Photogrowth: Non-Photorealistic Renderings Through Ant Paintings

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ABSTRACT

We introduce photogrowth, an evolutionary approach to the production of non-photorealistic renderings of images. The painting algorithm – inspired by ant colony approaches – is described and explained, giving emphasis to its novel aspects: the evolution of the sensory parameters of the ants; the production of resolution independent images; the rendering lines of variable width. The experimental results highlight the range of imagery that can be evolved by the system and show the potential of the approach for the production of large-format artworks.

Categories and Subject Descriptors

I.2.2 [**Artificial Intelligence**]: Automatic Programming; I.3.3 [**Computer Graphics**]: Picture/Image Generation—*Non-Photorealistic Rendering*

General Terms

Algorithms

Keywords

Evolutionary Art, Non-Photorealistic Rendering, Ant Colony

1. INTRODUCTION

The main goal of the research presented in this paper is the creation of large-scale non-photorealistic renderings (NPRs) of input images. The predominant artistic sources of inspiration for this work are ornamentation techniques. From a scientific point of view, areas such as evolutionary NPR and artistic filter evolution are of particular relevance.

Our approach can be seen as the evolution of a filter that transforms an input source image. The approach is inspired on ant colony approaches: the trails of artificial ants are used to produce an artistic rendering of the original. A interactive Genetic Algorithm (GA) is used to evolve the parameters that govern the behavior of ants' species, allowing the user to guide the algorithm to areas of the search space that she/he finds promising.

The novel characteristics of our approach derive, directly and indirectly, from the adoption of a scalable vector graphics, which contrasts with the pixel based approaches used in most ant colony painting algorithms. This enables the creation of resolution independent images and, as such, large-format artworks. The rendering algorithm represents the trail of each ant through a continuous line of varying width, which contributes to the expressiveness of the artworks.

We begin with a short survey of related work. Next, in the third section, we make a description of the photogrowth system, focusing on the behavior of the ants, on the evolutionary algorithm, and on the previewing and rendering modes. In the fourth section we present experimental results, making a brief analysis. Finally, we draw some conclusions and discuss aspects to be addressed in future work.

2. STATE OF THE ART

In this section we make a survey of related works, focusing on systems that use artificial ants for image generation purposes and on systems where evolutionary computation is employed for NPR purposes.

Tzafestas [20] presents a system where artificial ants pick-up and deposit food, which is represented by paint, and studies the self-regulation properties and complexity of the system and resulting images. Ramos and Almeida [18] explore the use of ant systems for pattern recognition purposes. The artificial ants successfully detect the edges of the images producing stylized renderings of the originals and smooth transitions between different images. The artistic potential of these approaches is explored in later works (e.g. [17]) and thorough his collaboration with the portuguese artist Leonel Moura, which resulted in several robotic swarm drawings (see e.g. [14]). Urbano [21, 22, 23, 24] presented several multi-agent systems based on artificial ants.

Aupetit et al. [1] present an interactive evolutionary computation system for the creation of ant paintings. They employ a GA to evolve parameters of the rules that govern the behavior of the ants. The artificial ants deposit paint on the canvas as they move thus producing a painting. In a later study, Monmarché [13] refines this approach exploring different rendering modes. Greenfield [5] presents an evolutionary approach to the production of ant paintings and explores the use of behavioral statistics of the artificial ants to automatically assign fitness. In [6] Greenfield adopted a multiple pheromone model where ants movements and behaviors are influenced (attracted or repelled) by both an en-

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vironmentally generated pheromone and an ant generated pheromone.

The use of evolutionary algorithms to create image filters and NPRs of source images has been explored by several researchers. Focusing on the works where there was an artistic goal, we can mention the research of: Neufeld and Ross ([19, 15]), where Genetic Programming (GP, [8]), multi-objective optimization techniques, and an empirical model of aesthetics are used to automatically evolve image filters; [9], which evolved live-video processing filters through interactive evolution; [10], where GP is used to evolve image coloring filters from a set of examples; [25], which employs Genetic Algorithms (GAs) to evolve filters that produce images that match certain features of a target image; Collomosse ([4, 3, 2]), which uses image salience metrics to determine the level of detail for portions of the image, and GAs to search for painterly renderings that match the desired salience maps; [7] uses GP to evolve procedural textures for 3D objects; [11] employ GP to evolve assemblages of 3D objects that are an artistic representation of an input image.

