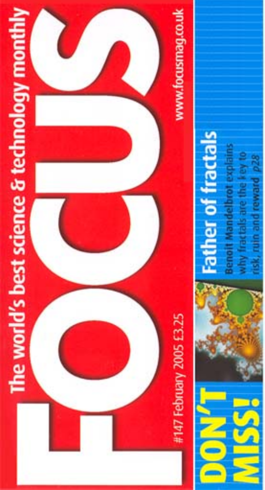
Maverick scientists

Benoit Mandelbrot, the father of fractals, talks to Emma Bayley

"Clouds are not spheres, mountains are not cones, coastlines are not circles and bark is not smooth"

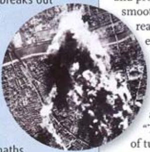


BENOIT'S CV

1924: Born 20 November, in Warsaw, Poland

1936: His family moved to Paris, where he attended school

1939: When WWII breaks out he moved south to avoid big cities, skipping much of his schooling and becoming largely self-taught



1947: He graduated from Paris's École Polytechnique in maths and physics, and moved to the United States with a scholarship to Caltech

1949-1954: He went from a PhD in Paris to a stint at MIT, then to the Institute for Advanced Study in Princeton to study with the great Hungarian-born mathematician John von Neumann

1958-1993: After four years in Geneva and France, he returned to the United States to work for IBM, first as a research staff member and then as an IBM fellow

Since 1987: He has held the post of Sterling Professor of Mathematical Sciences at Yale University. He has authored many books and hundreds of research papers, and has received countless honours, prizes and awards

BEFORE THE POLISH-BORN FRENCH-AMERICAN MATHEMATICIAN Benoit Mandelbrot made his mark on the world, scientists liked to forget about the imperfections and irregularities of nature. The study of perfect squares, triangles and planes had dominated their field for over 2,000 years, since the Greek geometer Euclid wrote maths' oldest treatise *Elements* and provided us with the tools to measure these flawlessly smooth shapes. Any question about how to measure the real shape of a tree, a coastline or anything with a rough edge could not be tackled by Euclidean geometry and had therefore been ignored.

But Mandelbrot changed all this when he invented fractal geometry, which enables us to measure roughness. "My whole career has been one long ardent pursuit of the concept of roughness," he says. "The roughness of clusters in the physics of disorder, of turbulent flows, of exotic noises, of chaotic dynamical systems, of the distribution of galaxies, of coastlines, of stock-price charts and of mathematical constructions."

Against the grain

What made this man want to go against the grain of over 2,000 years of classical thinking? And perhaps what is even more important, what has enabled him to succeed in taming roughness?

I meet Professor Mandelbrot at a London hotel to find out the answers to these questions while he is over from his home in Scarsdale, New York, to publicise his latest book, *The (Mis)behaviour of Markets*. He is a quiet, elderly man – he has recently celebrated his 80th birthday – smartly dressed in a suit and tie. As we get talking, his eyes light up and it is clear that he takes great pleasure in sharing the story of his life and work.

Two aspects of his personality were fundamental in setting him upon his quest to understand roughness, he tells me. The first was largely a result of circumstance. He was born in November 1924 in Warsaw, and by the time he was a teenager he was fending for himself in the French countryside during the height of the Second World War. ➡

Benoit Mandelbrot,
maverick mathematician
and the father of fractals

SEVEN AREAS OF FRACTAL INFLUENCE

The influence of fractals is wide-ranging and diverse

THE DISTRIBUTION OF THE GALAXIES
It remains an unsolved problem of cosmology to explain the irregular distribution of stars, galaxies and galaxy clusters across space. Many cosmologists now agree that this distribution can be best understood by seeing the Universe as a fractal.

WEATHER
Clouds have such irregular, complex shapes, that before Mandelbrot came up with fractal geometry it was impossible to measure them. Now the measurement and prediction of cloud coverage is one way in which fractals are applied to weather forecasting.

COMPUTER ANIMATION
Fractal geometry can produce shapes that look just like mountains, trees or clouds. This is why computer animators use Mandelbrot's tools as the quickest and most realistic way to draw artificial landscapes. Some of the alien landscapes we saw in the *Star Wars* movies were created using fractals.

➡ These early wartime lessons in independence and survival set him on a lone path that has characterised his career ever since. "Since my youth, I have been shamelessly disrespectful of received wisdom," he says.

In mathematical terms, he has moved at right angles to every fashion. "I wanted to keep far from organised physics and mathematics, and instead find a degree of order in some area where everyone else saw a lawless mess," he says.

A mysterious gift

The second aspect of his personality that has perhaps been even more central to his success is what he describes as a 'mysterious gift' which he discovered in himself when he was 18. "When I was at school and the professor was describing a mathematical problem, I immediately saw pictures in my mind of what he was describing, and these pictures made the answer to the problem very obvious to me," he says. "This gift was essential. It made me realise that the existing theories of geometry were oversimplifications. That's how, without having planned it, I've spent over 50 years studying roughness."

His ability to clearly visualise complex geometric shapes and use them to find solutions to mathematical problems where others would traditionally use formulae has meant that the eye has played a very important role in Mandelbrot's work. But he has been heavily criticised over the years for his reliance on pictures – his critics claiming that they are inaccurate and unreliable compared to numbers. But this has served only to drive Mandelbrot further from established thinking. "Pictures are undervalued in science," he insists. "And now we have computers, pictures can be as precise as we want."

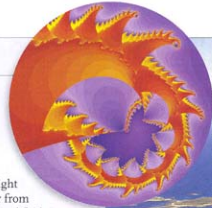
Unsurprisingly, he followed a jagged, nomadic path through his formal education, choosing to study a disparate range of subjects that did not meet with the approval of his tutors and which led to no clear-cut career. From École Polytechnique in Paris, he proceeded to Caltech in America and then to Princeton's Institute for Advanced Study, MIT, Harvard and Yale, eventually ending up with a job at IBM Research.

