The Construction of Jackson Pollock's Fractal Drip Paintings

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ABSTRACT

Between 1943 and 1952, Jackson Pollock created patterns by dripping paint onto horizontal canvases. In 1999 the authors identified the patterns as fractal. Ending 50 years of debate over the content of his paintings, the results raised the more general question of how a human being could create fractals. The authors, by analyzing film that recorded the evolution of Pollock's patterns as a function of time, show that the fractals resulted from a systematic construction process involving multiple layers of painted patterns. These results are interpreted within the context of recent visual perception studies of fractal patterns.

Throughout a decade of remarkable artistic development stretching from 1943 to 1952, American painter Jackson Pollock generated a vast body of distinct artwork by rolling large canvases across the floor of his windswept barn and dripping household paint on them from an old can with a wooden stick. In contrast to the broken lines painted by conventional brush contact with the canvas surface, he poured a constant stream of paint onto his horizontal canvases to produce uniquely continuous trajectories [1]. Although this technique initially polarized opinion, in the 50 years since Pollock's last major drip paintings were created, both art historians and the public have come to recognize his patterns as a revolutionary approach to aesthetics. However, it was not until 1999 that we, the present authors, identified the defining visual character of his patterns as fractal [2]—bearing the "fingerprint" of Nature's patterns [3], leading us to label Pollock's work "Fractal Expressionism" [4]. This discovery has triggered a multi-disciplinary debate over the precise process that Pollock used to generate his fractal patterns. For art theorists, the artistic significance of Pollock's fractals lies in the process of their generation. Pollock's method also offers an intriguing comparison for scientists studying fractal generation in Nature's systems. For psychologists, the process allows an investigation of the fundamental capabilities and limits of human behavior. How did a human being create such intricate patterns with such precision 25 years ahead of their scientific discovery? Most examples of "fractal art" are not painted by an artist but instead are generated indirectly using computer graphics [5]. Pollock received significant media attention at his creative peak in 1950 [6] and the resulting visual documentation of his painting technique offers a unique opportunity to study how fractals can be created directly by a human being. We have analyzed film sequences that recorded the evolution of Pollock's patterns during the painting process and have identified a systematic fractal construction process in which a work's fractal quality emerged within the first minute, followed by a period of up to 6 months during which Pollock added multiple layers of paint, thus fine-tuning the fractal content. We investigate here the techniques Pollock employed to refine the fractal content of his paintings over the years and interpret these results within the context of recent visual perception studies of fractal patterns.

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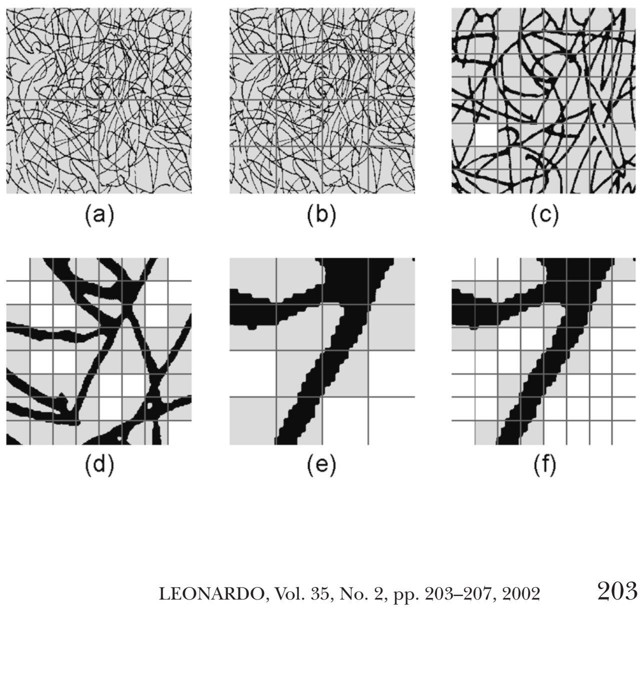
Fractal Analysis of the Drip Patterns

