The Visual Complexity of Pollock's Dripped Fractals

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1. Introduction

Fractals have experienced considerable success in quantifying the complex structure exhibited by many natural patterns and have captured the imagination of scientists and artists alike [Mandelbrot]. With ever widening appeal, they have been referred to both as "fingerprints of nature" [Taylor et al 1999] and "the new aesthetics" [Richards]. Recently, we showed that the drip patterns of the American abstract painter Jackson Pollock are fractal [Taylor et al 1999]. In this paper, we describe visual perception tests that investigate whether fractal images generated by mathematical, natural and human processes possess a shared aesthetic quality based on visual complexity.

2. Dripped Complexity

The art world changed forever in 1945, the year that Jackson Pollock moved from downtown Manhattan to Springs, a quiet country town at the tip of Long Island, New York. Friends recall the many hours that Pollock spent on the back porch of his new house, staring out at the countryside as if assimilating the natural shapes surrounding him (see Figure One) [Potter]. Using an old barn as his studio, he started to perfect a radically new approach to painting that he had briefly experimented with in previous years. The procedure appeared basic. Purchasing yachting canvas from his local hardware store, he simply rolled the large canvases (sometimes spanning five meters) out across the floor of the barn. Even the traditional painting tool - the brush - was not used in its expected capacity: abandoning physical contact with the canvas, he dipped the stubby, paint-encrusted brush in and out of a can and dripped the fluid paint from the brush onto the canvas below. The uniquely continuous paint trajectories served as 'fingerprints' of his motions through the air.

These deceptively simple acts fuelled unprecedented controversy and polarized public opinion of his work. Was this painting 'style' driven by raw genius or was he simply mocking artistic traditions? Sixty years on, Pollock's brash and energetic works continue to grab public attention and command staggering prices of up to

$40M. Art theorists now recognize his patterns as a revolutionary approach to aesthetics. However, despite the millions of words written about Pollock, the real meaning behind his infamous swirls of paint has remained the source of fierce debate in the art world [Varnedoe et al].

One issue agreed upon early in the Pollock story was that his paintings represent one extreme of the spectrum of abstract art, with the paintings of his contemporary, Piet Mondrian, representing the other. Mondrian's so-called "Abstract Plasticism" generated paintings that seem as far removed from nature as they possibly could be. They consist of elements - primary colors and straight lines - that never occur in a pure form in the natural world. In contrast to Mondrian's simplicity, Pollock's "Abstract Expressionism" speaks of complexity – a tangled web of intricate paint splatters. Whereas Mondrain's patterns are traditionally described as "artificial" and "geometric", Pollock's are "natural" and "organic" [Taylor 2002]. But if Pollock's patterns are a celebration of nature's organic shapes, what shapes would these be?
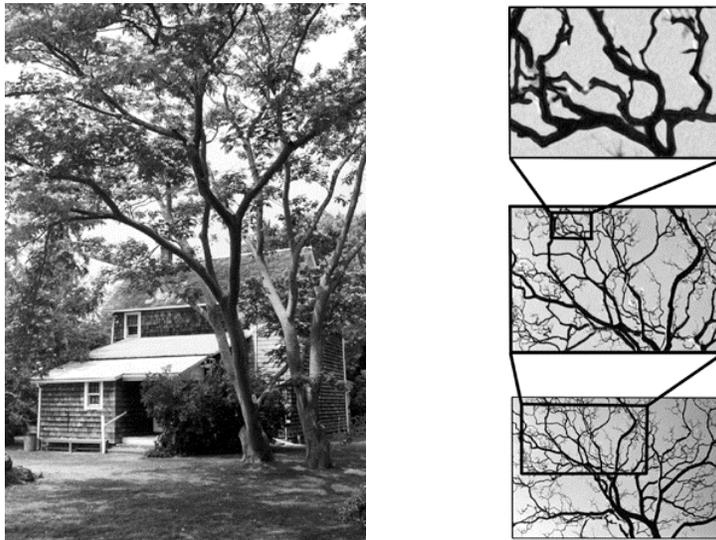

Figure 1. Left: Pollock's house on Long Island. In contrast to his previous life in Manhattan, Pollock perfected his drip technique surrounded by the complex patterns of nature. Right: Trees are an example of a natural fractal object. Although the patterns observed at different magnifications don't repeat exactly, analysis shows them to have the same statistical qualities (photographs by R.P. Taylor).

