Sticky Pixels: Evolutionary Growth by Random Drop Ballistic Aggregation

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Abstract

Over the years many techniques have been developed for simulating and modelling trees, ferns, crystals and natural structures. Indeed, many complex and realistic images have been formed. Often, these rely on rule based systems to create the structure, they start with a simple form and progressively refine it into a more complex form by applying rules. We use the notion of Sticky Pixels to form textures. The pixels (or objects) move around the space, when they touch another object they stick together to form a larger cluster. The objects aggregate and stop at the place and position where they first touched. Such an aggregation generates neighbourhoods of pixels that form natural looking shapes. The pixels may randomly walk around (such as using Brownian motion), or be guided along pre-defined routes (often described as ballistic), to obtain different structures. We use a ballistic aggregation technique, where the particles are randomly dropped onto a canvas, migrate and stick onto the closest position of the nearest cluster. We present Sticky Pixels, explain different parameters and describe our algorithm.

Keywords: Fractals, Evolutionary Art, Diffuse Limited Aggregation, Sticky Pixels

1 Introduction and Motivation

Growth in nature seems a complex phenomena to model. The branches and leaves grow to maximise the surface area and minimise the distance from the branches in order to balance the need of food production with the distance the food will travel [Herrmann, 1986]. But, often, it is by applying simple rules, that complex and intricate shapes are formed [Mandelbrot, 1982].

For many years different people have been modelling the natural world. They have generated models and computer graphics images of trees [Jones and Briggs, 1998] and plants [Měch and Prusinkiewicz, 1996], lightening [Reed and Wyvill, 1994; Evans et al., 2000] and and other forms in the natural sciences [Fleischmann et al., 1989]. Indeed, such natural objects are fractals [Mandelbrot, 1982] and are studied, modelled and simulated by scientists from physics, engineering and crystallography, for example.

Many of the growth forms use grammar-based (L-grammar) models, for example [Jones and Briggs, 1998] and [Měch and Prusinkiewicz, 1996]. (See Foley et al. [1990] for a general introduction on L-grammars). However, others use a notion of aggregation to 'grow' the formations, such as [Reed and Wyvill, 1994] and [Fleischmann et al., 1989]. In this paper we focus on growth patterns by aggregation. Aggregation is the process of growing a cluster by adding one particle at a time to a previous growth or an initial seed.

Our motivation is to generate 'textures' and produce 'emergence art' rather than to specifically simulate natural phenomenon. In this paper, we discuss the notion of 'sticky pixels' (section 2), briefly explain other models including Eden's model (section 3.1), Diffuse Limited Aggregation method (section 3.2), and Ballistic approach (section 3.4). We then present our implementation that uses a Random Drop Ballistic Aggregation method (section 4.2).

2 Aggregation by Sticky Pixels

The phrase "sticky pixels" [Sti, 2000] is used to describe models of how particles move around, in space, and join to form clusters. An object may be defined as sticky or 'stuck' to another object when it touches something that is already in the cluster [Prusinkiewicz, 1993]. The object itself may take the form of a pixel, but, it could be larger than a pixel, adapt over the course of time, or even represent a geometric shape.

Consider an experiment where we have a petri-dish (say) and a large number of particles. Over time we drop the particles into the dish allowing them to join together and form clusters. In this example, we can see that the outcome of the cluster may depend on some simple components:

1. the behaviour of the particles, how they move around the dish, whether the particles are attracted or repelled from each other (ie. how and whether they do stick together), the behaviour may also depend on factors such as the size, shape and type of the particles;

2. the container size, shape, area;

3. whether there is any anything else in the container, such as fixed point to attract to (a seed), whether another liquid is already present;

4. what external phenomena affect the experiment, such as heating up the dish or tilting the dish on one side, or how the particles are added to the dish.

3 Some Growth Models

There are many growth models and model variants, we briefly present some models of growth.

3.1 Eden's Model

One of the first computer models of growth was published in 1960 by Eden, as cited by [Herrmann, 1986]. Known commonly as the "Eden model", a single particle is set at the centre of a grid, with subsequent particles being added at random to bounding points. Such a growth is depicted in Figure 1.