During Pollock's peak years, 1947–1952, his drip paintings frequently were described as "organic," suggesting that the imagery in his paintings alluded to Nature. Lacking the cleanliness of artificial order, his dripped paint clearly stands in sharp contrast to the straight lines, triangles, squares and other "man-made" shapes known within mathematics as Euclidean geometry. But if Pollock's swirls of paint are indeed a celebration of Nature's organic shapes, what shapes would these be? Since Pollock's time, two vast areas of study have evolved to accommodate a greater understanding of Nature's rules. During the 1960s, scientists began to examine the dynamics of Nature's processes—how natural systems, such as the weather, evolve with time. They found that, although natural systems masqueraded as being disordered, lurking underneath was a re-

Fig. 1. A schematic representation of the authors' technique used to detect the fractal quality of Pollock's patterns. The surface of the painting is covered with a computer-generated mesh of identical squares. Then the size of the squares in the mesh is decreased gradually. Starting from the top left picture through to the bottom right picture, the square size is decreased, and in each case the number of occupied boxes (indicated by gray shading) and unoccupied ones can be counted. Note that the paint trajectories used in this schematic representation are not based on any specific Pollock painting. (© Richard Taylor)



markably subtle form of order. This dynamic was labeled chaotic, and an area of study called chaos theory was introduced to promote the understanding of Nature's dynamics [7]. Whereas chaos describes the dynamics of a natural system, fractal geometry describes the patterns that many of these chaotic processes leave behind [8]. Since the 1970s, many of Nature's patterns have been shown to be fractal [9]. Examples include coastlines, clouds, flames, lightning, trees and mountain profiles. Fractals look nothing like the traditional mathematical patterns, such as triangles and squares, that humanity has clung to with familiarity and affection. In contrast to the smoothness of these artificial shapes, fractals consist of patterns that recur upon finer and finer magnification, building up shapes of immense complexity.

Nature's fractals exhibit statistical self-similarity—the patterns observed at different magnifications, although not identical, can be described by the same statistics. We used a traditional method for detecting statistical self-similarity on actual Pollock paintings. Figure 1 uses a schematic representation of a Pollock painting in order to present a simple demonstration of the method. The technique involved covering a digitized image (for example, a scanned photograph) of the painting with a computer-generated mesh of identical squares and then calculating the statistical qualities of the pattern by analyzing which squares were occupied by the painted pattern (shaded gray in Fig. 1) and which were empty. Reducing the square size is equivalent to looking at the pattern at a finer magnification. Thus, in this way, we can compare the pattern's statistical qualities at different magnifications. When applied to Pollock's paintings, the analysis permits examination of pattern sizes ranging from the smallest speck of paint (0.8 mm) up to several meters (his drip paintings were typically between 1 and 5 m long); we find Pollock's patterns to be fractal over the entire size range—the largest observed fractal pattern is over 1,000 times larger than the smallest pattern [10]. This immense size range is significantly larger than for observations of fractals in other typical physical systems [11]. A consequence of observing the fractal patterns over such a large size range is that parameters that characterize the fractal statistics can be determined with great accuracy. A crucial parameter in characterizing a fractal pattern is the fractal

