FEATURE

Fractal expressionism

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Experimental observations of the paintings of Jackson Pollock reveal that the artist was exploring ideas in fractals and chaos before these topics entered the scientific mainstream

Fractal expressionism

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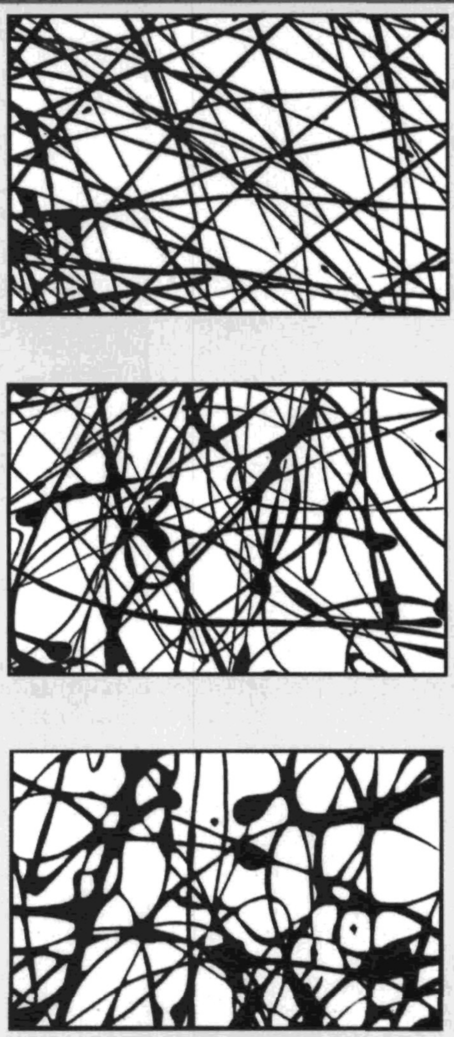
CAN SCIENCE be used to further our understanding of art? This question meets with reservations from both scientists and artists. However, for the abstract paintings produced by Jackson Pollock in the 1940s and 1950s, scientific objectivity proves to be an essential tool for determining their fundamental content. Pollock dripped paint from a can onto vast canvases on the floor of his barn. Although recognized as a crucial advance in the evolution of modern art, the precise quality and significance of the patterns created by this unorthodox technique remain controversial. Here we analyse Pollock's patterns and show that they are fractal. In other words, they display the fingerprint of nature.

In contrast to the broken lines painted by conventional brush strokes on canvas, Pollock used a constant stream of paint to produce a uniquely continuous trajectory as it splattered onto the canvas below. A typical canvas would be reworked many times over a period of several months, with Pollock building up a dense web of paint trajectories. This repetitive and cumulative process – sometimes called "continuous dynamic" painting – is strikingly similar to the way in which patterns evolve in nature.

1 Painting by numbers



Detail of non-chaotic (top) and chaotic (middle) drip trajectories generated by a pendulum, and a detail of Pollock's *Number 14, 1948* (bottom). The similarity between the chaotic drip painting and Pollock's painting is striking.

Nature, chaos and art

Other parallels with natural processes are also apparent. Gravity plays a central role for both Pollock and nature. Furthermore, by abandoning the easel, Pollock allowed the horizontal canvas to become a physical terrain to be traversed, and his approach from all four sides replicated the isotropy and homogeneity of many natural patterns. His canvases were also large and unframed, similar to a natural environment. Can these shared characteristics be the signature of a deeper common approach?

Since its discovery in the 1960s, chaos theory has been spectacularly successful in explaining many of nature's processes. Examples of chaotic behaviour in nature include the Gulf Stream, weather patterns, fluctuations in the human heart and Jupiter's Great Red Spot (see the books by Gleick and Ott in further reading). Could Pollock's painting process also have been chaotic?

There were two revolutionary aspects to the way in which Pollock painted and both have the potential to introduce chaos. The first was his motion around the canvas. In contrast to traditional brush–canvas contact techniques, where the artist's motions are limited to hand and arm movements, Pollock used his whole body to introduce a wide range of length scales into his painting. In doing so, Pollock's dashes around the canvas could possibly have followed Lévy flights: this special distribution of movements, first investigated by Paul Lévy in 1936, has recently been used to describe the statistics of chaotic systems. (In Brownian motion a particle makes random jumps and each jump is usually small: the resulting diffusion can be described by a Gaussian distribution with a finite variance. In Lévy-like diffusion, on the other hand, long flights are interspersed with shorter jumps, and the variance of the distribution diverges. See the articles by Klafter *et al.* and Tsallis in further reading).