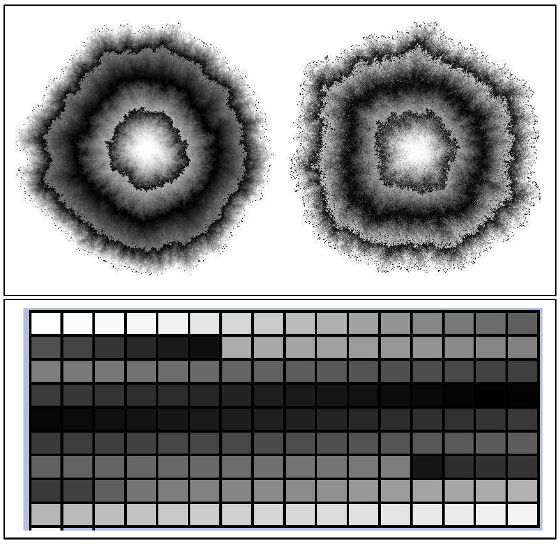

Figure 1: Growth aggregation using Eden's model. Left, using 4-connectivity adjacency rule; Right, using 8-connectivity. Below, colourmap for the visualization, showing bands of white, grey and black.

3.1.1 Adjacency and Lattice Arrangements

Here, and in any growth model, the notion of adjacency may be interpreted differently and may affect and bias the formed structure. For example, is an object connected if only the diagonals touch. If the diagonals imply adjacency then the object is 8-connected, otherwise it is 4-connected. Adjacency also depends upon the lattice structure and how the aggregate and particle movement is calculated and stored.

The lattice itself may be square, hexagonal or triangular [Meakin, 1986b]. Indeed, Morse et al.

[1990] in their parallel implementation, used a hexagonal matrix.

There are three common lattice representations (for storing and calculating the movement of particles):

Full-lattice, where the pixels are held and calculated on integer sized grids

Semi-lattice, where the calculation is done in floating-point arithmetic and rounded into integers to be stored in an integer based lattice.

Off-lattice, stores and calculates the particle positions and the coordinates of the particles in floating point numbers.

3.2 Diffusion Limited Aggregation

Diffuse Limited Aggregation (DLA), as presented by Witten and Sander [1981], is concerned with the generation of aggregates formed from the movement of randomly moving particles, Figure 2.

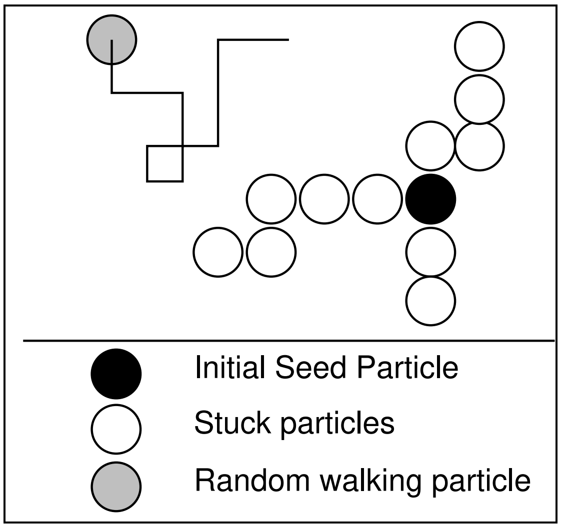

Figure 2: Diffuse Limited Aggregation. Particles enter the experiment away from the centre, they randomly move around. They stop and stick to the aggregate when they first touch.

An initial particle, a seed, is set in the centre of the lattice. The next particle is released at a random point, far from the origin of a lattice, and is allowed to move at random. When the moving particle touches the seed or another already aggregated particle, the new particle becomes immobile and stops where it touched. When the particle has joined the cluster a new particle is released. This process is repeated thousands of times.

As the movement of a particle is random, it may move away from the cluster – rather than towards it; the process may never terminate.

Thus, *launching* and *killing* circles are often employed, see Figure 3. Also, space leaping techniques may be used to move the particle longer distances, when it is far away from the cluster, to speed up the processing movement [Meakin, 1986a].

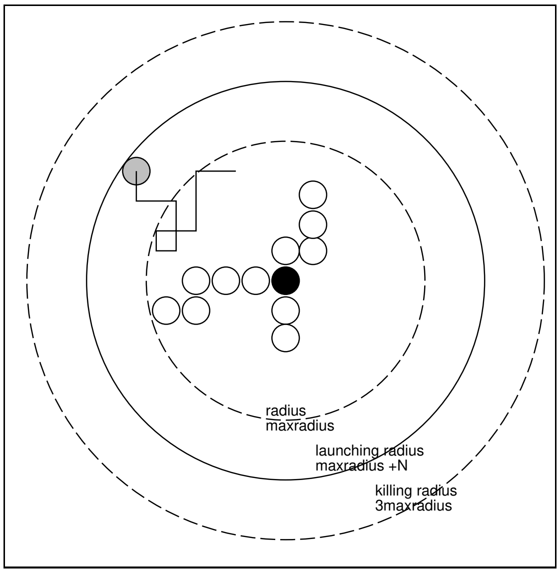

Figure 3: DLA with *launching* and *killing* circles. If the particle moves through the outer killing circle it is lost and a new particle is started at a random point on the launching circle.