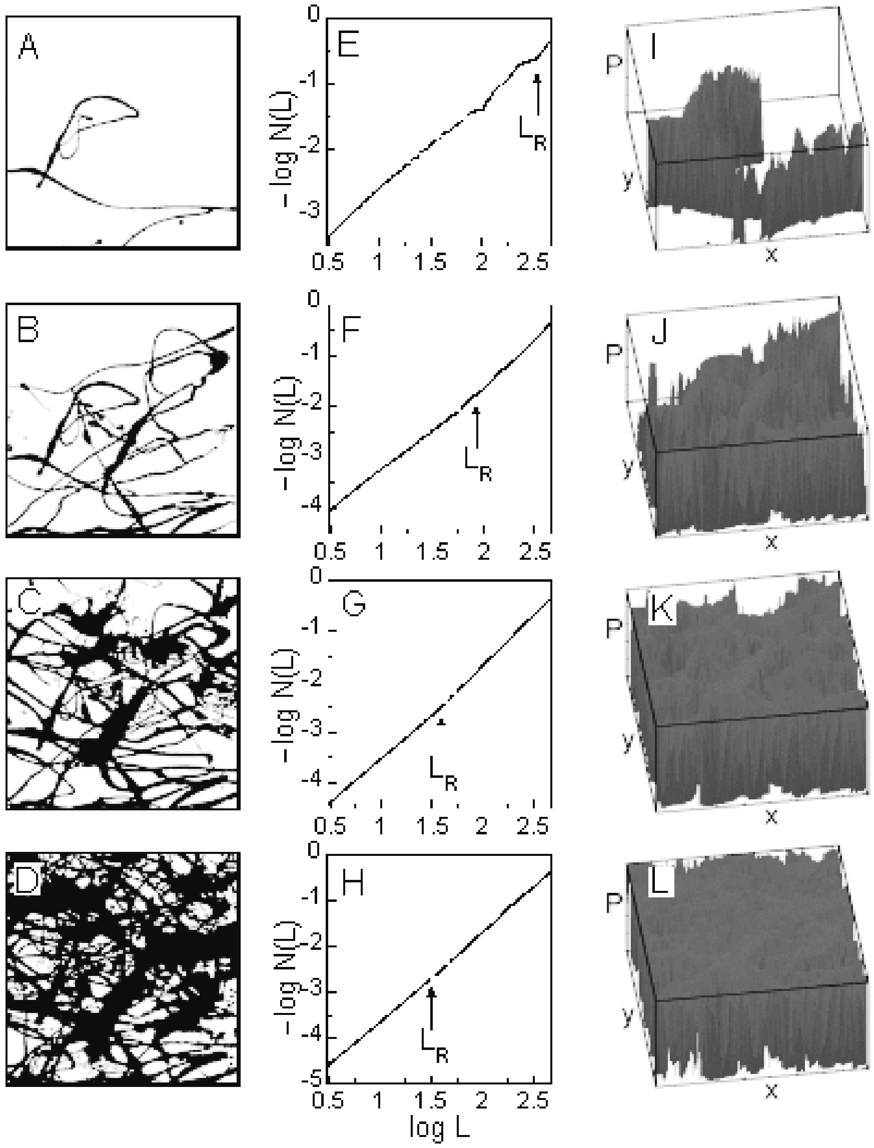


Fig. 2(a–d). A 69-×-69-cm section of a Pollock drip painting is shown at four different times during the painting's evolution. The values of *T* for the four images are: (a), 5 sec; (b), 20 sec; (c), 27 sec; and (d), 47 sec into Pollock's painting process. The painting process was filmed by P. Falkenberg and H. Namuth in 1950 (© Museum of Modern Art, New York, and H. Namuth). The completed painting, which measured 121.9 × 182.9 cm, no longer exists [22]. (e–h) The graphs shown are the corresponding plots of $-\log_{10}N(L)$ versus $\log_{10}L$ for the patterns shown in (a–d) [23]. (i–l) Pattern density plots corresponding to the paintings shown in (a–d). Each plot consists of the local pattern density *P* versus the *x* and *y* positions across the painting. (© Richard Taylor)

dimension, D, and this quantifies the scaling relationship between the patterns observed at different magnifications [12]. For Euclidean shapes, dimension is a simple concept that is described by the familiar integer values; for a smooth line (containing no fractal structure) D has a value of 1, while for a completely filled area its value is 2. However, for a fractal pattern, the repeating structure causes the line to begin to occupy area. D then lies in the range between 1 and 2 and, as the complexity and richness of the repeating structure increases, its value moves closer to 2. Using the computer-generated mesh shown in Fig. 1, we can obtain D by calculating the number of occupied squares in the mesh, $N(L)$, as a function of the size, L, of the squares. For a fractal pattern, $N(L)$ scales according to the power law relationship $N(L) \sim L^{-D}$, where D has a fractional value lying between 1 and 2 [13]. To detect a fractal pattern, we therefore construct a "scaling plot" of $-\log N(L)$ against $\log L$. For a fractal pattern, the data of this scaling plot will lie on a straight line. In contrast, if the pattern is not fractal, then the data will fail to lie on a straight line. Furthermore, for a fractal pattern the value of D

can be extracted from the gradient of the straight line. In this way, we can use the scaling plot both to detect and to quantify the fractal behavior.

