Composite Diffusion Limited Aggregation Paintings

Gary R. Greenfield
Department of Mathematics & Computer Science
University of Richmond
Richmond, VA 23173, USA
ggreenfi@richmond.edu

Abstract

Diffusion limited aggregation (DLA) is a modelling technique for simulating dendritic growth that has seen widespread application in the physical, biological, and social sciences. We introduce an artistic component to the basic technique by adding special effects parameters to a single particle, random walk DLA aggregation scheme. Our goal is to explore the potential of the enhanced scheme as a medium for algorithmic art. We use compositing to make collages of DLA patterns and we give examples of our resulting "DLA paintings".

1 Introduction

First introduced by Witten and Sander in 1981 [15], diffusion limited aggregation (DLA) describes a rule-based process that has been used to model many physical, biological, and social phenomena. In two dimensions, the idea is easy to explain: A "particle" is placed randomly in the plane and undergoes a random walk until either it encounters an existing structure — initially a fixed random particle or *seed* — in which case it adheres, or its time limit expires and it dies. The dendritic growth that results from releasing over time many, many particles has seen widespread application. DLA has been used to model electrodeposition [8], urban cluster growth [1], root system growth [2], and even aspects of string theory [7]. Mathematically, much of the interest in DLA structure formation has centered on its fractal-like nature [14], with considerable effort having been devoted to measuring the fractal dimension of DLA formations [8].

In this paper, we will consider an implementation of DLA for artistic purposes. DLA simulations have been used previously for special effects purposes in computer graphics. In particular, DLA has been used for imaging fractal-like phenomena such as ice formation and root formation [2]. Because there are so many variations of DLA models, it is not clear to us what role DLA has previously played in either fractal art or fractal music [14]. We note that Long [11] is currently investigating the use of dendritic structures as nonphotorealistic artistic effects using a DLA model based on path planning. The only *dedicated* fine arts application that we are aware of is the "Aggregation" series of prints exhibited by Lomas [9]. The fact that these are sophisticated, computationally intensive, three dimensional DLA simulations [10] has not been well publicized.

This paper is organized as follows. In Section 2 we present our basic two dimensional DLA model. In Section 3 we explain how we add various special effects parameters to the model. In Section 4 we discuss compositing using our DLA model and present our artistic results. In Section 5 we give our conclusions and discuss future work.

2 A DLA Model Based on Taxicab Geometry

To simplify managing a collection of particles moving, colliding, and adhering in the plane, Kobayashi et al. [8] propose simulating the DLA process using motion by a single particle at a time on a two dimensional integer lattice with distance measured using the Manhattan metric i.e., using taxicab geometry. Under this metric, the distance between two points (x_1, y_1) and (x_2, y_2) on the integer lattice is defined to be $d = |x_1 -$

$x_2| + |y_1 - y_2|$. This implies the ball of radius R centered at the origin is actually the “diamond” whose vertices are $(0, \pm R)$, $(\pm R, 0)$. We now describe the Kobayashi et al. model where only one particle at a time is ever present and in motion on the integer lattice. At each iteration, we first determine the radius R of the smallest diamond centered at the origin that contains the existing DLA structure. Next we release a particle from a location selected at random on the boundary of the diamond of radius $2R$. Now, we allow this particle to proceed on a random walk until either: (1) it meets and adheres to the existing structure, (2) it reaches the boundary of the diamond of radius $3R$, or (3) its time limit expires. In the latter two cases we remove the particle. The simulation halts when the bounding radius R reaches a predetermined value $R_{\max}$. To ensure a particle in motion remains located on the integer lattice, a particle moves by taking unit steps in one of the four compass directions. Figure 1 (left) shows the typical dendritic growth pattern that results using this model.