The second revolutionary aspect concerns the application of paint, which Pollock allowed to drip onto the canvas. In 1984 Robert Shaw of the University of California at Santa Cruz showed that the flow of water or other fluid from a dripping tap could be changed from non-chaotic to chaotic flow by making small adjustments to the flow rate (see Shaw in further reading). Likewise it is possible that Pollock could have exploited chaotic flow.

A simple experiment can be designed and built to investigate this possibility. The experiment consists of a pendulum that records its motion by dripping an identical paint trajectory onto a horizontal canvas. When left to swing on its own,

2 The natural look

Photographs of a 0.1 m section of snow on the ground (top), a 50 m section of forest (middle) and a 2.5 m section of Pollock's *One: Number 31, 1950* (bottom). It is difficult to judge the magnification, and hence the length scale, of such "self-similar" patterns. (Jackson Pollock. *One (Number 31, 1950)*. (1950). Oil and enamel on unprimed canvas, (269.5×530.8 cm). The Museum of Modern Art, New York. Sidney and Harriet Janis Collection Fund (by exchange). Photograph © 1999 The Museum of Modern Art, New York.)

the pendulum follows a predictable, non-chaotic motion. However, by knocking the pendulum at a frequency slightly lower than the one at which it naturally swings, the system becomes a "kicked rotator" (see the articles by Taylor and Tritton in further reading). The kick can be controlled very precisely by using, for example, electromagnetic driving coils. By tuning the frequency and magnitude of the kick, chaotic motion can be generated.

Just as Pollock's paintings are built from many criss-crossing trajectories, these pendulum paintings can also be built up trajectory by trajectory through the use of different launch conditions. In figure 1 sections of non-chaotic and chaotic drip paintings are compared with a section of Pollock's painting *Number 14, 1948*. The similarity between the chaotic drip painting and the painting by Pollock is striking.

If both patterns have been generated by chaos, what common quality would be expected in the patterns left behind? Many natural chaotic systems form fractals in the patterns that record the process. Examples include the edges of clouds, river patterns, coastlines and lightning paths (see the books by Mandelbrot and Gouyet in further reading). Nature builds its fractals using statistical self-similarity: the patterns observed at different magnifications, although not identical, are described by the same statistics. The results are visually more subtle than the instantly identifiable, artificial patterns generated using exact self-similarity, where the patterns repeat exactly at different magnifications.

Various visual clues help to identify statistical self-similarity. The first relates to "fractal scaling". The visual consequence of obeying the same statistics at different magnifications is that it becomes difficult to judge the magnification, and hence the length scale, of the pattern being viewed. This can be seen in nature and in Pollock's paintings (figure 2).

A second visual clue relates to "fractal displacement": this refers to the fact that different spatial locations on the pattern can be described by the same statistics. The visual consequence of this property is that the patterns gain a uniform character. The authors have measured a quantity known as the pattern density – the percentage of the canvas filled by the pattern within a 5×5 cm square – at various points on Pollock's *Number 14, 1948* and shown that it is uniform across the canvas.

Experimental art

These visual clues to fractal content can be confirmed by calculating the fractal dimension of Pollock's drip paintings. The large amount of repeating structure within a fractal pattern causes it to occupy more space than a smooth one-dimensional line, but not to the extent of completely filling the two-dimensional plane.

To detect and quantify this intermediate dimensionality of fractals, we calculate the fractal dimension, D, using the well established "box-counting" method. We cover the scanned photograph of a Pollock painting with a computer-generated mesh of identical squares, and then count the number of squares, $N(L)$, that contain part of the painted pattern. This count is repeated as the size L of the squares in the mesh is reduced. In this way the amount of canvas filled by the pattern can be compared at different magnifications. The largest size of square is chosen to match the size of the canvas, which can be several metres in dimension, and the smallest is chosen to match the finest paint work: the smallest value of L is typically 0.8 mm. Within this size range the count is not affected by any measurement resolution limits, such as those associated with the photographic or scanning procedures.