This fractal analysis technique is demonstrated in Fig. 2 for an untitled drip painting created during Pollock's "classic" period of 1950. During this period, Pollock was filmed while painting, and Figs 2(a–d) are processed images taken from one such film that show the drip painting at different times during its evolution [14]. First we will concentrate on the painted image shown in Fig. 2(d) and the equivalent scaling plot shown in Fig. 2(h). The region of the painting recorded by the film process was 690 by 690 mm, and the computer covered this region with a mesh of identical squares. The size of the largest square was chosen to match this area (i.e. $L = 690$ mm, corresponding to 1 square within the mesh), and the smallest is chosen to match the finest paintwork that can be resolved ($L = 3$ mm, corresponding to 52,900 squares). The validity of the counting technique increases in the small L limit where the number of squares is large enough to provide reliable counting statistics. For L values ranging from 3 to 32 mm (corresponding to log L ranging from 0.47 to 1.5 in Fig. 2), the graph displays the straight line expected for fractal behavior, and we calculate $D = 1.89$ from the gradient. However, for L values ranging from 32 to 690 mm (corresponding to log L ranging from 1.5 to 2.83 in Fig. 2), the number of squares in the mesh is sufficiently limited that the technique cannot differentiate between a spatially dense fractal pattern and a filled 2D plane. Consequently, we obtain $D = 2$ from the gradient for these large L values. This resolution limit (the maximum value of L at which the fractional D value can be resolved) is labeled L_R in Fig. 2(h). The way to enlarge the range of L over which the fractal pattern is observed is to increase L_R by expanding the area of the painting covered by the mesh. This increases the number of squares in the mesh for any given L and thus improves the counting statistics. However, this is not possible for the processed image in Fig. 2(d), because the filming process was restricted to the 690-mm section shown. Nevertheless, the characteristic observed over the L range of 3 to 32 mm is sufficient to detect the fractal scaling relationship (i.e. the straight line in the scaling plot) and is consistent with the fractal pattern observed in the larger paintings analyzed up to L values greater than 1 m (for example, the painting *Autumn Rhythm: Number 30, 1950,* discussed below, which is 5.26 m long).

The image shown in Fig. 2(d) was filmed 47 seconds into Pollock's painting process and, at this early stage of the painting's evolution, features only a black layer of enamel paint. This initial layer of paint forms the foundation of the painting and is labeled the "anchor" layer. To complete a painting, Pollock then would spend a period that varied from 2 days up to 6 months building multiple layers of colored trajectory patterns. In many paintings, though not all, he introduced the different colors more or less sequentially: the majority of trajectories with the same color 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 colored layers and examined the fractal content of each layer. We find that each individual layer consists of a uniform fractal pattern. The initial anchor layer in a Pollock painting determines the fractal character of the overall painting. As subsequent layers are added to this painting, the D value rises only slightly. For example, consider *Autumn Rhythm: Number 30, 1950,* which was painted during the same year as the painting shown in Fig. 2. The painting's D value rises from 1.66 (for just the black anchor layer) to 1.67 (for the complete painting with all four fractal layers of paint—black, brown, white and gray). In this sense, the subsequent layers merely fine-tune the D value established by the anchor layer. The anchor layer also visually dominates the painting. Pollock often chose an anchor layer of black, which contrasts with the light canvas background. Furthermore, the anchor layer occupies a larger surface area than any of the other layers. For *Autumn Rhythm: Number 30, 1950,* the anchor layer occupies 32% of the canvas space, while the combination of the other layers—brown, gray and white—occupies only 13%.

Since the fractal content and visual character of a Pollock painting are determined predominantly by the anchor layer, we have examined the evolution of this layer in detail. In the anchor layer's initial stage, the trajectories are grouped into small, unconnected "islands," each of which is localized to a specific region of the canvas. Pollock then went on to paint longer trajectories, extending across several meters. These extended trajectories joined the islands, gradually submerging them in a dense pattern of trajectories that became increasingly fractal in character. The visual evolution of this process is documented in Fig. 2(a–d), and the accompanying graphs of Fig. 2(e–h) indicate how the fractal character emerges with time, T. The first image, shown in Fig. 2(a), was recorded 5 seconds into the painting process and focuses on one of the islands. At this initial stage, the painting was not yet fractal, as confirmed by the plot of Fig. 2(e), which fails to condense onto a straight line. Note also that L_R lies at the extreme right of the graph—the pattern is so sparse that only at the largest L values does the technique interpret the pattern as a filled 2D plane. As the painting evolves with time, the resolution limit moves to a smaller L value as the density of the pattern increases. This rise in pattern density with time is quantified in Table 1, in which the percentage of the canvas area occupied by the painted pattern, A, is shown to rise rapidly over the first minute—by $T = 47$s, more than two-thirds of the surface is covered with paint. How this paint is distributed across the canvas surface is displayed in Figs 2(i–l), where the local pattern density, P, is plotted as a function of the x (width) and y (height) position coordinates within the canvas. To calculate P at a given location on the canvas, a square of side length $L = 0.56$ cm is drawn at that location. Within this square, the percentage of the canvas surface area filled by the painted pattern is then calculated. P is plotted between 0 and 100%, while x and y are plotted between 0 and 69 cm. Figures 2(i–l) show that the rapid rise in A with time is accompanied by an increase in spatial uniformity—a signature of Pollock's fractal patterning. The graphs of Figs 2(e–h) confirm this introduction of fractal content. By $T = 27$s, the graph in Fig. 2(g) identifies the pattern as fractal, and we obtain $D = 1.72$ from the gradient. By $T = 47$s, D has risen to 1.89, reflecting the rich com-

