Abstract Overlays using a Transport Network Model

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Abstract

For artistic purposes, we modify a unusual model for pattern formation derived from simulating transport networks using virtual ants. More specifically, by suitably coloring the pheromone trails produced by the virtual ants that form the transport networks, and by overlaying a series of such networks, we obtain abstract pieces that have interesting depth and color interactions. Moreover, because of the way they are formed, these patterns also tile the plane. The elegance and simplicity that results is contrasted with the complexity of the underlying simulation — a central theme which informs our work.

1 Introduction

In his ground breaking thesis, Jeff Jones modeled the evolution and formation of plasma transport networks of the slime mold *Physarum* by using an agent based simulation whose agents, or virtual ants, possess remote sensing capabilities. Here, a plasma transport network refers to the flow of protoplasmic sol through a gel matrix of fibers. The paper based on Jones' thesis that appeared in the journal *Artificial Life* [6] is filled with images of patterns that at first glance appear to be reaction-diffusion patterns in the best tradition of Turk [9], Witkin and Kass [11] or Young [12]. But, in fact, they are visualizations of the pheromone trails laid down by virtual ants.

The realization that these pheromone trails must have a smooth gradient, coupled with our previous experience working with both reaction-diffusion simulations [2, 4] as well as virtual ant simulations [1, 3] convinced us that Jones' visualizations could be adapted for artistic purposes. We envisioned first introducing color to provide better definition to the pheromone gradient. Then, taking as our inspiration the well known architectural "continua" patterns of Edwin Hauer [5] or the layered (usually interlocking) patterns and sculptures that Rinus Roelofs [7, 8] has exhibited, we envisioned stacking a series of these patterns as overlays to obtained finished abstract pieces. We use the word "inspiration" respectfully, because while the patterns of Hauer and Roelofs are regular and symmetric, our resulting abstract overlays are not.

This paper describes our methods and presents our results. It is organized as follows. In Section 2 we briefly describe the virtual ant simulation that forms the transport networks. In Section 3 we explain how we pseudorandomly color the networks. In Section 4 we present examples of some of the abstract overlays we were able to obtain. In Section 5 we give our conclusions and discuss future work.

2 Forming Transport Networks using Virtual Ants

To simulate the formation of a transport network, Jones places particle-like agents, which we shall refer to as virtual ants, on a two dimensional grid, or environment, whose opposite sides are identified so that topologically the grid becomes a torus. It is important that for simulation purposes the points where agents are located use real coordinates, while for visualization purposes the grid is viewed as consisting of $n \times m$ cells. A policy that is always in force is that only one virtual ant may inhabit a cell at a time. Virtual ants have a forward facing orientation that is specified by an angle between 0 and 360 degrees. At each time step of the simulation each ant experiences a motor stage followed by a sensory stage. That is, the ant attempts to move forward in the current direction one unit, and does so if it is not blocked, and then senses its environment in order to determine whether or not to rotate to a new heading. Of course at each time step each ant also deposits a fixed number of units of pheromone in the cell it occupies. This pheromone subsequently diffuses and evaporates. The two unusual features of the simulation are: (1) at each time step the order in which the virtual ants are sequenced to undergo these two stages is randomized, and (2) the sensing of pheromone by the ants is remote i.e. they do not sense pheromone from immediately adjacent cells but rather from a configuration of adjacent cells that is several units away in the forward direction. The underlying reasons why turning in response to pheromone detected remotely causes the patterns to form the way they do, or why it is unnecessary to place any pheromone whatsoever in some of the cells as sensory cues at time zero — contrast, for example, with Wan et al. [10] whose more traditional reaction-diffusion simulation for making maze patterns does depend heavily on an initial distribution of pheromone being placed in the environment to stimulate pattern formation — is beyond our scope. We refer the reader to Jones paper [6] for details of the theory as well as further connections to simulating biological transport networks.

The way we visualize the pheromone trail is to use a simple density plot as follows. After a prescribed number of time steps have occurred, we calculate the maximum value m of the pheromone over all cells. If a cell has pheromone level p, then its pheromone density is set to $d = p/m$, and if d is greater than a threshold (we used 0.05) the cell is colored according to the usual 0 to 255 (black to white) grayscale by assigning it a level of $\lfloor(1-d)255\rfloor$, otherwise it is colored with a nearly white background by assigning it a level of 242.