Values of the fractal dimension, D, are then extracted from a graph of $N(L)$ versus L, using the relation $N(L) \sim L^{-D}$. The validity of this expression increases as L becomes smaller and the total number of boxes in the mesh is large enough to provide reliable counting statistics. In our measurements the total number of boxes ranges from 100 to 4 million (figure 3). If the results are plotted on log–log axes, the gradient of the curve is $-D$. The straightness of the graph's curve reflects the statistical self-similarity of the pattern, and the accuracy of the method has been confirmed by analysing test patterns consisting of standard fractals of known dimension.

The two chaotic processes proposed for generating Pollock's paint trajectories – his body movements and the dripping fluid motions – operate across distinctly different length scales. These scales can be estimated from film and still photography of Pollock at work (see the programme by Falkenberg and Namuth in further reading). Based on the physical range of his body motions and the canvas size, his Lévy flights over the canvas are expected to cover the approximate length scales between 1 cm and 2.5 m. In contrast, the drip process is expected to shape the trajectories over length scales between about 1 mm and 5 cm. The latter range has been calculated from variables that affect the drip process (such as paint velocity and the height the paint is dropped from) and the absorption of paint by the canvas (such as paint fluidity and canvas porosity).

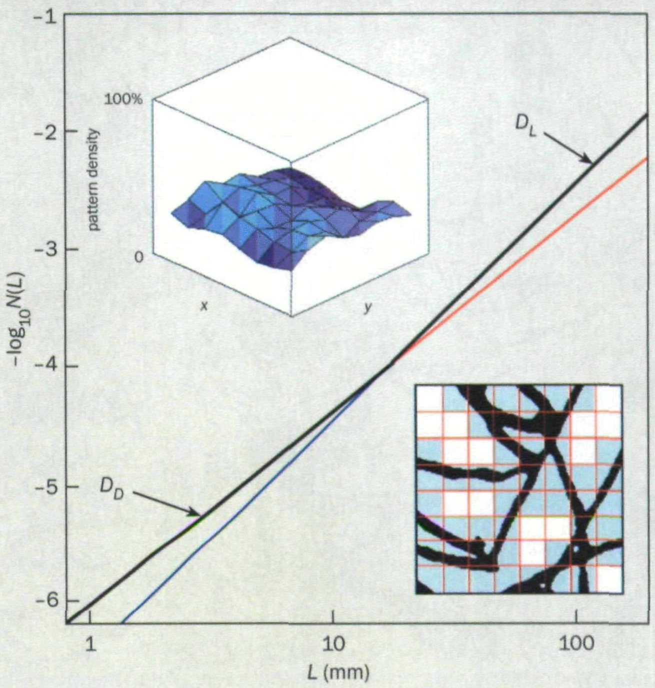
Given these two different length scales we would therefore expect the fractal analysis to reveal two different values of the fractal dimension, D, in the two different ranges. And this is what we find (figure 3). We call these different values the drip fractal dimension, D_D, and the Lévy flight fractal dimension, D_L. Systems described by two or more values of D are not unusual: examples from nature include trees and bronchial systems.

One consequence of having more than one value of D is that each value can only be observed over a limited range of scales. In 1998 David Avnir and colleagues at the Hebrew University of Jerusalem in Israel compared the fractals measured in a variety of physical systems, and found that the average range over which fractal behaviour was observed was approximately one order of magnitude (*Science* 1998 **279** 39–40). In their survey, Avnir and co-workers looked at all the papers reporting experimental evidence for fractal behaviour that were published in the *Physical Review* series of journals between 1990 and 1996. In reply to this work Benoit Mandelbrot of Yale University in the US stressed that so-called "limited-range" fractals are no less fractal than ones observed over many orders of magnitude (*Science* 1998 **279** 783–784).

The range of lengths over which the drip fractal dimension, D_D, applies was measured to be between 1.1 and 1.3 orders of magnitude, depending on the painting being analysed. The Lévy flight fractal dimension, D_L, was found to be valid over 2 orders of magnitude. The length scale that marks the transition between these two regimes typically occurs at 1–5 cm. These ranges are consistent with the values calculated above from the films and photographs of Pollock at work and from the physical properties of the paint and canvas.

