Perceptual and Physiological Responses to the Visual Complexity of Pollock's Dripped Fractal Patterns

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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. With ever widening appeal, they have been referred to both as "fingerprints of nature" and "the new aesthetics." Recently, we showed that the drip patterns of the American abstract painter Jackson Pollock are fractal. In this paper, we consider the implications of this discovery and present an overview of our investigations of human response to the visual qualities of fractals. We discuss results showing that fractal images generated by mathematical, natural and human processes possess a shared aesthetic quality based on visual complexity. In particular, participants in visual perception tests display a preference for fractals with mid-range fractal dimensions, and preliminary work based on skin conductance measurements indicate that these mid-range fractals also affect the observer's physiological condition.

KEYWORDS: fractals; aesthetics; visual perception

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 Fig. 1) (Potter, 1985). 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, 1998).

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?

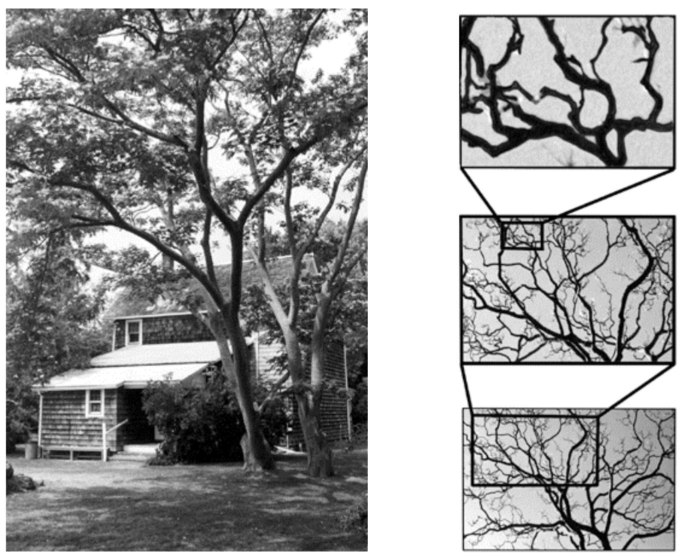

Fig. 1 Left: Pollock's house on Long Island. In contrast to his previous life in Manhattan, Pollock perfected his drip technique surrounded by the complex patterns of nature. Right: Trees are an example of a natural fractal object. Although the patterns observed at different magnifications don't repeat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

Nature's Fractals

Since the 1970s many of nature's patterns have been shown to be fractal (Mandelbrot, 1977). 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 Fig. 1, 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 (Mandelbrot, 1977). 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. For the repeating patterns of a fractal line, D lies between one and two and, as the complexity and richness of the repeating structure increases, its value moves closer to two (Mandelbrot, 1977). 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 2 (left column) demonstrates how a pattern's D value has a profound effect on the visual appearance. The two natural scenes have D values of 1.3 (top) and 1.9 (bottom). Table 1 shows D values for various natural forms:

Natural pattern	Fractal dimension	Source
Coastlines: South Africa, Australia, Britain Norway	 1.05-1.25 1.52	 Mandelbrot 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 (modeled)	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

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) 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).

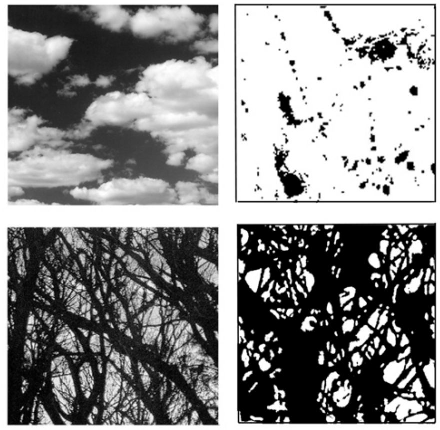

Fig. 2 Examples of natural scenery (left column) and drip paintings (right column). Top: Clouds and Pollock's painting *Untitled* (1945) are fractal patterns with D=1.3. Bottom: A forest and Pollock's painting *Untitled* (1950) are fractal patterns with D=1.9. (Photographs by R.P. Taylor).

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 reveals 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 Fig. 3, he perfected this technique over ten years. Art theorists categorize the evolution of Pollock's drip technique into three phases (Varnedoe, 1998). 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 Fig. 2). 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 Fig. 3). In his 'classic' period of 1948-52, he perfected his technique and D rose more gradually (second dashed gradient in Fig. 3) to the value of D = 1.7-1.9. An example is *Untitled* from 1950 (see Fig. 2) 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?