It is intriguing that beautiful and natural-looking structures are formed from such random motion, such as illustrated later.

3.3 Probability and Epidemic Aggregation

A DLA aggregation, for example, is made from a cluster of collided particles. It may usefully include other parameters and probabilistic events, such that not every particle sticks to the main cluster. Indeed, in physics it is often useful to model the 'stickiness' of the particles to control whether a particle sticks where it collides, or adjoins in the future, or whether it sticks at all. Additionally, other particles may stimulate growth more rapidly in a certain area by attracting more particles to a certain point, or they could destroy and infect part of the pre-built cluster, or leave trails behind after 'bouncing' into the aggregation [Herrmann, 1986].

3.4 Ballistic Aggregation

Traditionally, the particles move in a simulated Brownian motion, itself fractal in nature [Mandelbrot, 1982], but it is possible to allow the particles to be added to the cluster using different methods. One such method is called ballistic aggregation. Here, the particles travel along straight lines, and are added to the aggregate whenever they touch a particle in the cluster.

This generates simpler structures, to those generated by the DLA's. Indeed, the ballistic models are tradditionaly not viewed as being fractal [Ramanlal and Sander, 1985].

3.5 Cluster-Cluster Aggregation

So far we have only mentioned the situation where a single particles diffuses at a time and the cluster remains stationary. However, it is possible to start with a suspension of particles and allow them all to diffuse and form clusters as they collide. Then the larger clusters diffuse, collide with other clusters or particles to form yet larger aggregates. When modelling such an interaction, often, the repulsive energy of two colliding particles or aggregates is considered along with their kinetics, mass and mass distribution [Lin et al., 1989].

4 Evolutionary Textures

We present our implementations and adaptations of these techniques, including (1) Random Drop with mask, and (2) Random Drop Ballistic Aggregation.

4.1 Random Drop with Mask

It is interesting, and not surprising, that the Eden growth system can be modelled, although wastefully, by dropping random pixels into the grid. If the dropped pixels fall adjacent to a seed then they stick, otherwise another point is chosen. Such a model may be improved by increasing the 'drop zone' like the killing circles in the DLA method. We have implemented such a growth model, that also uses a mask. By changing the mask we can change the sticky conditions. Thus, for the new proposed point to stick, the mask, when AND'ed with the cluster, must return a value greater than 2 (for example). Thus the mask biases the growth to places where there are two or more adjacent cluster points. This has the tendency to inhibit long tendrils. Using a local 4 and 8-connection mask (Figure 4A,B) we get results as in Figure 1 (left, right respectively), and using a wider mask (Figure 4C,D) a smoother growth is formed Figure 5 (left, right respectively).

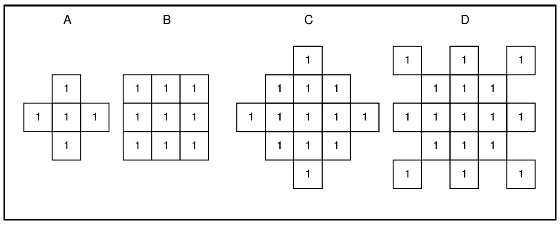

Figure 4: Masks used to control aggregation and inhibit tentril growth.

4.2 Random Drop Ballistic Aggregation

In our hybrid model, the particles are randomly dropped onto the lattice and then stick to the *closest* point in the current aggregation, see Figure 6. If an object is dropped on top of a point that is already in the cluster, then that particle is rejected.

This growth algorithm encourages tendril growth. See, Figure 7.

We use an off-lattice calculation method, with the particles being stored on a regular grid. We generate the dropped particles over a circular dropping zone. To do this, we generate two real random numbers,

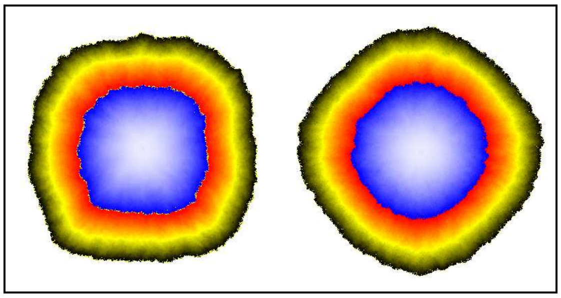

Figure 5: Eden model, by random dropping and probability masks to control growth from dropping aggregation.