3. Nature's Fractals

Since the 1970s many of nature's patterns have been shown to be fractal [Mandelbrot]. In contrast to the smoothness of artificial lines, fractals consist of patterns that recur on finer and finer scales, building up shapes of immense complexity. Even the most common fractal objects, such as the tree shown in Figure One, contrast sharply with the simplicity of artificial shapes.

An important parameter for quantifying a fractal pattern's visual complexity is the fractal dimension, D. This parameter describes how the patterns occurring at different magnifications combine to build the resulting fractal shape. For Euclidean shapes, dimension is described by familiar integer values - for a smooth line (containing no fractal structure) D has a value of one, whilst for a completely filled area (again containing no fractal structure) its value is two. However, the repeating structure of a fractal pattern causes the line to begin to occupy area. D then lies between one and two and, as the complexity and richness of the repeating structure increases, its value moves closer to two [Mandelbrot]. For fractals described by a low D value, the patterns observed at different magnifications repeat in a way that builds a very smooth, sparse shape. However, for fractals with a D value closer to two, the repeating patterns build a shape full of intricate, detailed structure. Figure Two (left column) demonstrates how a pattern's D value has a profound effect on the visual appearance. The three natural scenes from top to bottom have D values of 1.0, 1.3 and 1.9 respectively. Table One shows D values for various natural forms:

Natural pattern	Fractal dimension	Source
Coastlines: South Africa, Australia, Britain	1.05-1.25	Mandelbrot
Norway	1.52	Feder
Galaxies (modeled)	1.23	Mandelbrot
Cracks in ductile materials	1.25	Louis et al.
Geothermal rock patterns	1.25-1.55	Campbel
Woody plants and trees	1.28-1.90	Morse et al.
Waves	1.3	Werner
Clouds	1.30-1.33	Lovejoy
Sea Anemone	1.6	Burrough
Cracks in non-ductile materials	1.68	Skejltorp
Snowflakes (modelled)	1.7	Nittman et al.
Retinal blood vessels	1.7	Family et al.
Bacteria growth pattern	1.7	Matsushita et al.
Electrical discharges	1.75	Niemyer et al.
Mineral patterns	1.78	Chopard et al.

Table 1. D values for various natural fractal patterns

4. Pollock's Fractals

In 1999, we published an analysis of twenty of Pollock's dripped patterns showing that they are fractal [Taylor et al 1999]. To do this we employed the well-established 'box-counting' method, in which digitized images of Pollock paintings were covered with a computer-generated mesh of identical squares. The number of squares N(L)
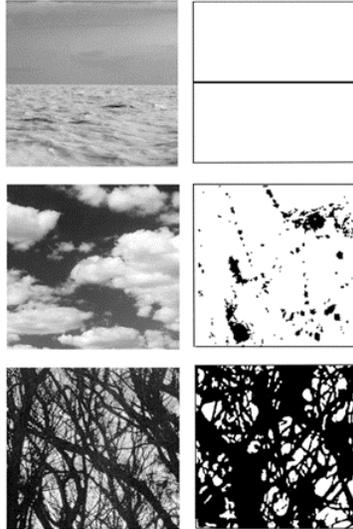
Figure Two. Examples of natural scenery (left column) and drip paintings (right column). Top: the horizon forms a line with D=1. Middle: Clouds and Pollock's painting *Untitled* (1945) are fractal patterns with D=1.3. Bottom: A forest and Pollock's painting *Untitled* (1950) are fractal patterns with D=1.9. (Photographs by R.P. Taylor).