Table 1. A summary of the anchor layer's parameters as they evolve during the first 47 seconds of the painting process (see the text for the definition of each parameter).

T (sec)	*D*	L_R (cm)	*A* (%)
5	non-fractal	34.8	3.3
20	1.52	8.4	16.5
27	1.72	3.9	42.5
47	1.89	3.1	70.2

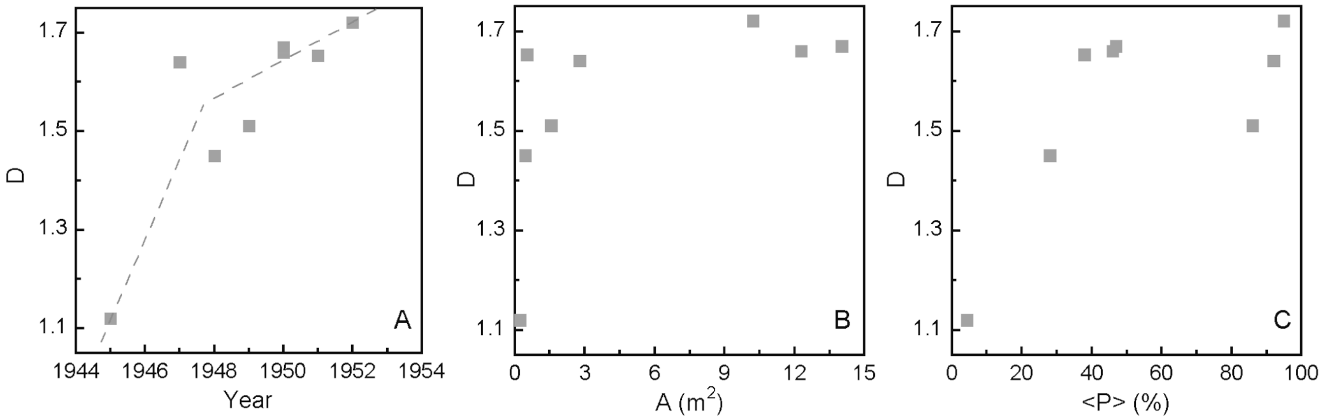


Fig. 3. (a) The fractal dimensions *D* of eight Pollock paintings are plotted against the years in which they were painted. The dashed lines are guides to the eye indicating two approximate rates of evolution in *D* through the years. (b) The *D* values are plotted against canvas area for the same eight paintings plotted in (a). (c) The *D* values are plotted against the percentage of the canvas area occupied by the pattern. (© Richard Taylor)

plexity of fractal structure in the pattern shown in Fig. 2(d). At this stage, after less than 1 minute, the crucial stage of Pollock's fractal generation process is over: the anchor layer has been defined.

Perception of the Fractal Patterns

Labeling the formation of the anchor layer phase one, and the subsequent multi-layer fine-tuning process phase two, we note that for some of Pollock's works, there was also a phase three, which took place after the painting process was completed. The uniformity and fractal character of the completed patterns sometimes deteriorated towards the canvas edge. To compensate for this, Pollock cropped some of his canvases after he had finished painting, removing the outer regions of the canvas and retaining the highly fractal central regions. The completed paintings, generated by this highly systematic three-phase process, follow the fractal scaling relationship (as detected by a straight line within the scaling plots) with remarkable accuracy and consistency. How did Pollock arrive at this remarkable fractal-generation process? Some insight can be obtained by considering investigations of human aesthetic judgments of fractal images. A recent survey performed by one of the authors (Taylor) revealed that, out of 120 people questioned, over 90% of subjects found fractal imagery to be more visually appealing than non-fractal imagery, and it was suggested that this choice was based on a fundamental appreciation arising from humanity's exposure to Nature's fractal patterns [15]. The survey highlights the possibility that the enduring popularity of Pollock's Fractal Expressionism is based on an instinctive appreciation for Nature's fractals shared by Pollock and his audience.