Our measurements on Pollock's painting *Blue Poles: Number 11* gave a value of $D_D = 1.72$. For comparison, we note that typical values of D for natural fractal patterns such as coastlines and lightning are 1.25 and 1.3. Our analysis also shows that Pollock refined his dripping technique, with D_D increasing steadily through the years (see Taylor *et al.* in further reading). *Untitled: Composition with Pouring II*, one of his first drip paintings from 1943, has a D_D value close to 1. *Number 14, 1948*; *Autumn Rhythm: Number 30, 1950;* and *Blue Poles: Number 11*, which was painted in 1952, have values of 1.45, 1.67 and 1.72 for D_D. In each case the value of D_L was higher than D_D (and quite close to 2), indicating a more efficient space-filling fractal pattern at the larger scales.

3 A detailed look at a Pollock painting



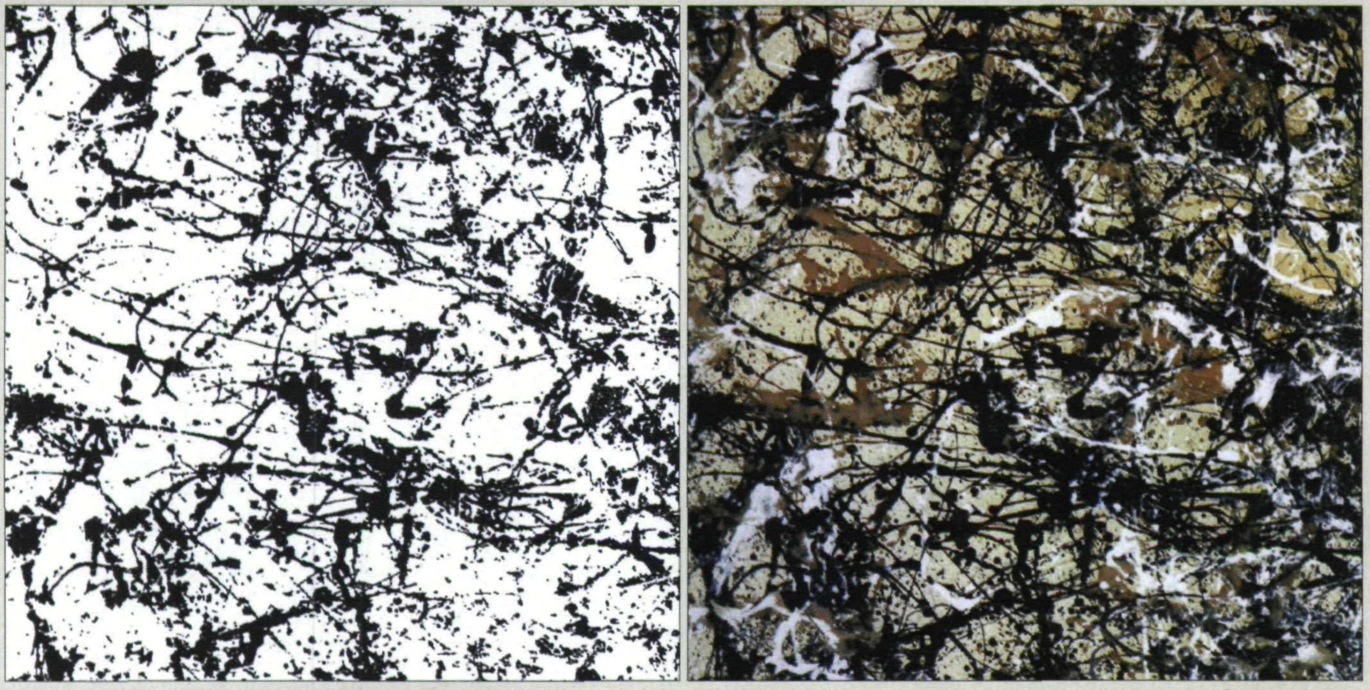
Pollock's painting *Blue Poles: Number 11* was analysed by covering a scanned photograph of the painting with a computer-generated mesh and counting the number of squares, N, that contain part of the pattern (lower inset). When N is plotted against L, the size of each square, on log–log axes, the data fall on a single line (the black line): the fractal dimension of the painting is given by the gradient of the line. Like many of Pollock's paintings, *Blue Poles* contains layers of different colour: the graph shows N versus L for the aluminium layer. There are in fact two gradients, and hence two fractal dimensions: 1.63 at short lengths (red line) and 1.96 at longer lengths (blue). (The fractal dimension of the whole painting is 1.72 at short lengths and 1.98 at longer lengths.) The two gradients can be related to Pollock's drip technique and to his movements around the canvas. The upper inset shows a plot of pattern density (the percentage of the canvas filled by the pattern within a 5×5 cm square) versus position across a 43×43 cm section of the painting *Number 14, 1948*.

