Ant Paintings using a Multiple Pheromone Model

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Abstract

Ant paintings are visualizations of the paths made by a simulated group of ants on a toroidal grid. Ant movements and interactions are determined by a simple but formal mathematical model that often includes some stochastic features. Previous ant paintings used the color trails deposited by the ants to represent the pheromone, but more recently color trails and pheromones have been considered separately so that pheromone evaporation can be modelled. Here, furthering an idea of Urbano, we consider simulated groups of ants whose movements and behaviors are influenced by both an external environmentally generated pheromone and an internal ant generated pheromone. Our computational art works are of interest because they use a formal model of a biological system with simple rules to generate abstract images with a high level of visual complexity. We strive to show how designing ways to make ant paintings becomes an artistic pursuit.

1. Introduction

Ant paintings trace their origins to the ant colony simulation experiments of Ramos [8, 9, 10]. He investigated the use of ant colony simulations for image processing purposes. A group led by Monmarché [1] appears to be the first to actually use the term "ant painting" to describe the abstract images made by virtual ants that roam over a toroidal canvas. In their model, ants deposit scent by laying down one color while searching for the scent (i.e. color) deposited by other ants. Monmarché et al. used a small number of virtual ants, typically 4-6. Ant behavior was controlled by a *genome* that determined what color ants should deposit, what color ants should seek, and their exploration tendencies. Ant paintings were evolved using an *interactive* genetic algorithm. An unusual feature of their simulation was that the sensory mechanism of the virtual ants was modelled in such a way that ants were responsive only to the luminance values of the colors representing scent instead of their tristimulus values. In [3] we evolved ant paintings using a model where ants were responsive to tristimulus color values. We also introduced a *non-interactive* genetic algorithm by designing fitness functions to evolve ant behavior based on arithmetic expressions that required us to measure the exploration and exploitation capabilities of the ants. Three examples of the ant paintings made by ants that we evolved using this model are shown in Figure 1.

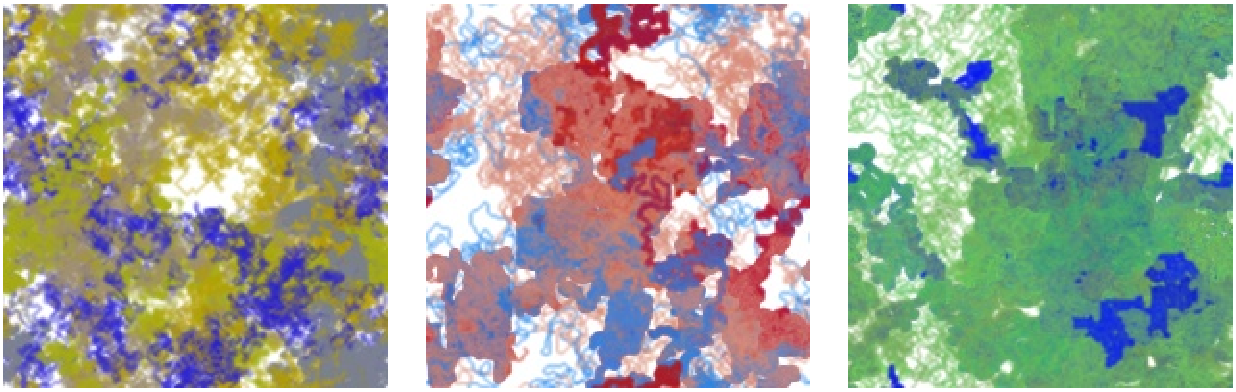

Figure 1: *Three ant paintings made using a model where color deposited by the ants is interpreted as scent.*

The "scent" in ant paintings evolved using such methods had limited diffusion properties and no evaporation properties. Urbano [14] addressed the latter shortcoming by considering a model where each individual cell in the *environment* exuded scent — the attractant — until it was visited by an ant. By diffusing and evaporating this exuded scent; by using two competing species of ants; and by marking each cell according to which species of ant reached it first, Urbano's technique yielded ant paintings that were "finished" once there were no more unvisited cells left to exude scent. The visual characteristics of these ant paintings are influenced both by the number of ants and their initial placement. Figure 2 shows three ant paintings using this model that we made by setting the parameter values for the model so that each non-visited cell produced five units of scent every time step, seven percent of the scent in each cell was evaporated every time step, and two percent of the scent in each cell was diffused over its Moore neighborhood of radius one — the eight neighboring cells that surround the 3×3 square with the cell at its center — after every time step.