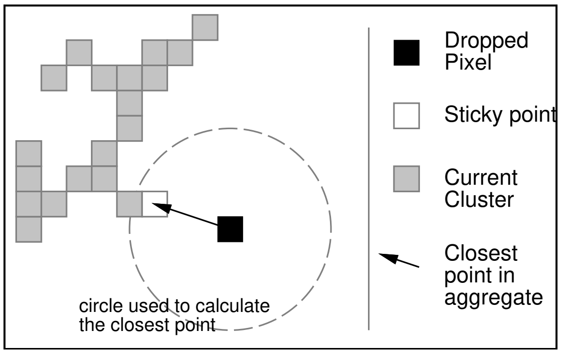

Figure 6: Random Dropped Ballistic Aggregation (RDBA). The dropped particle is aggregated to the closest tendril.

one representing a circle radius and the other an angle round the circle. A Euclidean distance is calculated from this dropped point to the cluster elements, and the closest sticky position, to the dropped particle, is then chosen.

The 'brute force' and naive approach is to linearly search for the closest. However, increasing concentric circles may be used to search for the closest pixel of the cluster, see Figure 6. We use the midpoint algorithm to calculate the exact position of where to stick the new particle [Foley et al., 1990].

Figure 8 shows 100000 pixels dropped, and Figure 9 shows a nearly full drop zone.

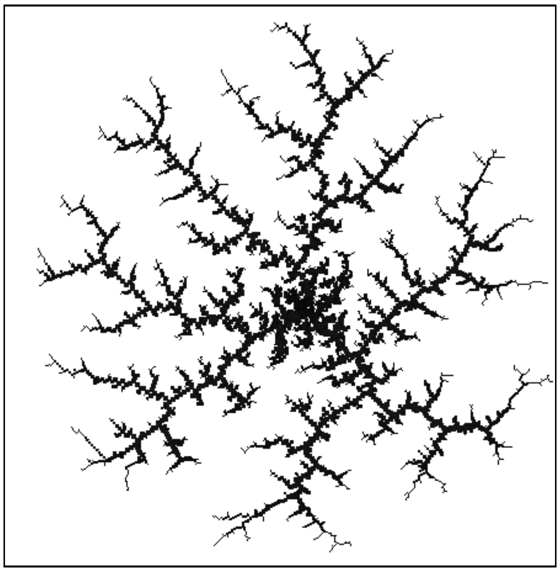

Figure 7: Beautiful natural-looking structures, using ballistic aggregation.

4.3 Biased Drop

We have investigated different dropping strategies, including:

1. N points being dropped at the same place.

2. points being dropped on the circumference of a circle, Figure 10. The circumference acts as an attractor for the growth to generate lightning bolt formations that are similar in form to those generated by Reed and Wyvill [1994].

3. N points being dropped a set distance from the previous, Figure 11. We used a circular bias; once one pixel had been dropped, the next n pixels were dropped in a small circular offset from the previous, see Figure 11. This is similar to Davidovitch et al. [2000] who use chaotic functions instead of random numbers.

   The closest sticky position, in the aggregate, is always found for each pixel that is dropped, whether it is an initial dropped pixel, or is taken from an offset.

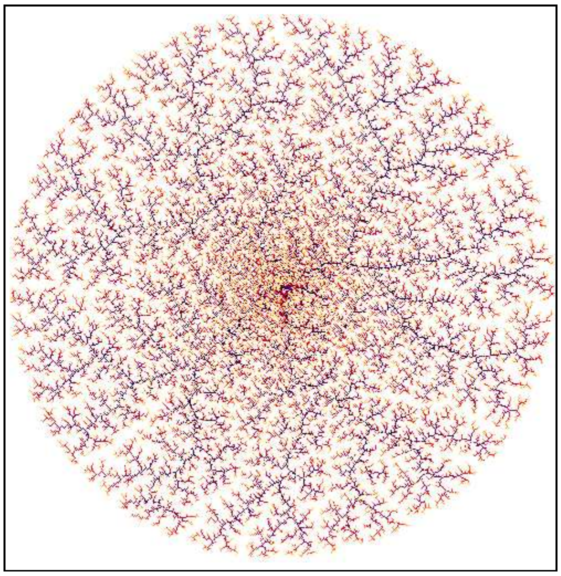

Figure 8: Random Dropped Ballistic Aggregation with 100000 aggregated pixels.