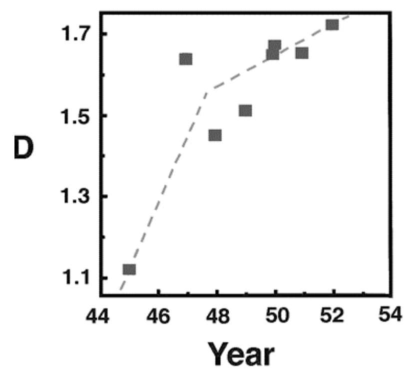

Fig.3 The fractal dimension D of Pollock paintings plotted against the year in which they were painted (1944 to 1954). See text for details.

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, 1987, Geake et al, 1997, Gilden et al, 1993, Knill et al, 1990, Pentland, 1984, and Rogowitz et al, 1990). 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, 1996, Pickover, 1995, Richards, 2001). 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, 1995), similar to Pollock's paintings. However, a 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, 1996, Sprott, 1993). 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 an experiment 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 2 shows some of the images used in the survey (for the full set of images see Spehar et al, 2003). 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". Introduced by Cohn in 1894, the forced choice technique is well-established for securing value judgments. In our experiments, 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 are presented elsewhere, Fig. 4 shows the results from a survey involving 220 participants (Spehar et al, 2003). 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 pattern density).

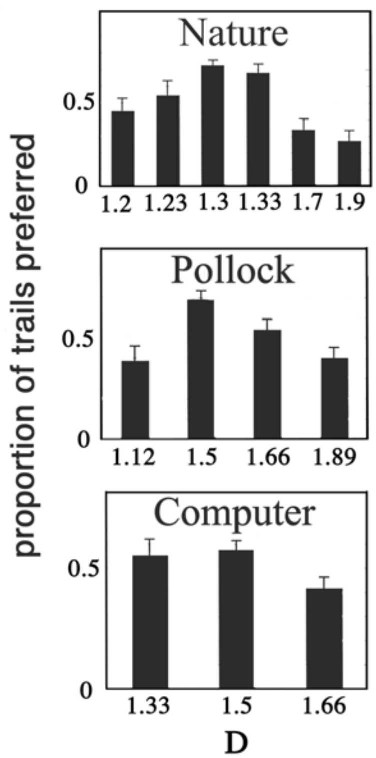

Fig.4. Visual preference tests for natural fractals (top), Pollock's fractals (middle) and computer fractals (bottom). In each case, the y axis corresponds to the proportion of trails for which patterns of a given D value were chosen over patterns with other D values. The uncertainty bars shown above each column represent variations between participants.

Physiological Response to Fractals

Does this visual appreciation for mid-range D values affect the physiological performance of the observer? This question motivated us to re-examine a previous study performed by one of us (J.A.W.) on the physiological restorative effects produced by exposure to different pattern types (Wise et al, 1986). The images used are shown in Fig. 5:

a photograph of a forest scene (top), a reproduction of a savannah landscape (middle) and a pattern of scattered squares (bottom). In addition, a white panel served as a control.

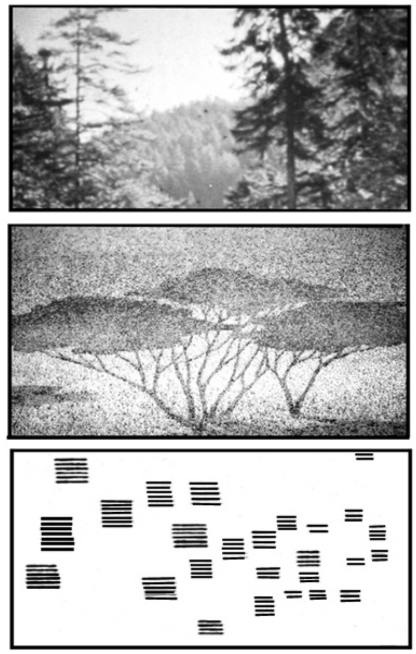

Fig. 5 Images used in the physiological experiments (see text for details).

Performed at the NASA-Ames Research Center, twenty-four subjects were seated singly in a simulated space station cabin facing a bulkhead featuring one of the four images (~1m x 2m). These subjects performed a sequence of three types of stress-inducing mental tasks (arithmetic, logical problem solving and creative thinking) with each task period separated by a one minute recovery period (see Fig.6(a)). To measure the subject's physiological response to the stress of mental work, skin conductance was monitored continuously (Wise et al, 1986). Prior studies have shown skin conductance to be a reliable indicator of mental performance stress with higher conductance occurring under high stress (Ulrich et al, 1986). As an example, Fig. 6(a) shows the rise and fall in conductance measured over the work/rest sequence for participants exposed to the control image. Each participant's conductance was first transformed to a common scale of Z-scores, and then these Z scores were averaged across subjects for each task (Wise et al, 1986, Wise et al, 2003).