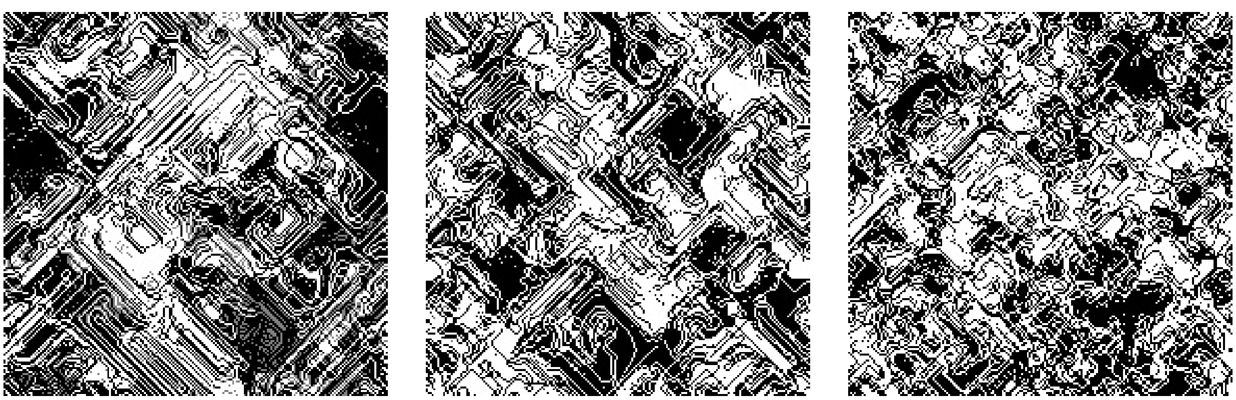

Figure 2: *Ant paintings in the style of Urbano using 50, 100, and 500 randomly placed ants, respectively, to mark each cell of a* 200×200 *toroidal grid on the basis of which one of two species of ants reaches it first. Cells in the grid attract ants by exuding scent.*

Of related interest are the efforts of Moura et al. [5, 6] to build autonomous robots that execute "swarm paintings", because both Urbano and Moura appeal to the concept of *stigmergy* to help explain why their virtual and physical software controlled entities are able to exhibit creative or artistic tendencies. Stigmergy [13] refers to the situation where the behavior of agents in swarms is controlled wholly by external, environmental factors. Recent work of Semet et al. [12] used virtual ants that were responsive to environmental cues that were provided by *users* in addition to interactions with other ants in order to develop image processing techniques for producing non-photorealistic visual effects. This brief, but by no means complete, exposition of previous work brings us full circle, since as early as 1993 Tolson began experimenting with swarms of agents that were externally controlled by having a user introduce visual cues into the environment in order to produce visual special effects for video stills and animations [11].

In this paper, we will consider a swarm of virtual ants that is responsive to two scents — one produced by the environment and one produced by the ants themselves. Further, by allowing ants to make two types of marks, we will describe how we are able to make ant paintings where ants simultaneously couple the method of Urbano to create a background image together with more traditional ant colony simulation evaporation-diffusion foraging methods [2] to conduct further processing of this image. Our goal is to explore and develop new forms of ant painting. This paper is organized as follows. In Section 2 we introduce our multiple pheromone model, in Section 3 we explain how we make an ant painting, in Section 4 we discuss the methods we use to control the behavior of our ants, in Section 5 we present examples of the ant paintings that were produced using our model, and in Section 6 we offer our conclusions. Before proceeding with the technical details we wish to point out that it is still an open problem to decide how to evaluate the creativity of a swarm of agents [4], and it is still a highly contentious issue to decide precisely what it should mean for a computational work of art to possess aesthetic merit [7, 15].