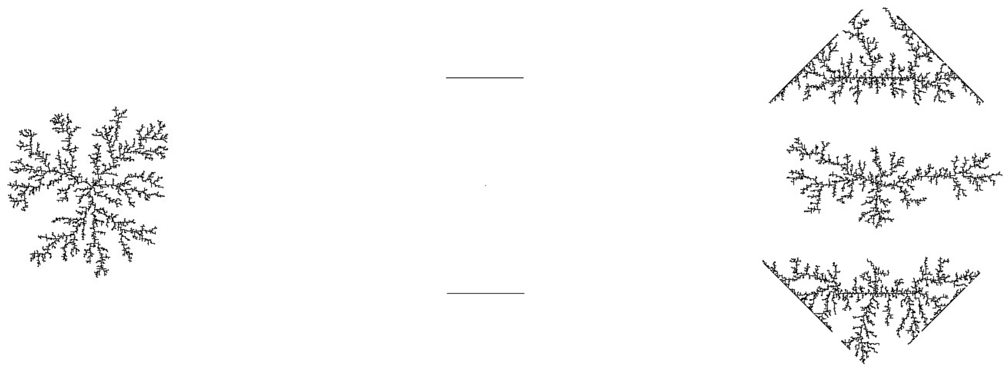

Figure 1: Left: The dendritic growth pattern arising from the Kobayashi et al. DLA simulation model using a single seed. Middle: A initial seed pattern with a central seed and two horizontal line segments of seeds. Right: The DLA structures resulting from this seed pattern when growth is constrained to a diamond of fixed radius.

3 Adding Visual Effects to the Model

We add visual effects to the model using two different methods. The first method uses seeds arranged in line segments to influence the dendritic growth of the central seed. Figure 1 (rightmost images) illustrates this phenomenon. The two horizontal segments above and below the central seed absorb particles and define zones immediately above and below the central seed that are difficult for subsequently released particles to penetrate. This forces the growth of the central structure to be horizontal. One of the subtle points in implementing this effect is that the constantly increasing boundary distance R that determines where new particles are released from must be calculated based on the size of the central dendrite, not the maximum distance from the origin of all “frozen” particles. Figure 2 (leftmost images) shows another example using this technique. To obtain the middle image of Figure 2 several horizontal and vertical line segments of seeds were used to influence the growth of the cental dendrite. It was this contrast between the geometric pattern of the seeds and the fractal-like texture of the dendrites and that led us to think in terms of using DLA simulation as an (algorithmic) artistic medium.

The second method we use for creating visual effects is to introduce a diffusion process that we have used in other time-based simulations [6] in order to make the color deposited at a pixel (i.e., lattice point) where a particle adheres have greater impact on the composition as a whole. In our DLA model, when a particle adheres, the color intended for the pixel where adhesion is to take place is diffused throughout the immediate neighborhood of that pixel. To be more precise, the target adhesion pixel receives 4/16ths of the intended color, the four pixels at the cardinal compass points each receive 2/16ths of the intended color, and the four pixels diagonal to the target pixel each receive 1/16th of the intended color. Since our background canvas is always initialized to all white, this means that over time the intended color will concentrate in those areas with the highest density of dendritic pixels. Figure 2 (right) shows an example of a “painterly” DLA where the directional growth of the dendrite resulted from using a (horizontal) line segment of initial seeds centered at the origin. Occasionally we further enhance this effect by lightening the intended color as the taxicab distance from the origin to the pixel being colored increases.

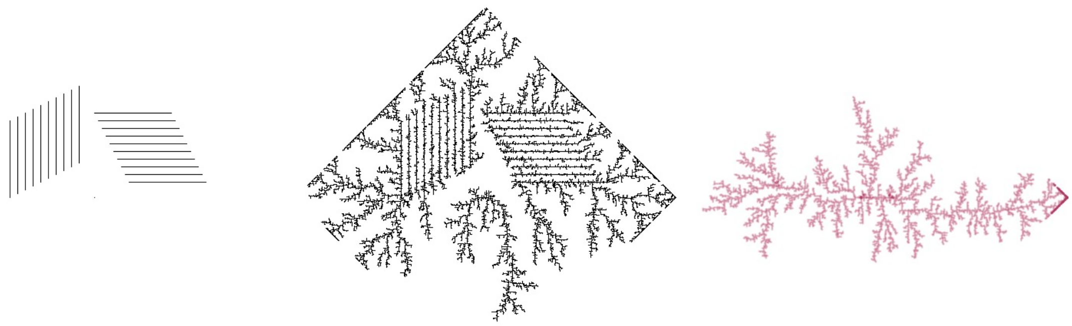

Figure 2: Left: A initial seed pattern consisting of a central seed and a series of vertical and a horizontal line segments of seeds. Middle: The resulting DLA structure. Right: The painterly “diffusion effect” that results by allowing each particle to share its color with its eight nearest neighbors when it adheres to the existing structure. A central horizontal segment of seeds was used.