It is clear from this analysis that Pollock's painting process was geared to more than simply generating a fractal painting—otherwise he could have stopped after 20 seconds (see Figs 2[b,f]). Instead he continued beyond this stage and used the three-phase process over a period lasting up to 6 months. The result was a fine-tuning of the patterns to produce a fractal painting described by a highly specific *D* value. In Fig. 3(a) the *D* values of eight paintings are plotted against the year in which they were painted. Our investigations show that Pollock refined his technique through the years, with the *D* value of his completed paintings rising from 1.12 in his early attempts in 1945 to 1.72–1.89 at his peak in 1950–1952. Art historians categorize Pollock's development of the drip technique into his "preliminary" phase (circa 1943), his "transitional" phase (circa 1947) and his "classic" phase (circa 1950) [16]. Figure 3(a) indicates a rapid increase in *D* during the evolution from the "preliminary" to the "transitional" phase as he established his technique, followed by a more gradual increase as he refined his technique towards the "classic" style. Each of the *D* values shown in Fig. 3(a) is re-plotted against canvas area in Fig. 3(b). Similarly, in Fig. 3(c) the *D* values are re-plotted against the percentage of the canvas area covered by paint. These plots reveal a correlation between the high *D* values of his "classic" patterns and his use of a large canvas and high pattern density during that period. Why would Pollock refine his process to generate fractals with high *D* values? It is interesting to note that, in a recent survey designed to investigate the relationship between a fractal pattern's *D* value and its aesthetic appeal, subjects expressed a preference for patterns with *D* values of 1.8 [17], similar to Pollock's "classic" paintings of 1950. Although a subsequent survey reported much lower preferred values of 1.26, this second survey indicated that self-reported creative individuals have a preference for higher *D* values [18], perhaps compatible with Pollock's quest to paint patterns with such values.

Finally, in addition to exploring the aesthetic appeal of Pollock's patterns, perception studies also may provide an answer to one of the more controversial issues surrounding Pollock's drip work. Over the last 50 years there has been persistent theoretical speculation that Pollock painted illustrations of objects (for example, human figures) during the early stages of a painting's evolution and then obscured them with subsequent layers of paint [19]. Since fractal patterns do not incorporate any form of figurative imagery, our analysis excludes the possibility that the initial stages of his paintings featured painted figures. Why, then, is the "figurative" theory so persistent? A possible answer can be found by considering our analysis in the context of the perception studies by Rogowitz and Voss [20]. These studies indicate that people perceive imaginary objects (such as human figures, faces, animals, etc.) in fractal patterns with low *D* values. For fractal patterns with increasingly high *D* values, this perception falls off markedly. Rogowitz and Voss speculate that their findings explain why people perceive images in the inkblot psychology tests first used by Rorschach in 1921. Their analysis shows that inkblots are fractal with a D value close to 1.25 and thus will trigger perceptions of objects within their patterns. Although this is not discussed by Rogowitz and Voss, their results may explain the Surrealist method of “free association,” in which the artists stared at painted patterns until an image “appeared” [21]. It could be that the patterns produced by the Surrealists (e.g. Ernst’s “frottage,” Dominguez’s “decalcomania” and Miró’s washes) were fractal patterns of low dimension. These findings also explain why figures might be perceived in the initial layers of Pollock’s paintings. In Fig. 2, the fractal analysis of the evolution of Pollock’s patterns shows that his paintings started with a low D value, which then gradually rose as a painting evolved towards completion. Thus it is consistent with the findings of Voss and Rogowitz that an observer would perceive objects in the initial patterns of a Pollock painting (even though they are not there) and that these objects would “disappear” as D rose to the high value that characterized the completed pattern.