Beneath the surface

How did Pollock construct and refine his fractal patterns? In many paintings, though not all, he introduced the different colours more or less sequentially: the majority of trajectories with the same colour were deposited during the same period in the painting's evolution. To investigate how Pollock built his fractal patterns, we have electronically deconstructed the paintings into their constituent coloured layers and calculated the fractal content of each layer. (Indeed, the data in figure 3 are for the aluminium layer of *Blue Poles: Number 11.*) We find that each individual layer consists of a uniform fractal pattern. As each of the coloured patterns is reincorporated to build up the complete pattern, the fractal dimension of the overall painting rises. Thus the combined pattern of many colours has a higher fractal dimension than any of the single-colour layers.

The first layer in a Pollock painting plays a pivotal role – it

4 Pollock: back to basics



A comparison of the black anchor layer (left) and the complete pattern consisting of four layers (black, brown, white and grey on a beige canvas) for the painting *Autumn Rhythm: Number 30, 1950* (right). The complete pattern occupies 47% of the canvas surface area, while the anchor layer occupies 32%. The fractal dimensions are $D_D = 1.66$ and $D_L = 1.93$ for the anchor layer, and $D_D = 1.67$ and $D_L = 1.94$ for the complete painting. Pollock painted this work, which measures 2.66×5.30 m, in 1950. (Jackson Pollock. *Autumn Rhythm (Number 30, 1950)*. The Metropolitan Museum of Art, George A Hearn Fund, 1957. (57.92) Photograph © 1980 The Metropolitan Museum of Art)

has a significantly higher fractal dimension than any of the subsequent layers. This first layer essentially determines the fractal nature of the overall painting, acting as an anchor layer for the subsequent layers which then fine-tune the fractal dimension. Pollock's *Autumn Rhythm: Number 30, 1950* and its black anchor layer are compared in figure 4.

Pollock's legacy

Pollock died in 1956, before chaos and fractals were discovered. It is highly unlikely, therefore, that Pollock consciously understood the fractals he was painting. Nevertheless, his introduction of fractals was deliberate. For example, the colour of the anchor layer was chosen to produce the sharpest contrast against the canvas background. This layer also occupied more canvas space than the other layers, suggesting that Pollock wanted this highly fractal anchor layer to visually dominate the painting. Furthermore, after the paintings were completed he would remove regions near the edge of the canvas where the pattern density was less uniform.

Pollock also took steps to perfect the "drip and splash" technique itself. His initial drip paintings of 1943 consisted of a single layer of trajectories that, although distributed across the whole canvas, only occupied 20% of a relatively small canvas (0.35 m^2). By 1952 he was painting multiple layers of trajectories that covered over 90% of much larger canvases, some as large as 10 m^2. This increase in both the canvas size and the density of the trajectories was accompanied by a rise in the fractal dimension of the patterns from close to 1 to 1.72. Indeed, because the fractal dimension follows such a distinct evolution with time, fractal analysis could be employed as a quantitative, objective technique to both validate and date Pollock's drip paintings.

Pollock's contribution to the evolution of art is secure. He described nature directly. Rather than mimicking it, he adopted the language of nature – fractals – to build his own patterns. In doing so he was, in many ways, ahead of his contemporaries in art and science.

Further reading

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C Tsallis 1997 Lévy distributions *Physics World* July pp43–45

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