The maverick scientist

At the time, the bosses at IBM were going out of their way to employ maverick scientists, giving them the freedom to follow their whims in the hope that they would do something brilliant for the company. It was the most perfect working environment for the young Mandelbrot. He was free to take whatever direction he pleased in his research, an opportunity no university post could ever have given him. "If I hadn't had IBM, I simply wonder what would have happened," he says. "Many of the things that I did couldn't have been done because I simply wouldn't have had the means."

As it was, he was able to plunge himself into several uncharted areas, all of which, he only later came to realise, had one thing in common: roughness. "For ages I didn't realise that it was roughness I was studying," he says. "It was like being the first to wander in the Alps. I was going from one question to another, and only very gradually did I realise that roughness was the common factor."

Once that realisation dawned on him, Mandelbrot's work became a little more defined. But it was still many years before



A coastline is an example of a fractal (left), containing the same geometric patterns in different scales

ECONOMICS
Mandelbrot has been trying to persuade economists for over 40 years that fractal geometry can provide more accurate models of price changes than their traditional models. While his views are gradually being accepted, for now established models remain dominant.

ENGINEERING
One area where you might least expect to see fractal geometry in use is engineering, where smooth lines and perfectly formed shapes prevail. In the last few years, however, engineers – realising the constraints of Euclidean geometry – have started to use fractal geometry in their work.

What is a fractal?

A fractal is a geometric pattern or shape whose parts echo the whole. Think of a fern. It is made up of fronds, that are made up of smaller fronds, that are made up of smaller fronds still, all of which are miniature versions of the whole. This quality, which is found throughout nature – in clouds, in trees, in mountains – is called self-similarity. But how do you measure it?

In 1967, Mandelbrot raised the question: "How long is the coast of Britain?" A coastline is a classic fractal, because if you look at it from an aeroplane, you see the same crinkly, rough edge as when you look at it up close with a magnifying glass – it is self-similar on all scales.

If you were to measure it with a ruler, you would miss out many of the nooks and crannies, and therefore get a result that would fall short of the real answer. A smaller ruler would get a more accurate result, but you would still be missing out much of the 'roughness' in your measurement.

Mandelbrot found a way around this problem by plotting the measurement you get for each size ruler you use. Something unusual happens as you use ever-smaller rulers: the length you measure grows faster than the rulers shrink, a phenomenon measured by a quantity called 'fractal dimension'.

In Euclidean terms, a straight line has a fractal dimension of one and a plane has a fractal dimension of two. However, the British coastline, it turns out, has a fractal dimension of about 1.25. Having this sort of 'fractional' dimension is a characteristic that is possessed by all fractals.

he coined the word 'fractal' – from 'fractus', the past participle of the Latin word 'frangere', meaning 'to break' – to describe the new geometry he was formulating.

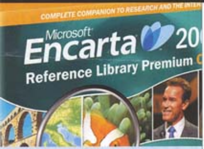
"I had the very strong impression that I was skating on very thin ice and that if I didn't exert extreme caution I would get into trouble," he says. "When I coined the word fractal, I had been working on fractal geometry for at least 15 years. Giving it a label any earlier would have been overselling it. I may be a troublemaker, but I can also be very conservative," he chuckles.

Fractal geometry

Today, most scientists would agree that fractal geometry has become an accepted arm of mathematics. Indeed, some 16- and 17-year-old maths pupils have begun to study it alongside Euclidean geometry, and it has been applied to countless other areas of scientific enquiry from engineering to computing and economics.

"I am a persistent man," says Mandelbrot as our conversation draws to a close. "Once I decide something, I hold to it with extraordinary tenacity. I pushed and pushed to develop my ideas of fractality."

It's taken over half a century of hard work, but it can now be said with absolute certainty that Benoit Mandelbrot has changed the way we view the world. Without him, roughness would still be an ignored frontier in science, and clouds would still be spheres.

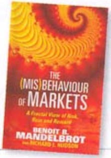


DATA COMPRESSION
In 1992, Microsoft released the Encarta Encyclopedia CD. It contained thousands of articles, 7,000 photographs, 100 animations and 800 colour maps, in less than 600 megabytes of data. This feat was achieved through the mathematics of fractal data compression.

RIVER FLOWS
The question of how much a river may flood is a very important one, as prosperity or poverty can hang on the outcome. Since Mandelbrot's studies of the 'Nile pattern' of flooding in the 1960s, it has been generally accepted that river flow and flooding can best be described by fractal geometry.

BOOK GIVEAWAY

We have five copies to give away of *The (Mis)behaviour of Markets* by Benoit Mandelbrot and Richard L Hudson, published by Profile Books and worth £18.99 each. For your chance to win one, simply send the answer to the following question to the address on p39. In which city was Benoit Mandelbrot born?



FRACTAL FINANCE

Unravelling the turbulent mathematics of markets

In his latest book *The (Mis)behaviour of Markets*, Mandelbrot writes: "The very heart of finance is fractal." For over 40 years, he has been developing his own fractal models of financial markets. Markets, he believes, are far riskier than economists believe.

There are two assumptions that have been at the root of economics since its foundation 100 years ago. The first is that price changes are 'normally' distributed – that is, most price changes are small moves up or down; very rarely are there extremely large changes. Second, price changes are statistically independent – that is, a price change today has nothing to do with past prices.

Mandelbrot tears down these assumptions and shows how his fractal models provide a far more accurate description of the risks involved in financial markets. "If we can map the human genome, why can we not map how a man loses his livelihood?" he says. "Finance must abandon its bad habits and adopt a scientific method."