Conclusions

The profound nature of Pollock’s contribution to modern art lies not only in the fact that he could paint fractals on a canvas but in how and why he did so. In this paper we have used a fractal analysis technique to examine the painting process Pollock used to construct his drip paintings. By analyzing film of Pollock painting, we conclude that Pollock used a remarkably systematic method capable of generating intricate patterns that exhibit fractal scaling criteria with precision and consistency. Clearly, a discussion of Pollock’s fractals would be incomplete without considering the art-historical context of his work. It is hoped therefore that the results presented here will stimulate a debate among scientists, psychologists and art theoreticians regarding the artistic significance of Pollock’s fractal drip paintings.

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References and Notes

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2. R.P. Taylor, A.P. Micolich and D. Jonas, “Fractal Analysis of Pollock’s Drip Paintings,” *Nature* **399** (1999) p. 422.

3. B.B. Mandelbrot, *The Fractal Geometry of Nature* (New York: W.H. Freeman, 1977).

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5. For examples of computer-generated fractal art, see the following books: J. Briggs, *Fractals—The Patterns of Chaos* (London: Thames and Hudson, 1992); C.A. Pickover, *Patterns, Chaos and Beauty: Graphics from the Unseen World* (New York: St. Martin’s Press, 1990); H.-O. Peitgen, *The Art of Fractals. A Computer Graphical Introduction* (Berlin: Springer Verlag, 1988). Note that Pollock was not the only artist to generate fractals without the aid of a computer. Early Chinese landscape paintings also have recently been analyzed for fractal content. See R.F. Voss, “Local Connected Fractal Dimension Analysis of Early Chinese Landscape Paintings and X-Ray Mammograms,” in Y. Fisher, ed., *Fractal Image Coding and Analysis, NATO ASI Series F* (Norway: Springer-Verlag, 1995). Although the individual brushstrokes were found to be fractal, the images constructed from the brushstrokes were non-fractal illustrations. In contrast, for Pollock’s paintings, the image itself was a fractal pattern.

6. P. Falkenberg and H. Namuth used 16-mm color film to record Pollock’s painting process in 1950. In addition, Namuth also used black-and-white film to record Pollock and took over 200 black-and-white photographs of the artist during the same year. For a detailed description see H. Namuth, “Photographing Pollock,” in B. Rose, ed., *Pollock Painting* (New York: Agrinde Publications, 1980). Also see Landau [1] and Varnedoe [1].

7. See, for example, J. Gleick, *Chaos: Making a New Science* (New York: Penguin Books, 1987).

8. See Mandelbrot [3] and Gleick [7].

9. See, for example, Briggs [5] and J.-F. Gouyet, *Physics and Fractal Structures* (Berlin: Springer-Verlag, 1996).

10. See Taylor et al. [2] and [4].

11. Unlike fractal patterns generated by mathematical equations, fractals in physical systems do not range from the infinitely large through the infinitesimally small. Instead, physical fractals are observed across only a limited range of sizes. A recent survey of observations of fractals in physical systems suggests that the largest pattern is typically only 30 times larger then the smallest pattern. See D. Avnir, O. Biham, D.A. Lidar and O. Malcai, “Is the Geometry of Nature Fractal?” *Science* **279** (1998) pp. 39–40.

12. See Mandelbrot [3] and Gouyet [9].

13. See Mandelbrot [3] and Gouyet [9].

14. Pollock painted the image on a glass surface with the camera recording from below. Using a video recording of the original film, we processed the image to remove background color variations. We also reflected the image around the vertical axis, so that the final image appears from Pollock’s point of view. We then converted the resulting black-and-white representation shown in Fig. 2(a) into a bitmap format for fractal analysis.

15. R.P. Taylor, “Splashdown,” *New Scientist* **2144** (1998) p. 31.

16. William Rubin, “Jackson Pollock and the Modern Tradition Part IV,” *Art Forum* No. 5 (May 1967) p. 32.

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19. See Varnedoe [1] pp. 87–132.

20. R.E. Rogowitz and R.F. Voss, “Shape Perception and Low Dimension Fractal Boundary Contours,” in B.E. Rogowitz and J. Allenbach, eds., *Proceedings of the Conference on Human Vision: Methods, Models and Applications,* S.P.I.E. **1249** (1990) pp. 387–394.

21. D. Ades, “Dada and Surrealism,” in Nikos Stangos, ed., *Concepts of Modern Art* (London: Thames and Hudson, 1974).

22. See Landau [1] and Varnedoe [1] for more details.

23. For technical explanation of the mathematical functions employed here, see Mandelbrot [3].

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