The change in this mean Z conductance between work and rest periods was found to depend on which image participants observed during their session. The forest scene was expected to be most effective in reducing this level-of-stress variation because it was a photograph of a natural scene. Instead, participants exposed to the less realistic savannah reproduction experienced the smallest physiological responsiveness to the stress of mental work, as determined by ANOVA on the changes in mean Z score conductance between images ($F(3, 60) = 3.025$, $p < 0.036$) (Wise et al, 1986).

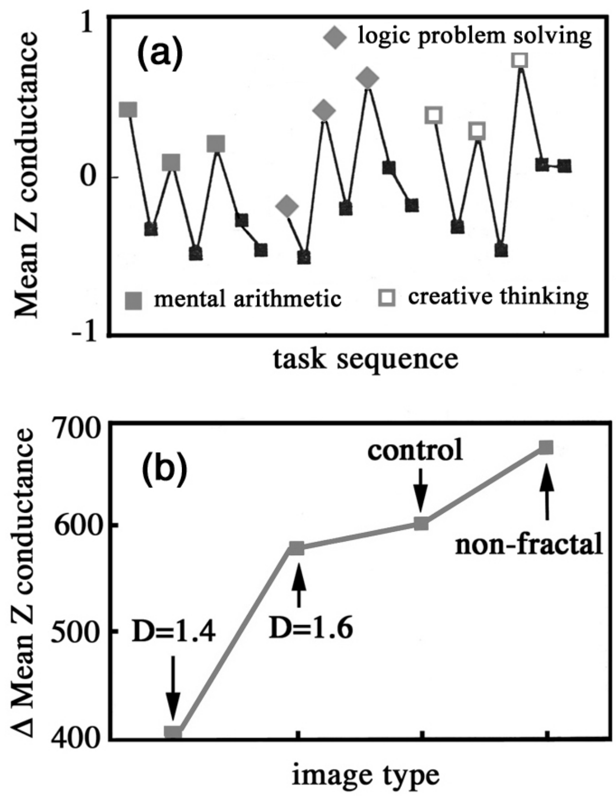

Fig.6 Physiological response to fractals: (a) Mean Z conductance during the task sequence (black squares indicate rest periods), (b) average change in mean Z conductance between work and rest periods for each image.

To investigate this surprising result, we analyzed each image using the 'box-counting' fractal analysis method (Taylor et al, Physics World, 1999). The pattern of squares was found not to be fractal, whilst the savannah reproduction and the forest photograph were both found to be fractal with D values of 1.4 and 1.6 respectively. These fractal analysis results are summarized in Fig. 1(c) along with the change in mean conductance for each image. Whereas the non-fractal square pattern heightened the physiological response compared to the control, the two fractal patterns provided damped responses. The savannah scene, which provided the greatest damping, has a D value previously identified as being in the aesthetically pleasing range whilst the forest D value falls outside this boundary.

Incorporation of natural images into artificial environments has previously been proposed as a method for stress reduction (Ulrich et al, 1983). However, our results indicate that 'naturalness' may not be enough: the pattern's fractal dimension will determine its impact on stress-reduction. We stress the preliminary nature of the above results. Current experiments are aimed at demonstrating the ‘universal’ character of the response, using fractal images formed by nature’s processes, by mathematics and by humans. In addition to investigating electrodermal response, we are also investigating other physiological indicators, including electrocardiograms, pulse activity and pupillography. Based on our preliminary findings, mid-range D fractal patterns could be incorporated into a range of environments to reduce stress levels, particularly in situations where people are deprived of nature’s fractals – for example, in research stations in space and at the Antarctic (Taylor, 2001, Taylor, New Architecture, 2003).

Future Studies

Skin conductance measurements might appear to be a highly unusual tool for judging art. However, our preliminary experiments provide a fascinating insight into the impact that art can have on the physiological condition of the observer. We expect our findings to apply to a remarkably diverse range of fractal patterns appearing in art, architecture and archeology spanning more than five centuries. In addition to Pollock's dripped fractals, other examples of fractals include the Nasca lines in Peru (pre-7th century) (Castrejon-Pita et al, 2003), the Ryoanji Rock Garden in Japan (15th century) (Van Tonder et al, 2002), Leonardo da Vinci's sketch *The Deluge* (1500) (Mandelbrot, 1977), Katsushika Hokusai's wood-cut print *The Great Wave* (1846) (Mandelbrot, 1977), Gustave Eiffel's tower in Paris (1889) (Schroeder, 1991), Frank Lloyd Wright's Palmer House in Michigan (1950) (Eaton, 1998), and Frank Gehry's proposed architecture for the Guggenheim Museum in New York (2001) (Taylor, 2001).

Is Jackson Pollock an artistic enigma? According to our results, 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 interesting to speculate that Pollock 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 are currently investigating 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. In summary, fractals constitute a novel test bed for visual studies, with the reward of providing an improved understanding of our relationship to natural environments.

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