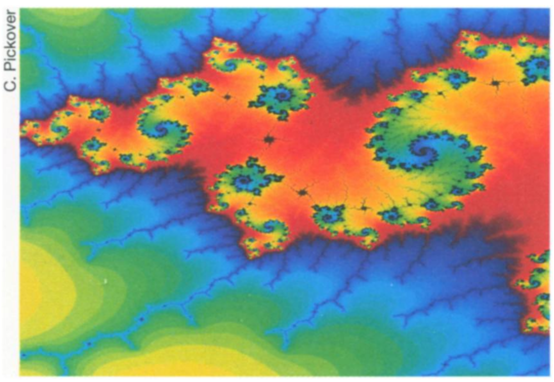
Fractal Past, Fractal Future

By IVARS PETERSON

On a clear, brisk morning, a child marvels at the frilled intricacy of frost splayed across a sunlit windowpane. In the laboratory, a scientist peers at the minutely branched structure of a cluster of gold particles.

A character in Tom Stoppard's 1993 play *Arcadia* asks, "If there is an equation for a curve like a bell, there must be an equation for one like a bluebell, and if a bluebell, why not a rose?" If you asked a mathematician how to characterize the shape of a flower or Jack Frost's handiwork or metallic sprays, the answer would probably refer to forms called fractals.

Fractals have invaded the popular imagination. Calendars, computer screens, and books feature vivid, phantasmagorical images of weirdly branched, wildly swirling structures. Cartoonist Sidney Harris depicts a refurbished living room decorated with squiggles. "We did the whole room over in fractals," the hostess explains. Composer-pianist Zach Davids turns the subtly varying fractal intervals between successive heartbeats into musical sequences to create "Heartsongs"—a remarkably pleasing score without apparent rhythm, meter, or harmony.



C. Pickover

The word "fractal" was coined only 25 years ago by Benoit B. Mandelbrot, IBM Fellow Emeritus at the Thomas J. Watson Research Center in Yorktown Heights, N.Y., and mathematics professor at Yale University. Based on the Latin adjective meaning "broken," it conveyed Mandelbrot's sense that the geometry of nature is not one of straight lines, circles, spheres, and cones, but of a rich blend of structure and irregularity.

Although irregular, many natural forms also show a striking property. A fragment of rock looks like the mountain from which it was fractured. Clouds keep their distinctive wispiness whether viewed distantly from the ground or close-up from an airplane window. A tree's twigs often have the same branching structure seen near its trunk. Indeed, nature is full of shapes that are self-similar, repeating themselves on different scales within the same object.

During the late 19th and early 20th centuries, mathematicians constructed self-similar curves in the course of attempts to prove or disprove certain intuitive notions about space, dimension, and area. They described the curves as "pathological."

It was mathematics "skating on the edge of reason," remarks mathematician Hans Sagan of North Carolina State University in Raleigh. This byway was almost completely ignored by scientists. Such curves didn't seem relevant to their concerns.

Yet physicists were having great difficulty in answering seemingly simple questions about phenomena such as diffusion. When a person in a breezy room opens a bottle of perfume, how long does it take for someone on the other side of the room to smell it?

In turbulent air currents, perfume molecules take paths wispier, stringier, and more contorted than the routes they follow in a calm setting. "It's only with Mandelbrot's insight—that all this wispiness involves those pathological 19th-century mathematical constructions—that physicists were able eventually to start to attack those problems," says Michael F. Shlesinger of the Office of Naval Research in Arlington, Va.

One of the very few scientists who appreciated early on the peculiar geometric complexity of natural phenomena was physicist Jean Baptiste Perrin (1870–1942), who studied the erratic movements of microscopic particles suspended in liquids and remarked on the self-similar structures of natural objects.

"Consider, for instance, one of the white flakes that are obtained by salting a solution of soap," Perrin wrote in 1906. "At a distance, its contour may appear sharply defined, but as we draw nearer, its sharpness disappears. . . . The use of a magnifying glass . . . leaves us just as uncertain, for fresh irregularities appear every time we increase the magnification, and we never succeed in getting a sharp, smooth impression, as given, for example, by a steel ball."

Mandelbrot had an advantage over Perrin and other predecessors in that he could commandeer computers to calculate and display stunning, unpredictable images of the extraordinary mathematical forms. Today, what 19th-century mathematicians could barely imagine can be speedily depicted and explored in three-dimensional, Technicolor splendor. Still, as graphic techniques continue to improve, "there's probably a lot more left to see and appreciate," notes Clifford A. Pickover, a research scientist at IBM.

Nowadays, fractals enter into scientists' descriptions of a wide range of phenomena, from the branching of air passages in the lungs and the flight paths of wandering albatrosses to the fracturing of a chunk of metal. Researchers are also looking toward the fractal frontiers.

Fractals have, for example, a potentially important role to play in characterizing weather systems and in providing insights into various physical processes, such as the occurrence of earthquakes or the formation of deposits that shorten battery life. Some scientists view fractal statistics as a doorway to a unifying theory of medicine, offering a powerful glimpse of what it means to be healthy.

Fractals lie at the heart of current efforts to understand complex natural phenomena. Unraveling their intricacies could reveal the basic design principles at work in our world.

Only recently, there was no word to describe fractals. Today, we are beginning to see such features everywhere. Tomorrow, we may look at the entire universe through a fractal lens. □

1926 Flight of rocket powered by liquid propellant

1926 Isolation of an enzyme (urease)

1926 Schrödinger's wave mechanics introduced

1926 X rays used to create mutations in fruit flies

1927 Heisenberg's uncertainty principle proposed

1928 Margaret Mead's *Coming of Age in Samoa* published

1928 Penicillin discovered

1929 Evidence of uniformly expanding universe

1929 Earth's magnetic field reversals discovered

1930 Antiparticles proposed