For the remainder of this paper we will keep our simulation settings fixed. If the grid is $n \times m$, then the number of ants used will be 15% of the total number of cells; the sensing neighborhood will be the three cells that are located 9 units away at angles of $-22.5°$, $0°$, and $22.5°$ off the current heading; and when a turn to follow scent is made by a virtual ant the turning angle will be 45°. By duplicating the decay rate and the diffusion process of Jones [6] we were able to validate our implementation by comparing test runs such as the 200×200 example shown in Figure 1 against Jones' charts that systematically explore the parameter settings.

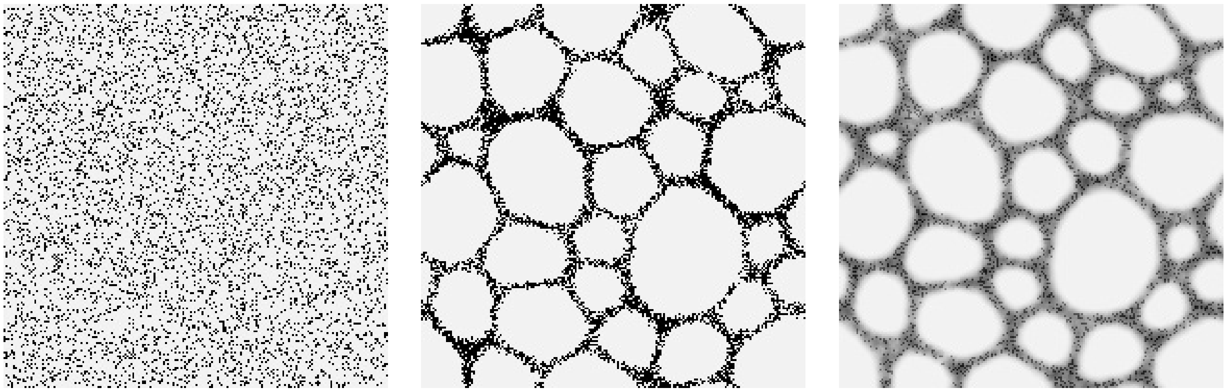

Figure 1: Left: Initial distribution of 6000 virtual ants. Center: The distribution of the virtual ants after 500 time steps. Right: Density plot of the pheromone trail after 500 time steps.

3 Imaging the Pheromone Trail

To color a pheromone density plot we must choose a color component between 0 and 255 for each of the three color components red, green and blue. Most often this was done by randomly generating a value within a specified subrange. Our first thought was to try and color the density pattern so that the color faded as it approached the boundary of the transport network, but because the interiors of the networks can have anomalies (possibly due to pheromone build-up caused by ants frozen for long periods of time) this created awkward artifacts and hot spots within the interior, especially for darker colors, and proved to be unworkable. Instead, by letting the color darken as it approached the boundary, and by taking advantage of the fact that our thresholding scheme guaranteed crisp, well defined boundaries we were able to achieve better effects — and even leverage the anomalies to produce an illusion of depth — by doing just the opposite. Thus in the end we simply scaled the three color components uniformly based on the density (see Figure 2).

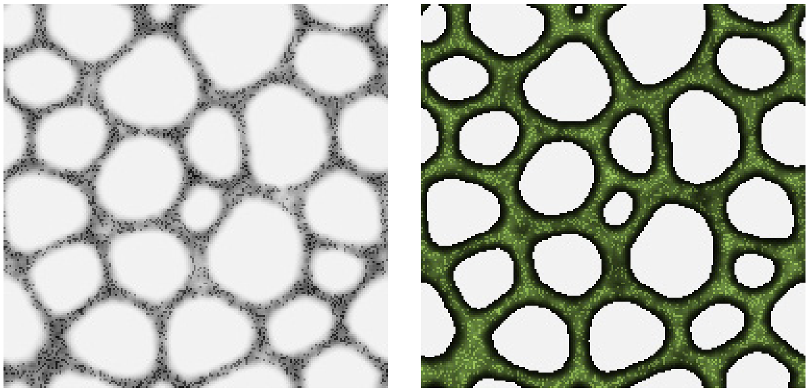

Figure 2: Left: A pheromone density plot colored using grayscale levels. Right: The same plot colored by uniformly scaling the color components of the RGB color $(175, 228, 104)$.

Our patterns are not symmetric, but because the simulation treats the environment as toroidal they do tile the plane. Figure 3 shows an "exploded" view of a portion of this induced tiling using the colored pattern shown in Figure 2.