4 Composite DLA Paintings

In this section we use our DLA model as described above to create two different types of composite DLA paintings. First, we composite a series of simple DLA dentritic paintings that each use a single central seed to make our radial composites. Second, we use a template seed pattern, and by successively translating and rotating this template, we are able to composite a series of DLA paintings to create our translation composites. Perhaps compositing is a bit of a misnomer here, since by iterating our DLA simulation *without* resetting the background to all white successive DLA structures are, in fact, superimposed on top of one another rather than being composited in the traditional sense.

4.1 Radial Composites

As indicated, to make what we call a radial composite we place a single seed at the origin and composite a number of dendrites made from that seed by merely re-running the DLA simulation without resetting the background to all white and by letting each run proceed for the same length of time. In this way the individual asymmetric dendrites are layered to yield a radially balanced final image with a galaxy-like appearance. This is due to the core buildup around the central seed. Figure 4 shows some of the steps in the compositing progression from one layer to five layers.

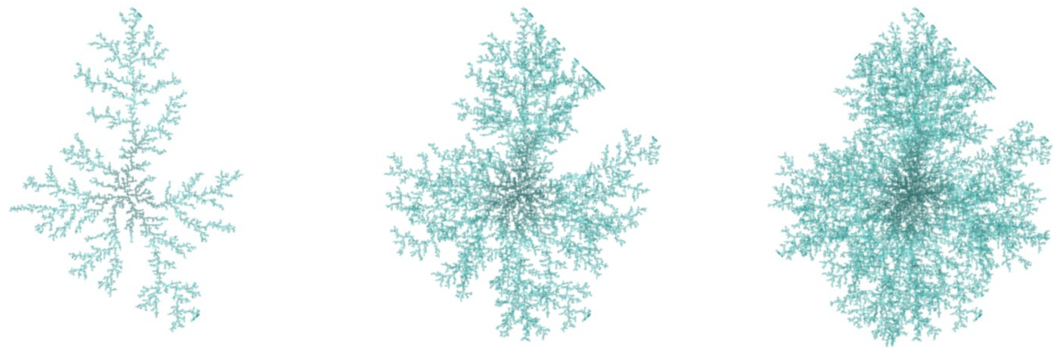

Figure 3: The fromation of a radial composite DLA painting. Left to right, one then three then five dendrites.

4.2 Translation Composites

To make what we call a translation composite, we first make a "template" using a single seed at the origin and two tiny squares filled with seeds situated on the line $y = x$ and equidistant from the central seed. The resulting DLA simulation yields three small dendrites that are transverse to this line. Next, by reflecting the template across the y-axis so that the two tiny squares are now on the line $y = -x$ and then restarting the simulation an "X" figure with a central core and four cores on the diagonals results. Moreover for artistic effect these dendrites are "framed" by letting the simulation run long enough for the diffused color to build-up along the boundary edges of the constraining diamond. The size of the diamond and the degree to which the frame is allowed to buildup are both a function of the length of time the simulation is allowed to run for. Via template translation with respect to this "X" the process is repeated four more times to create a larger "X" of five framed diamonds whose structure as a whole is similar to the original five core structures described above. The resulting composite (see Figure 4) exhibits both symmetry and randomness on different levels. We feel it is an effective artistic statement about a (mathematical) relationship between symmetry and randomness.