2. The Multiple Pheromone Model

We treat pheromones as units of virtual substances that are found within the cells of an $N \times N$ toroidal grid. These pheromones can be detected and measured by the M virtual ants that roam on the grid. In this paper the linear dimension of the grid will always be $N = 200$ and the number of ants will always be $M = 100$ with the understanding that ants may be further distinguished as belonging to different castes or species. Ants maintain a compass heading that is one of the following eight compass directions: N, NE, E, SE, S, SW, W, or NW. Before advancing from one cell to the next ants sense the amount of each type of pheromone in the three cells that are at the three compass headings that are currently directly in front of them. Based on this data they must choose to advance to one of these three cells. To simulate "noise" within the system, with probability $1/200 = 0.005$ at every step one of the three cells to advance to is randomly selected. The reason we limit ant's turning ability to forty-five degrees per time step is to try and discourage ants from going in circles, a common problem in many ant colony simulations. After every time step, for each cell, E percent of each pheromone is evaporated and D percent of each pheromone is diffused (in equal parts) to the eight neighboring cells comprising the cell's Moore neighborhood of radius one. For all the results shown here we set $E = 7$ and $D = 3$.

In our model, individual cells exude a pheromone — the attractant — until they are "harvested" by being visited by an ant, while ants deposit pheromone in every cell they visit — the repellant — throughout the entire course of the simulation run. The ant repellent pheromone is the same for both species. In this regard, our ants are not biologically plausible. We let P_c denote the number of units of cell pheromone each cell generates per time step and P_a denote the number of units of ant pheromone each ant generates per time step. In our model cells can be simultaneously occupied by more than one ant.

3. Making an Ant Painting

For visualization purposes (i.e. to develop the aesthetic of an ant painting) we divide the ants into two groups of roughly equal size. We think of these two groups as representing different castes or species. For convenience we denote these two groups as A and B. All cells of the grid are initially gray. If an ant of type A (respectively B) is *first* to visit a gray cell it is re-colored white (respectively black). However, if a cell has already been re-colored *and* the amount of cell pheromone has dropped below the cell threshold T_c, then the cell is re-colored (i.e. post-processed) to a shade of blue when the visiting ant is of type A, and to a shade of red when the visiting ant is of type B. Thus in our model the ants themselves first create a black and white visual substrate, called the "underpainting," which is then used for further image processing as the ants create what we call the "overpainting." An ant painting is pronounced finished when either all cells of the grid have been visited or 2000 time steps have occurred.

Initial positioning of the ants influences the look of the substrate the ants will subsequently over-paint. Figure 2 shows a substrate where the ants are randomly placed in the environment. Figure 3 shows the stylistic differences that occur when ants are segregated by type and initially clustered around two distinct points. Our clustering results do not duplicate those of Urbano because there is an ant avoidance mechanism in effect (see next section). The reason that diagonal movement is favored by the ants is due to the fact that for ease of computation we are using grid coordinates as ant positions. This means ants travelling diagonally can establish better separation between themselves and other ants and become more successful at finding unvisited cells or picking up cell pheromone gradients.

