Fractal Geometry

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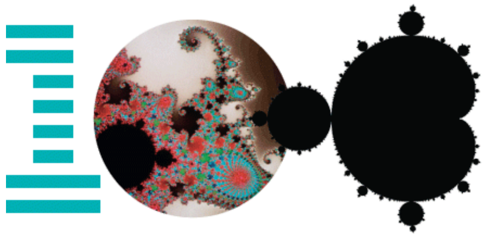

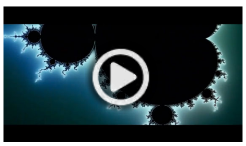

Fractal geometry in They Were There

Learn more about Benoit Mandelbrot and fractal geometry in the IBM Centennial film, They Were There. *(Beginning at 26:55)*

THE PASSING OF A MAVERICK

01/05

On October 14, 2010, the scientific community lost a great colleague, visionary and friend as Benoit Mandelbrot passed away at the age of 85 in Cambridge, Massachusetts. Dr. Mandelbrot is survived by his wife Aliette; two sons, Laurent and Didier; and three grandchildren.

MANDELBROT SAID

"In the whole of science, the whole of mathematics, smoothness was everything. What I did was to open up roughness for investigation."

01/05

Geometry. Its principles are taught to young students across the world. The Pythagorean theorem. Surface area and volume. Pi. This classical, or Euclidean, geometry is perfectly suited for the world that humans have created. But if one considers the structures that are present in nature, that which are beyond the realm of smooth human construction, many of these rules disappear. Clouds are not perfect spheres, mountains are not symmetric cones, and lightning does not travel in a straight line. Nature is rough, and until very recently this roughness was impossible to measure. The discovery of fractal geometry has made it possible to mathematically explore the kinds of rough irregularities that exist in nature.

In 1961, Benoit Mandelbrot was working as a research scientist at the Thomas J. Watson Research Center in Yorktown Heights, NY. A bright young academic who had yet to find his professional niche, Mandelbrot was exactly the kind of intellectual maverick IBM had become known for recruiting. The task was simple enough: IBM was involved in transmitting computer data over phone lines, but a kind of white noise kept disturbing the flow of information—breaking the signal—and IBM looked to Mandelbrot to provide a new perspective on the problem.

Since he was a boy, Mandelbrot had always thought visually, so instead of using the established analytical techniques, he instinctually looked at the white noise in terms of the shapes it generated—an early form of IBM's now-renowned data visualization practices. A graph of the turbulence quickly revealed a peculiar characteristic. Regardless of the scale of the graph, whether it represented data over the course of one day or one hour or one second, the pattern of disturbance was surprisingly similar. There was a larger structure at work.

The problem was familiar to Mandelbrot, and he recalled the advice his mathematician uncle, Szolem Mandelbrojt, had given him years ago in France—attempt to make something of the obscure theories of iteration established by French mathematicians Pierre Fatou and Gaston Julia. Their work intrigued mathematicians around the world and revolved around the simplest of equations: $z = z^2 + c$. With a variable of z and parameter of c, this equation maps values on the complex plane—where the x-axis measures the real part of complex number and the y-axis measures the *imaginary* part (i) of a complex number.

At the time of the advice, Mandelbrot couldn't find any breakthrough, but the intellectual freedom he found at IBM allowed him to fully engage this new project. In 1980, building on the technology and talent of IBM, Mandelbrot used high-powered computers to iterate the equation, or use the equation's first output as its next input. With these computers, Mandelbrot crunched and manipulated the numbers a thousand times over, a million times over, and graphed the outputs.

The result was an awkwardly shaped bug-like formation, and it was perplexing to say the least. But as Mandelbrot looked closer, he saw the detailed edges of this formation held smaller, repeating versions of the larger bug-like formation. What's more, every smaller version held more complex detail than the previous version. These structures were not exactly alike, but the general shape was strikingly similar, it was only the details that differed. The specificity of these details, it turned out, was limited only to the power of the machine computing the equation, and similar shapes could continue on forever—revealing more and more detail, on an infinite scale. This was a definite geometry, there were rules and parameters to this roughness, but it was a form of geometry previously unidentified by the scientific community.

Mandelbrot set zoom
Watch for the repeating structures contained in the Mandelbrot set.

Instantly, Mandelbrot knew he was onto something. He saw unquestionably organic structures in the details of this shape and quickly published his findings. This shape and structure, later known as the Mandelbrot set, was an extraordinarily complex and beautiful example of a "fractal" object, fractal being the name coined by Mandelbrot in 1975 to describe such repeating or self-similar mathematical patterns. But it wasn't until his 1982 book, *The Fractal Geometry of Nature*, that Mandelbrot would receive public attention and widespread legitimacy. In this book, Mandelbrot highlighted the many occurrences of fractal objects in nature. The most basic example he gave was a tree. Each split in a tree—from trunk to limb to branch and so forth—was remarkably similar, he noted, yet with subtle differences that provided increasing detail, complexity and insight into the inner-workings of the tree as a whole. True to his academic roots, Mandelbrot went beyond identifying these natural instances and presented the sound mathematical theories and principles upon which his newly coined "fractal geometry" was based.

What emerged was a geometry of the cosmos—one that broke all Euclidean laws of the man-made world and deferred to the properties of the natural world. If one identified an essential structure in nature, Mandelbrot claimed, the concepts of fractal geometry could be applied to understand its component parts and make postulations about what it will become in the future. This new way of viewing our surroundings, this new perception of reality, has since led to a number of remarkable discoveries about the worlds of nature and man, and has shown that they are not as disconnected as once thought.

Take biology, for example. Fractal patterns have appeared in almost all of the physiological processes within our bodies. For ages, the human heart was believed to beat in a regular, linear fashion, but recent studies have shown that the true rhythm of a healthy heart fluctuates radically in a distinctively fractal pattern. Blood is also distributed throughout the body in a fractal manner. Researchers in Toronto are using ultrasound imaging to identify the fractal characteristics of blood flows in both healthy and diseased kidneys. The hope is to measure the fractal dimensions of these blood flows and use mathematical models to detect cancerous cell formations sooner than ever before. In the fractal approach, doctors won't need sharper medical images or more powerful machines to see these miniscule pre-cancerous structures. Math, rather than microscopes, will provide the earliest detection.

Biology and healthcare are only some of the latest applications of fractal geometry. The developments arising from the Mandelbrot set have been as diverse as the alluring shapes it generates. Fractal-based antennas that pick up the widest range of known frequencies are now used in many wireless devices. Graphic design and image editing programs use fractals to create beautifully complex landscapes and life-like special effects. And fractal statistical analyses of forests can measure and quantify how much carbon dioxide the world can safely process.

Today, we have merely scratched the surface of what fractal geometry can teach us. Weather patterns, stock market price variations and galaxy clusters have all proven to be fractal in nature, but what will we do with this insight? Where will the rabbit hole take us? The possibilities, like the Mandelbrot set, are infinite.

Benoit Mandelbrot was an intellectual jack-of-all-trades. While he will always be known for his discovery of fractal geometry, Mandelbrot should also be recognized for bridging the gap between art and mathematics, and showing that these two worlds are not mutually exclusive. His creative approach to complex problem solving has inspired peers, colleagues and students alike, and instilled in IBM a strong belief in the power of perspective. Decades after his discovery of the Mandelbrot set, data visualization continues to provide fresh and unexpected insights into some of the world's most difficult problems by altering our perspective, challenging our preconceptions and revealing connections previously invisible to the eye.

Transforming the World →