4.3 Discussion

It is clear that the math and art community places emphasis upon, has an appreciation for, and shows a devotion to symmetry. It is interesting to compare the technique we have used for coupling symmetry and randomness to make our translation composites with the methods and results obtained by Field who couples symmetry with (deterministic) chaos. As explained in [4], the abstract art works of Field are obtained by imaging iterates of nonlinear dynamical systems that are constructed so that the resulting desired symmetry is internally induced. Our method is more heavy handed in the sense that the resulting symmetry is externally induced. From an art theory point of view, it is interesting to note that there is research in the field of cognitive science to support the claim that humans have evolved to find symmetry to be aesthetically pleasing [12, 16].

5 Conclusions and Future Work

We have used a simple two-dimensional diffusion limited aggregation (DLA) model as the basis for a medium in which to explore and create algorithmic art. As a tentative first step, we showed the results of compositing the painterly dendrites that one can create using this model to make DLA paintings. We have argued that these paintings invite the viewer to reflect on the nature of randomness and symmetry.

Our DLA paintings are monochrome. Future work should consider how to more effectively manage color. Another promising avenue for future work might be the use of this medium as a motif or texture generator to use in compositing similar to the way Verotsko [13] uses line drawing motifs to composite some of his larger algorithmic compositions.

Our use of templates with simple geometric patterns of seeds was "proof of concept" and more needs to be done in this area. A standard DLA technique known as *stickiness* [3] could also be added to the model to make dendritic structures more "fluffy". To implement stickiness, a parameter s, where $0 < s \leq 1$, is introduced to determine the probability a particle adheres each time it bumps into an existing DLA structure. We expect such considerations and improvements can lead to more complex and compelling imagery.

References

[1] Batty, M., *Cities and Complexity*, MIT Press, Cambridge, MA, 2005.

[2] Bourke, P., Constrained limited diffusion aggregation in 3 dimensions, *Computers and Graphics*, Volume 30, Number 4, 2006, 646–649.

[3] Bourke, P., Diffusion Limited Aggregtion, http://local.wasp.uwa.edu.au/ pbourke/fractals/dla/ (accessed March, 2007).

[4] Field, M., Golubitsky, M., *Symmetry in chaos: a search for pattern in mathematics, art, and nature*, Oxford University Press, Oxford, 1992.

[5] Gaylord, R., Tyndall, W., Diffusion limited aggregation, *Mathematica in Education*, Volume 1, Number 3, 1992, 6–10, http://library.wolfram.com/infocenter/Articles/2866/ (accessed December, 2006).

[6] Greenfield, G., On evolving multi-pheromone ant paintings, *2006 IEEE World Congress on Computational Intelligence Proceedings*, 2006, 7425–7431.

[7] Halsey, T., Diffusion-limited aggregation: a model for pattern formation, *Physics Today*, Volume 53, Number 11, 2000, 36–47, http://www.physicstoday.org/pt/vol-53/iss-11/p36.html (accessed December, 2006).

[8] Kobayashi, Y., Niitsu, T., Takahashi, K., Shimoida, S., Mathematical modeling of metal leaves, *Mathematics Magazine*, Volume 76, Number 4, 2003, 295–298.

[9] Lomas, A., 2006 Bridges Exhibit of Mathematical Art, London, UK, 2006, http://www.bridgesmathart.org/art-exhibits/bridges06/lomas.html (accessed December, 2006).

[10] Lomas, A., private communication, 2006.

[11] Long, J., http://www.cs.usask.ca/grads/jsl847/ (accessed March, 2007).

[12] Ramachandran, V., Hirstein, W., The science of art: a neurological theory of aesthetic experience, *Journal of Consciousness Studies*, Volume 6, 1999, 15–52.

[13] Verotsko, R., Algoritmic art, http://www.verostko.com/ (accessed December, 2006).

[14] Voss, R., Fractals in nature: from characterization to simulation, *The Science of Fractal Images*, eds. H. Peitgen and D. Saupe, Springer-Verlag, New York, 1988, 36–38.

[15] Witten, T., Sander, L. Diffusion-limited aggregation, a kinematic critical phenomenon, *Physical Review Letters*, Volume 47, 1981, 1400–1403.