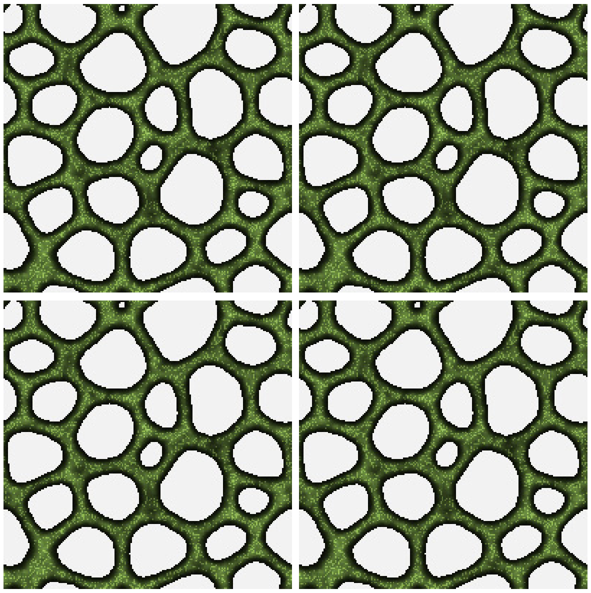

Figure 3: An exploded tiling using the colored pattern shown in Figure 2.

4 Transport Overlay Patterns

A pseudorandomly colored pheromone density pattern is just that; a visualization of the pheromone trail that the virtual ant simulation produces. It would take considerable care and effort to interweave, blend or mask multiple transport networks. But it is not difficult to just redistribute the ants, rerun the simulation, and then keep overlaying the resulting transport networks using what is analogous to a back to front painter's algorithm. Figure 4 shows one of our test runs using two such transport networks. For comparison, in Figure 5 we also show an exploded tiling using this pattern.

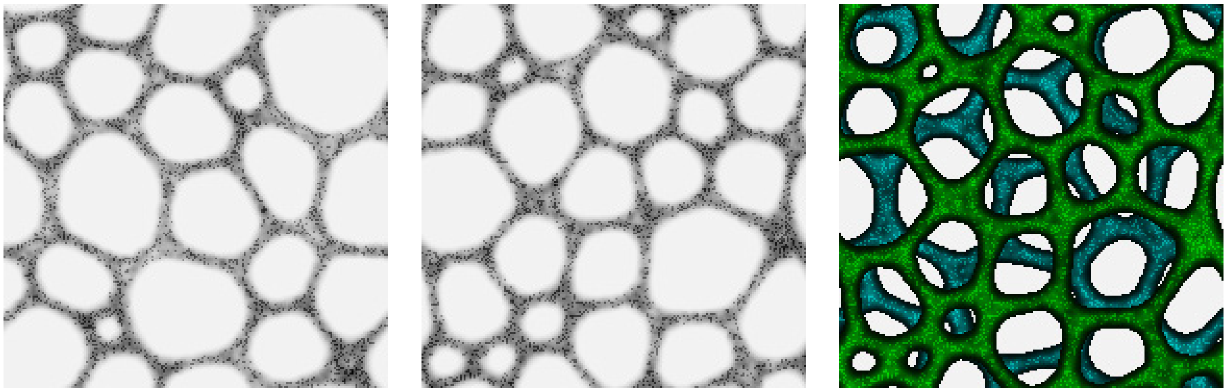

Figure 4: Left: First grayscale density plot. Center: Second grayscale density plot. Right: The two plots pseudorandomly colored with the second overlaid on top the first.

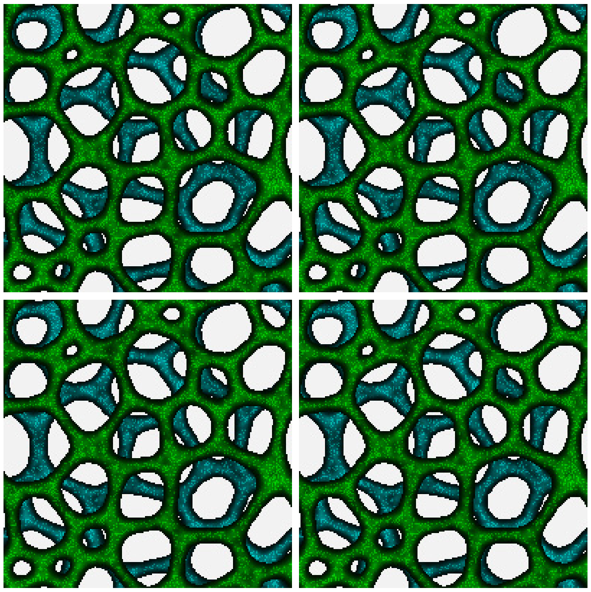

Figure 5: An exploded tiling using the colored pattern shown in Figure 4.