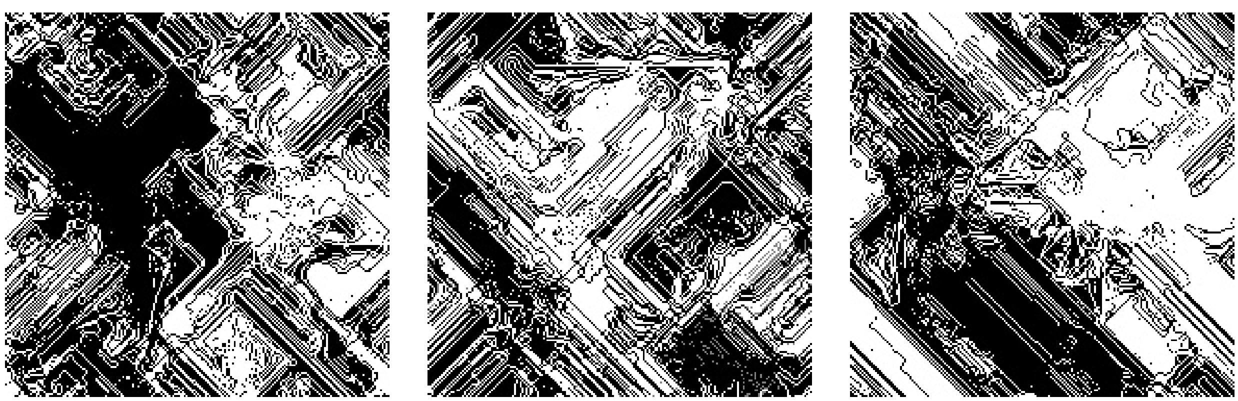

Figure 3: *Ant paintings in the style of Urbano using 100 ants on a* 200×200 *grid where the two species of ants are segregated and initially clustered around separate points. The left and right images use cluster points located one-fourth and three-fourths away from the left edge of the horizontal bisector. The image in the middle uses the centers of the first and third quadrants for cluster points.*

Another stylistic difference in substrate we experimented with was to allow ants of type B to advance three cells during each time step. Figure 4 shows substrate backgrounds of this type. There are many other possibilities one could consider. However, because we were more interested in ant interactions and the effect of using two scents for substrate post-processing, we did not continue with this line of inquiry.

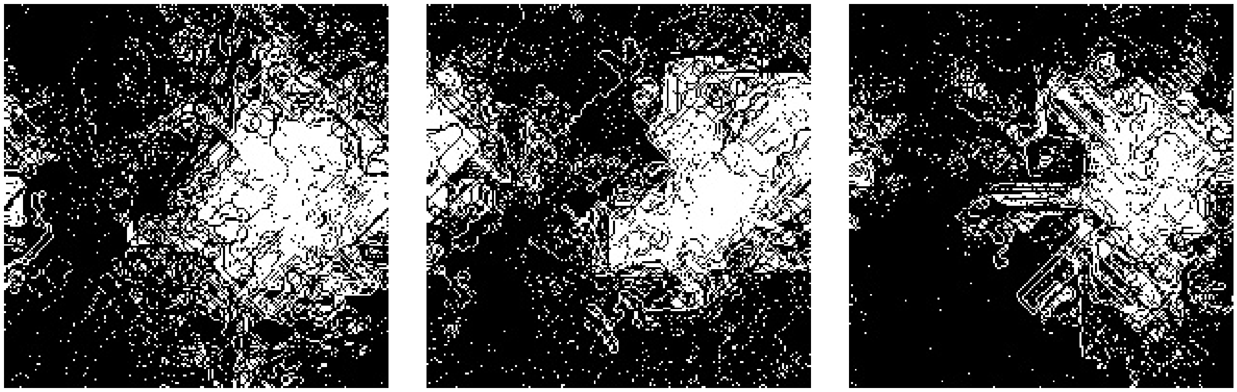

Figure 4: *Ant paintings for use as substrates made by 100 ants on a* 200×200 *grid where the two species of ants are segregated and initially clustered around separate points but ants of one species move three times as fast as the other.*