[16] Zeki, S., *Inner Vision, An Exploration of Art and the Brain*, Oxford University Press, New York NY, 1999.

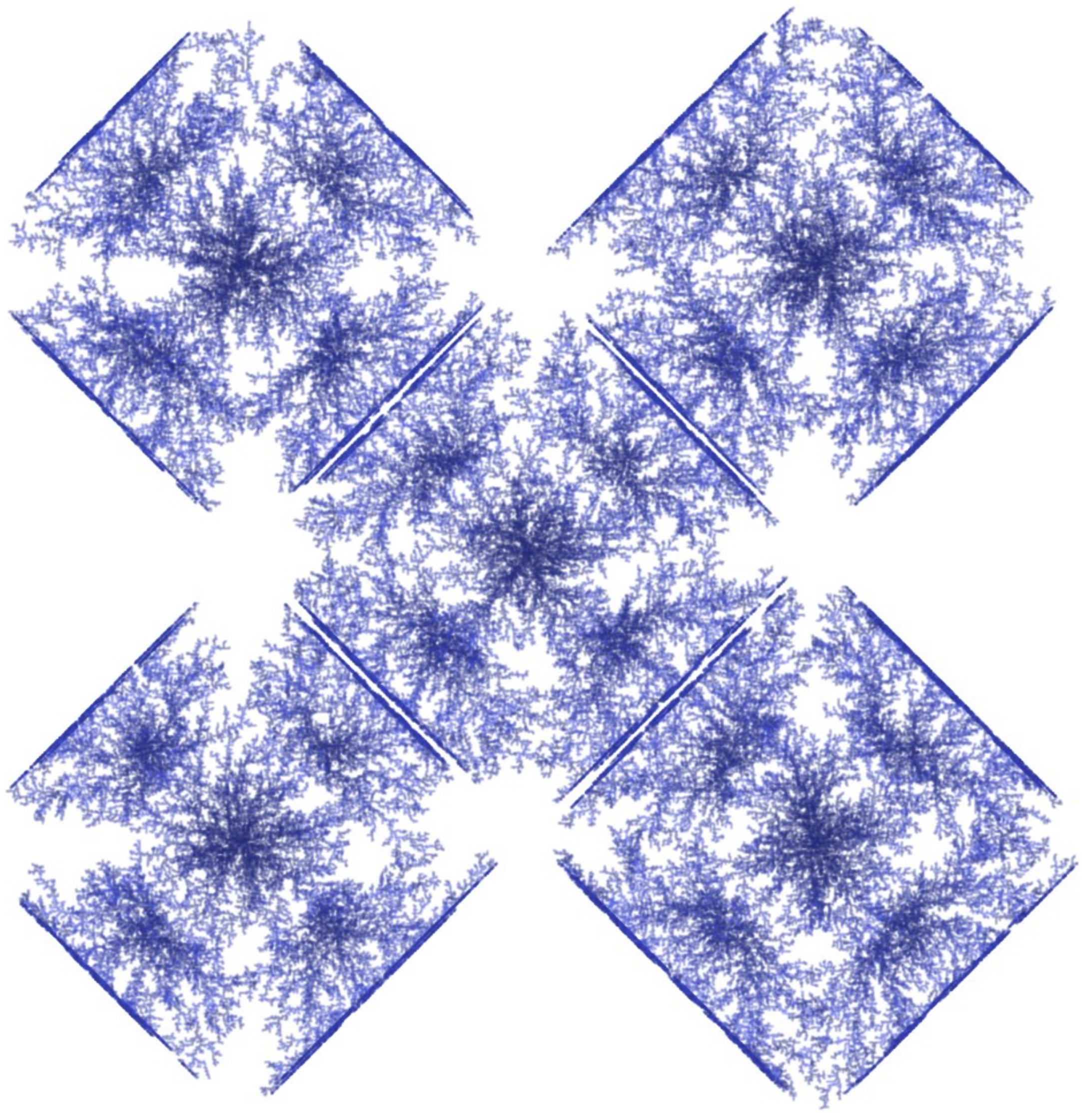

Figure 4: A translation composite DLA painting.