We judged the square $n = m = 200$ overlays to be too austere, and too similar to visualizations found in technical publications. Therefore we changed to a rectangular 200×250 grid, and to move further away from transport network visualization and into the realm of image composition, we added a third layer. It was at this point that our efforts produced overlays that met our aesthetic criteria. They gave a better indication of the underlying complexity that is involved, and they looked like they had more intent. it is at this juncture we felt they qualified as ”abstract overlay” art pieces based on transport networks that were obtained as visualizations of pheromone trails from a virtual ant colony simulation. Figure 6 shows an example of this type.

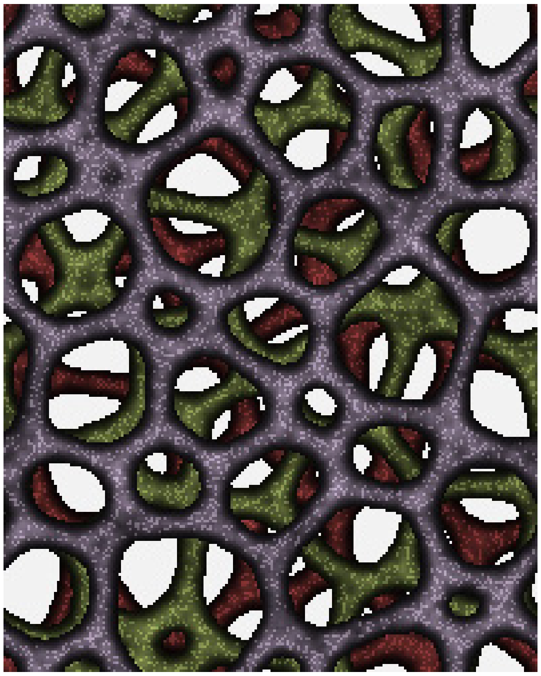

Figure 6: *Transport Network Overlay #5854*. A non-square, three-layer, pseudorandomly colored “abstract overlay” image produced by our virtual ant simulation.

We found that four layers seemed to reach the limit of what could be judged aesthetic without being discordant or disruptive. But with four layers, color selection became more difficult. Figure 7 shows an example with four distinct colors for the layers and an example using four different shades of the same color for the layers.

5 Conclusions and Future Work

A viewer would have to be “in the know” to ascertain that an image such as *Transport Network Overlay #5854* in Figure 6 is generated from a virtual ant colony simulation that required several minutes of execution time. We find it compelling that modeling physical and biological processes can lead to aesthetic creations. As part of future work, we would like to investigate using transport networks for non-photorealistic effects. A first step would be use masking and transparency to embed recognizable digital imagery within the layers.

References

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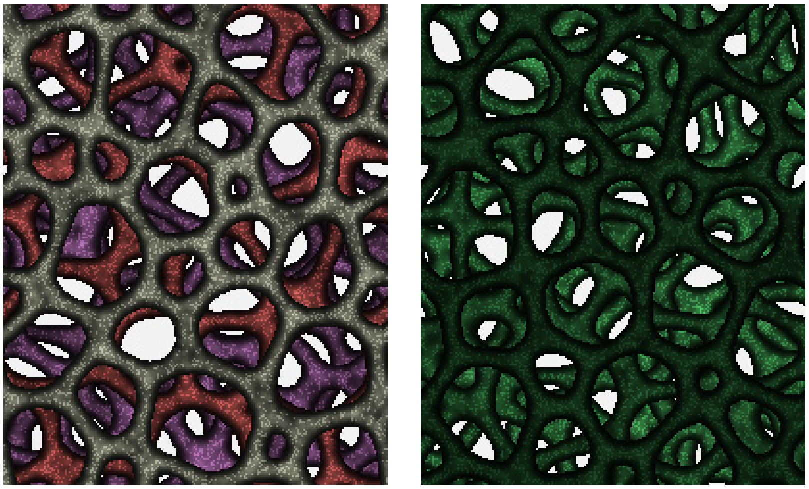

Figure 7: Two four-layer transport network overlays. Left: The layers have distinct colors. Right: The layers are colored using four shades of the RGB color $(94, 224, 116)$.

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