4. Virtual Ant Behavior

The purpose of generating, diffusing, and evaporating scent is to create scent *gradients* for ants to follow. Thus in order to define ant behavior we must define how they will react in the presence of such gradient fields. In a failed experiment, we first tried allowing the ants to advance to the cell within their three-cell field of vision that had the largest *combined* scent. This had no discernable effect on substrate creation, but when the threshold for over-painting came in to play, the result was that the ants conglomerated and became aligned along a few closed contours thereby creating faint difficult to detect trails in a sea of black, white, and gray. Ant paintings failed to reach completion because the small numbers of cells still generating attractant were not sufficient to draw ants away from their blind devotion to self-reinforcing trail following. The flaw in this model is clear. If cell-produced pheromone is supposed to act as an attractant, then ant-produced pheromone should act as a repellent so that the search for cells that have not yet been visited can be encouraged. Ant pheromone is used to deflect ants away from paths of already visited cells. This prevents either stagnation setting in due to ant pheromone trail following or image corruption setting in due to excessive post processing of non-gray cells prior to all cells having been visited. If we let S_c be the *maximal cell* pheromone value in the ant's current three cell field of vision, and s_a be the *minimal ant* pheromone value within the ant's current three cell field of vision, then the simple behavioral rule we define for our virtual ants is to advance in the direction where S_c was detected whenever $S_c > T_c$, but to advance in the direction where s_a was detected otherwise. Using this rule, up to the initial locations and headings of the ant population, ant paintings will be uniquely determined by the amount P_a of pheromone that ants are able to release into the environment during each time step, the amount P_c of pheromone that never visited cells are able to release into the environment during each time step, and the cell scent threshold value T_c that controls when overpainting of already visited cells occurs. Because of the non-linear interactions between these three parameters in our model, it can be difficult to anticipate what the resulting ant paintings will look like.

5. Some Examples of Multiple Pheromone Ant Paintings

To reveal the overpainting process that the ants are now capable of performing on the black and white substrate they have created, in Figure 5 we show examples of ant paintings where the threshold parameter T_c was set to a trace value and ant overpainting was halted by "timing out." As is to be expected, even though color is not diffused, such paintings reveal ant trails similar to the ones found in the ant paintings shown in Figure 1.

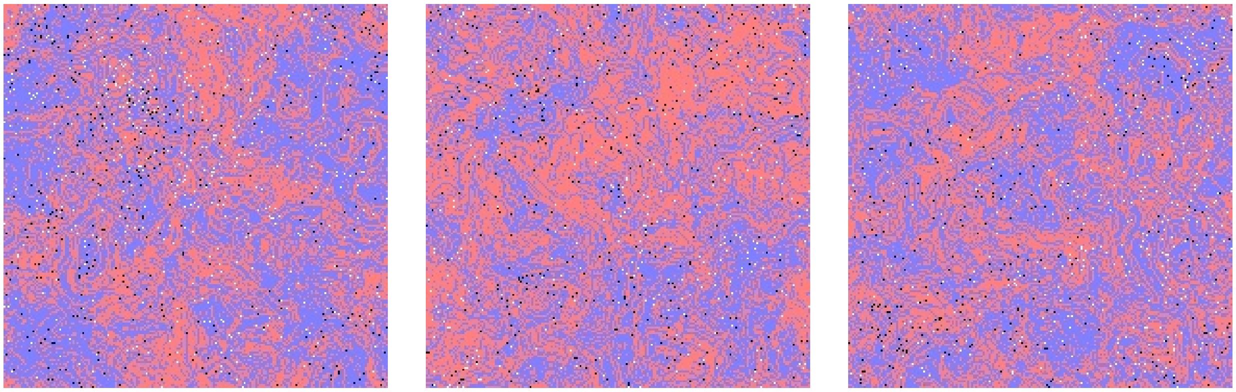

Figure 5: *Ant paintings demonstrating the image post processing to red and blue that occurs after the substrate image has been formed by coloring gray cells either black or white.*

We did not systematically explore the parameter space available to us. However, we did fix the cell threshold T_c at 40, the ant pheromone production parameter P_a at 1, and vary the cell pheromone production parameter P_c from 5 to 45 in non-uniform increments in order to determine how to best control the overpainting of the substrate in such a way as to achieve ant paintings that we felt held the best visual interest. Figure 6 shows some of the test results that led us to settle upon our preferred value of 45 for P_c. The ant paintings in Figure 6 were obtained by initially separating and clustering the two species of ants around points on the horizontal bisector.