that contained part of the painted pattern were then counted and this was repeated as the size, L, of the squares in the mesh was reduced. The largest size of square was chosen to match the canvas size (L~2.5m) and the smallest was chosen to match the finest paint work (L~1mm). For fractal behavior, N(L) scales according to $N(L) \sim L^{-D}$, where $1 < D < 2$. The D values were extracted from the gradient of a graph of log N(L) plotted against log L. Details of the procedure are presented elsewhere [Taylor et al 1999].

Recently, we described Pollock's style as 'Fractal Expressionism' [Taylor et al, Physics World, 1999] to distinguish it from computer-generated fractal art. Fractal Expressionism indicates an ability to generate and manipulate fractal patterns *directly*. In many ways, this ability to paint such complex patterns represents the limits of human capabilities. Our analysis of film footage taken at his peak in 1950 reveal a remarkably systematic process [Taylor et al, Leonardo, 2002]. He started by painting localized islands of trajectories distributed across the canvas, followed by longer extended trajectories that joined the islands, gradually submerging them in a dense fractal web of paint. This process was very swift with the fractal dimension rising sharply from D=1.52 at 20 seconds to D=1.89 at 47 seconds. He would then break off and later return to the painting over a period of several days, depositing extra layers on top of this initial layer. In this final stage he appeared to be fine-tuning the D value, with its value rising by less than 0.05. Pollock's multi-stage painting technique was clearly aimed at generating high D fractal paintings [Taylor et al, Leonardo, 2002].

As shown in Figure Three, he perfected this technique over ten years. Art theorists categorize the evolution of Pollock's drip technique into three phases [Varnedoe]. In the 'preliminary' phase of 1943-45, his initial efforts were characterized by low D values. An example is the fractal pattern of the painting *Untitled* from 1945 which has a D value of 1.3 (see Figure Two). During his 'transitional phase' from 1945-1947, he started to experiment with the drip technique and his D values rose sharply (as indicated by the first dashed gradient in Figure Three). In his 'classic' period of 1948-52, he perfected his technique and D rose more gradually (second dashed gradient in Figure Three) to the value of D = 1.7-1.9. An example is *Untitled* from 1950 (see Figure Two) which has a D value of 1.9. Whereas this distinct evolution has been proposed as a way of authenticating and dating Pollock's work [Taylor et al, Scientific American, 2002] it also raises a crucial question for visual scientists - do high D value fractal patterns have a special aesthetic quality?
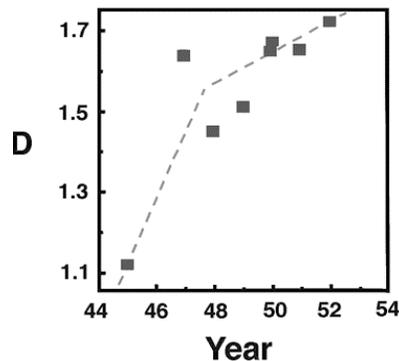

Figure Three. The fractal dimension D of Pollock paintings plotted against the year in which they were painted (1944 to 1954). See text for details.

5. The Aesthetics of Fractals

The prevalence of fractals in our natural environment has motivated a number of studies to investigate the relationship between a pattern's fractal character and its visual properties [Cutting et al, Geake et al, Gilden et al, Knill et al, Pentland, and Rogowitz et al]. Whereas these studies have concentrated on such aspects as perceived roughness, only recently has the 'visual appeal' of fractal patterns been quantified [Aks et al, Pickover]. The discovery of Pollock's fractals re-invigorates this question of fractal aesthetics. In addition to fractal patterns generated by mathematical and by natural processes, there now exists a third family of fractals - those generated by humans [Taylor 2001].