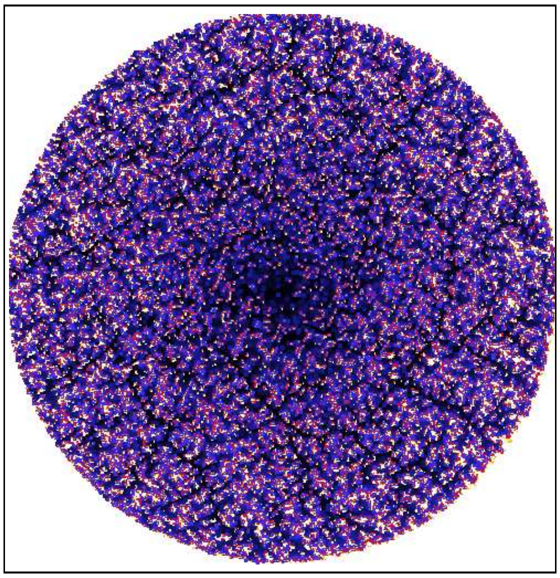

Figure 9: Random Dropped Ballistic Aggregation with a nearly full drop zone.

5 Summary/Conclusion

We have presented a brief overview of growth models using Sticky Pixels, described (1) a Random Drop implementation of Eden's model, and (2) a Random Dropped Ballistic Aggregation model. We have shown that different models may be generated by using different dropping and sticking strategies.

Through generating these and similar images presented in this paper, we observe that (a) the larger masks, used for the Eden's model implementation, have a tendency to inhibit long tendrils, and (b) the closest pixel search strategy, used in our RDBA model, encourages long thin tendrils to form. Thus, it would be interesting to use such a mask tendril inhibitor in the RDBA model.

Even though, the RDBA model encourages long thin tendrils to form, we believe the method generates some interesting textures and beautiful forms. Moreover, some interesting growths may be generated by adapting the model and (say) using a circular bias to some dropped pixels.

Finally, we believe 'sticky pixels' is more descriptive and is perhaps a more accessible phrase than others (such as using 'Diffuse Limited Aggregation'). Indeed, sticky pixels incorporates methods and models that, perhaps, are not strictly a simulation of a physical model or attempt to model a real life or world phenomena.

6 Acknowledgements

I acknowledge Peter Welch, Peter Linnington for their help and conversations, and Peter Kenny for proof reading the document.

References

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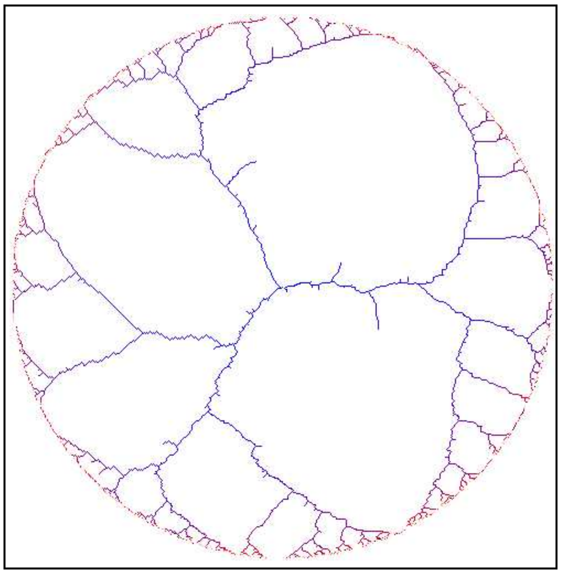

Figure 10: Random Dropped Ballistic Aggregation with pixels being dropped on the circumference of the outer circle.

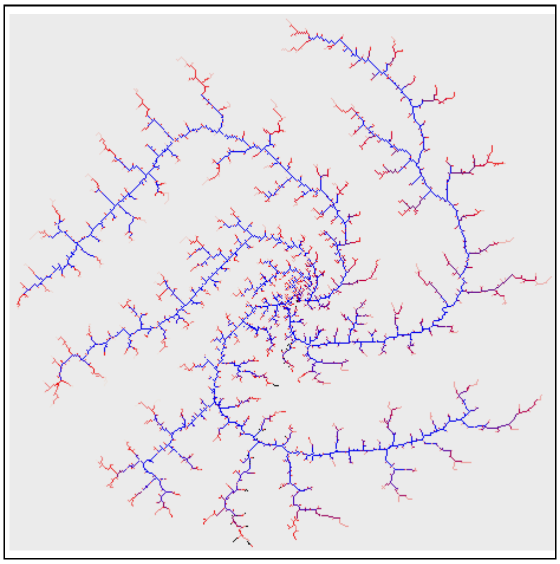

Figure 11: Random Dropped Ballistic Aggregation with a circular bias of the dropped pixels.

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