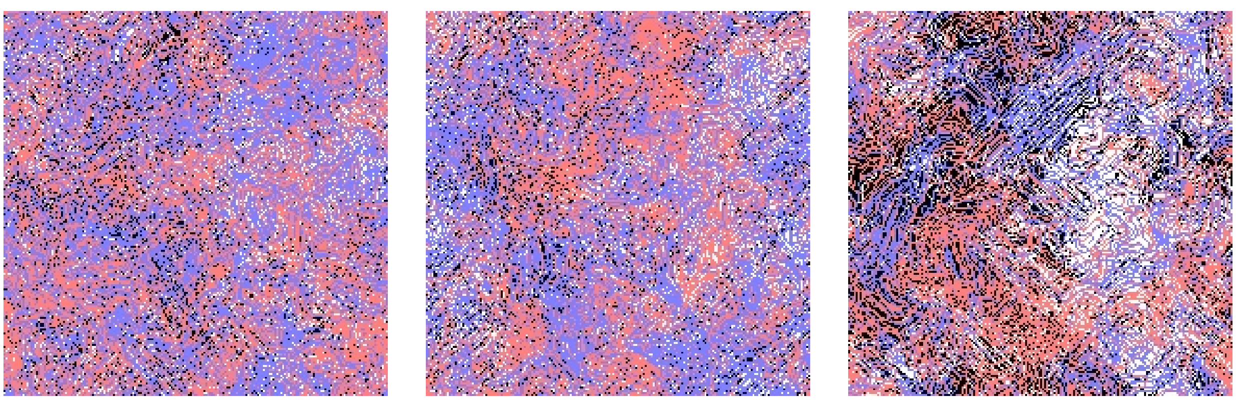

Figure 6: *Ant paintings where the cell pheromone generation parameter P_c is varied, left to right, from 20 to 30 to 45 units to show how we arrived at a value that gave the desired balance between revealing the details of both the underpainting and overpainting.*

Finally, in Figure 7 we show a trio of ant paintings that were made using the parameter values above that we finally settled upon, but invoked different initial configurations and/or cell advancement rates for the two species of ants.

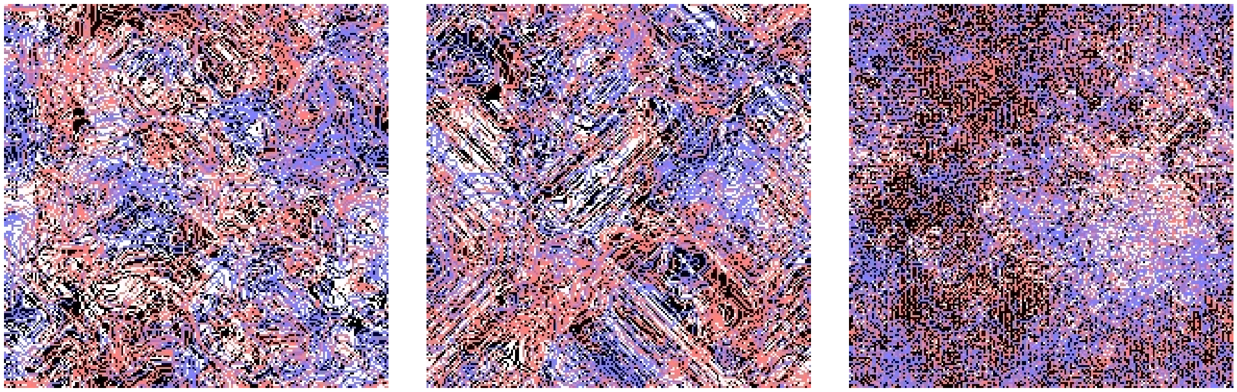

Figure 7: *A trio of ant paintings with the parameters P_c, P_a, and T_c fixed. The one on the left used random initial placement of the ants; the one in the center clustered* all *the ants initially about a point in the lower left of the painting; and the one on the right separated and clustered the ants on the horizontal bisector, but also advanced one species of ant three cells per time step while only overpainting the last of the three cells visited.*