Previous ground-breaking studies have concentrated on computer-generated fractals. In 1995, Pickover used a computer to generate fractal patterns with different D values and found that people expressed a preference for fractal patterns with a high value of 1.8 [Pickover], similar to Pollock's paintings. However, a subsequent survey by Aks and Sprott also used a computer but with a different mathematical method for generating the fractals. This survey reported much lower preferred values of 1.3 [Aks

et al]. Aks and Sprott noted that the preferred value of 1.3 revealed by their survey corresponds to prevalent patterns in the natural environment (for example, clouds and coastlines have this value) and suggested that perhaps people's preference is actually 'set' at 1.3 through a continuous visual exposure to patterns characterized by this D value. However, the discrepancy between the two surveys seemed to suggest that there isn't a universally preferred D value but that the aesthetic qualities of fractals instead depend specifically on how the fractals are generated.

To determine if there are any 'universal' aesthetic qualities of fractals, we carried out a survey incorporating all three categories of fractal pattern: fractals formed by nature's processes, by mathematics and by humans. We used 15 computer-generated images of simulated coastlines, 5 each with D values of 1.33, 1.50 and 1.66; 40 cropped images from Jackson Pollock's paintings, 10 each with D values of 1.12, 1.50, 1.66 and 1.89; and 11 images of natural scenes with D values ranging from 1.1 to 1.9. Figure Two shows some of the images used in the survey.

Within each category of fractals (i.e. mathematical, natural and human), we investigated the visual appeal as a function of D. This was done using a 'forced choice' visual preference technique, in which participants were shown a pair of images with different D values on a monitor and asked to chose the most "visually appealing". In the surveys, all the images were paired in all possible combinations and preference was quantified in terms of the proportion of times each image was chosen. Although details will be presented elsewhere, Figure Four shows the results from a survey involving 220 participants [Spehar et al]. Taken together, the results indicate that we can establish three categories with respect to aesthetic preference for fractal dimension: 1.1-1.2 low preference, 1.3-1.5, high preference and 1.6-1.9 low preference. (Note: a set of computer generated random dot patterns with no fractal content but matched in terms of density (area covered) to the low, medium and high fractal patterns were used to demonstrate that aesthetic preference is indeed a function of D and not simply density).

6. Future Studies

Is Jackson Pollock an artistic enigma? According to our surveys, the low D patterns painted in his earlier years should have more 'visual appeal' than his later *classic* drip paintings. What was motivating Pollock to paint high D fractals? Should we conclude that he wanted his work to be aesthetically challenging to the gallery audience? It is possible that he regarded the visually restful experience of a low D pattern as being too bland for an artwork and wanted to keep the viewer alert by engaging their eyes in a constant search through the dense structure of a high D pattern. We plan to investigate this intriguing possibility by performing eye-tracking experiments on Pollock's paintings, which will assess the way people visually assimilate fractal patterns with different D values.
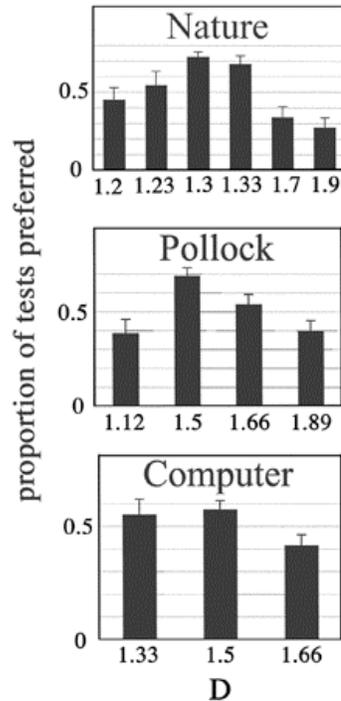
Figure Four. Visual preference tests for natural fractals (top), Pollock's fractals (middle) and computer fractals (bottom). In each case, the y axis corresponds to the proportion of trails for which patterns of a given D value were chosen over patterns with other D values.

Acknowledgments

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