmology Prize.

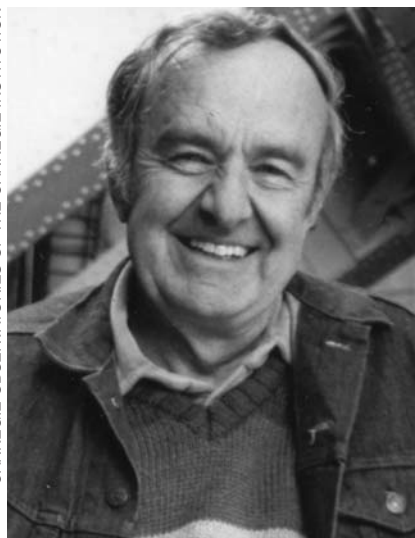
Born on 18 June 1926 in Iowa City, Iowa, Sandage enrolled briefly at the University of Miami and then joined the US Navy for the last year of World War II. He told astronomer Martin Johnson years later that his subsequent path was decided by reading Johnson's book *Time, Knowledge and the Nebulae* (Faber and Faber, 1945). Sandage graduated in physics and philosophy in 1948 from the University of Illinois. In 1949 he embarked on a PhD at Caltech under the supervision of Walter Baade, and in 1950 he started work at the Carnegie Observatories in Pasadena as Hubble's observing assistant. After becoming a staff member in 1952, he remained associated with the observatories all his life.

Besides his association with Hubble and Baade, the two giants of extragalactic observational research of the time, he also worked with theoretician Martin Schwarzschild on models for stars at the end of their hydrogen-burning phase. Their seminal 1952 paper explained the abrupt turnoff of the bright end of the observed "main sequence" in globular clusters and the fact that red giants were dying stars rather than young stars as had been previously supposed. Sandage used that insight the following year to estimate the age of the globular cluster Messier 3 as 5 billion years.

In 1953, the year that Sandage submitted his PhD, Hubble died and Sandage, at age 27, became responsible for developing the Carnegie Observatories cosmology program, which used the 60- and 100-inch telescopes on Mount Wilson and the newly commissioned 200-inch one on Mount Palomar. Being on the Carnegie staff gave him ample observing time, and he used it, with Hubble's associates Milton Humason and Nicholas Mayall, to extend Hubble's velocity-distance diagram for galaxies. Their 1956 paper contained redshifts for 920 galaxies, compared with the 24 originally used by Hubble. Sandage also extended Hubble's galaxy classification scheme with his 1961 *The Hubble Atlas of Galaxies* (Carnegie Institution of Washington).

By 1958, however, Sandage realized that there were problems with the distance scale, even after its revision by Baade. Sandage showed that what Hubble had thought were the brightest stars in galaxies were extended clouds of ionized gas, or HII regions. And he

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Allan Rex Sandage