6. Conclusions

We further developed a model of Urbano for generating ant paintings where cells exude ant attractant by incorporating mechanisms for additional ant communication though the use of pheromones that are deposited by the ants themselves and by allowing ants to make two types of marks. The result is that the ants first create a substrate image, or underpainting, and then post process that image by overpainting. We have described how we chose the parameters for our model and we have presented examples of ant paintings that were made according to a variety of initial conditions. We used only one simple rule to govern the behavior of our ants. It is to be expected that either more complex ant behavior rules, or additional ant behaviors triggered by the presence of additional pheromone substances would yield imagery of even greater artistic interest or potential. **Because grayscale reproduction of our ant paintings introduces contrast artifacts, the reader may wish to consult http://www.mathcs.richmond.edu/∼ ggreenfi/ to see the images in full color.**

References

[1] Aupetit, S., Bordeau, V., Monmarché, N., Slimane, M., Venturini, G.: Interactive evolution of ant paintings, *2003 Congress on Evolutionary Computation Proceedings* (eds. B. McKay et al.), IEEE Press, **2**, 2003, 1376–1383.

[2] Dorigo, M., Stutzle, T., *Ant Colony Optimization*, MIT Press, Cambridge MA, 2004.

[3] Greenfield, G., Evolutionary methods for ant colony paintings, *Applications of Evolutionary Computing, EvoWorkshops 2005 Proceedings*, Springer-Verlag Lecture Notes in Computer Science, LNCS 3449 (eds. F. Rotlauf et al.), 2005, 478–487.

[4] McCormack, J., Open problems in evolutionary music and art, *Applications of Evolutionary Computing, EvoWorkshops 2005 Proceedings*, Springer-Verlag Lecture Notes in Computer Science, LNCS 3449 (eds. F. Rotlauf et al.), 2005, 428–436.

[5] Moura, L., Pereira, H., *Man + Robots: Symbiotic Art*, Institut d'Art Contemporain, Lyon/Villeurbanne, France, 2004.

[6] Moura, L., Ramos, V., Swarm paintings — nonhuman art, *Architopia: Book, Art, Architecture, and Science* (eds. J. Maubant et al.), Institut d'Art Contemporain, Lyon/Villeurbanne, France, 2002, 5–24.

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

[8] Ramos, V., Almeida, F., Artificial ant colonies in digital image habitats - a mass behaviour effect study on pattern recognition, *Proceedings of ANTS'2000 - 2nd International Workshop on Ant Algorithms: From Ant Colonies to Artificial Ants* (eds. M. Dorigo et al.), Brussels, Belgium, 2000, 113–116.

[9] Ramos, V., Merelo, J., Self-organized stigmergic document maps: environment as a mechanism for context learning, *AEB2002, First Spanish Conference on Evolutionary and Bio-Inspired Algorithms* (eds. E. Alba et al.), Mérida, Spain, 2002, 284–293.

[10] Ramos, V., Self-organizing the abstract: canvas as a swarm habitat for collective memory, perception and cooperative distributed creativity, *First Art & Science Symposium, Models to Know Reality* (eds. J. Rekalde et al.), Bilbao, Spain, 2003, 59–59.

[11] Robertson, B., Computer artist Michael Tolson, *Computer Artist* **2**, 1993, 20–23.

[12] Semet, Y., O'Reilly, U., Durand, F., An interactive artificial ant approach to non-photorealistic rendering, *Genetic and Evolutionary COmputation - GECCO 2004* (eds. K. Deb et al.), Springer-Verlag Lecture Notes in Computer Science, **3102**, 2004, 188–200.

[13] Theraulaz, G., Bonabeau, E., A brief history of stigmergy, *Artifical Life* **5:2**, 1999, 97–116.

[14] Urbano, P., Playing in the pheromone playground: experiences in swarm painting, *Applications of Evolutionary Computing, EvoWorkshops 2005 Proceedings*, Springer-Verlag Lecture Notes in Computer Science, LNCS 3449 (eds. F. Rotlauf et al.), 2005, 478–487.

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