3. PHOTOGROWTH

Photogrowth is composed of three main modules:

1. Evolutionary engine;
2. Previewing engine;
3. Rendering engine;

The evolutionary module is an interactive GA that allows the evolution of a series of parameters that govern the behavior of the ants. The previewing module is responsible for the production of the ant paintings during the evolutionary runs. The rendering engine is typically used offline to produce high quality renderings of specific ant paintings.

A graphic user interface gives access to these modules. It is composed of two windows (see Fig. 1: one depicts the paintings produced by the ants of the current population and allows the user to assign fitness to them, indicating a value between 0 and 10); the other, allows the user to navigate through populations, change the input image, inspect and edit the genotype of a given individual, save and load experiments and individuals, invoke the rendering engine, etc.

The following sections present the photogrowth system. We begin by describing the behavior of our painting ants. Next we present the evolutionary algorithm, focusing on the representation and genetic operators. Finally we highlight the differences between the previewing and rendering modes.

3.1 Painting Ants

Our painting ants live on the 2D world provided by the input image and they paint on a painting canvas that is initially empty (i.e., black in the experiments reported in this paper). Both living and painting canvas have the same dimensions and the ants move simultaneously on both canvas. The painting canvas is used exclusively for depositing ink. It has no interference with the behavior of the ants. They share these worlds with other artificial ants of the same species. Each ant has a position, color, deposit transparency and energy, all the remaining parameters are shared by the entire species. If the energy of an ant is bellow a given energy threshold it dies, if is is above a given threshold it generates offspring.

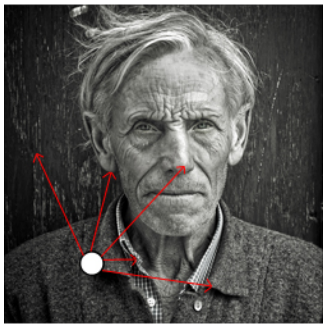

Figure 2: An ant with five sensory vectors.

The luminance of an area of the living canvas represents the available energy at that point. Therefore, ants may gain energy by traveling through light areas. The energy of an ant is updated as follows:

$$energy = (energy + b(x, y) * gain) * decay \quad (1)$$

where $b(x, y)$ is a function that returns the luminance (in the [0,1] interval) of the area where the ant is placed, *gain* is a scalar that represents the energy gain rate, and *decay* is a scalar in the $[0, 1[$ interval that represents the energy decay rate. The energy consumed by the ant is removed from the environment, as will be explained later in detail.

The ants' movement are determined by how they react to light. Each ant senses the environment by "looking" in several directions (see Fig. 2). In the experiments described in this paper we use 10 sensory vectors, each vector has a given direction relative to the current direction of the ant and a length. The sensory organs return the luminance value of the area where each vector ends. To update the position of an ant one calculates: the sum of the sensory vectors divided by their norms, multiplied by the luminance of their end point and by the weight the ant gives to each sensor, the result is multiplied by a scaling scalar that represents the ant's base speed:

$$\Delta\vec{p} = vel * \sum_{i=1}^{10} \frac{\vec{v}_i}{|\vec{v}_i|} * b((x, y), \vec{v}_i) * w_i \quad (2)$$

where, $\Delta\vec{p}$ is the displacement vector, (x, y) is the current position of the ant, vel is the ant's base velocity; $\vec{v}_i$ is the sensory vector i; $b((x, y), \vec{v}_i)$ a function that returns the luminance of the area at coordinates $(x, y) + \vec{v}_i$; w_i is the weight associated with $\vec{v}_i$.

Subsequently, to represent inaccuracy of movement and sensory organs, the direction $\Delta\vec{p}$ is perturbed by the addition Perlin noise [16] to its angle. Therefore, the position of the ant at instant $t + 1$ is given by the following formula:

$$(x, y)_{t+1} = (x, y)_t + perlin_{noise}(t, \Delta\vec{p}) \quad (3)$$

The ant simulation algorithm follows the following steps:

1. Initialization: n ants are placed on the canvas on pre-established positions; Each ants assumes the color of the area where it was placed; Their energy and deposit transparencies are initialized using the species parameters;

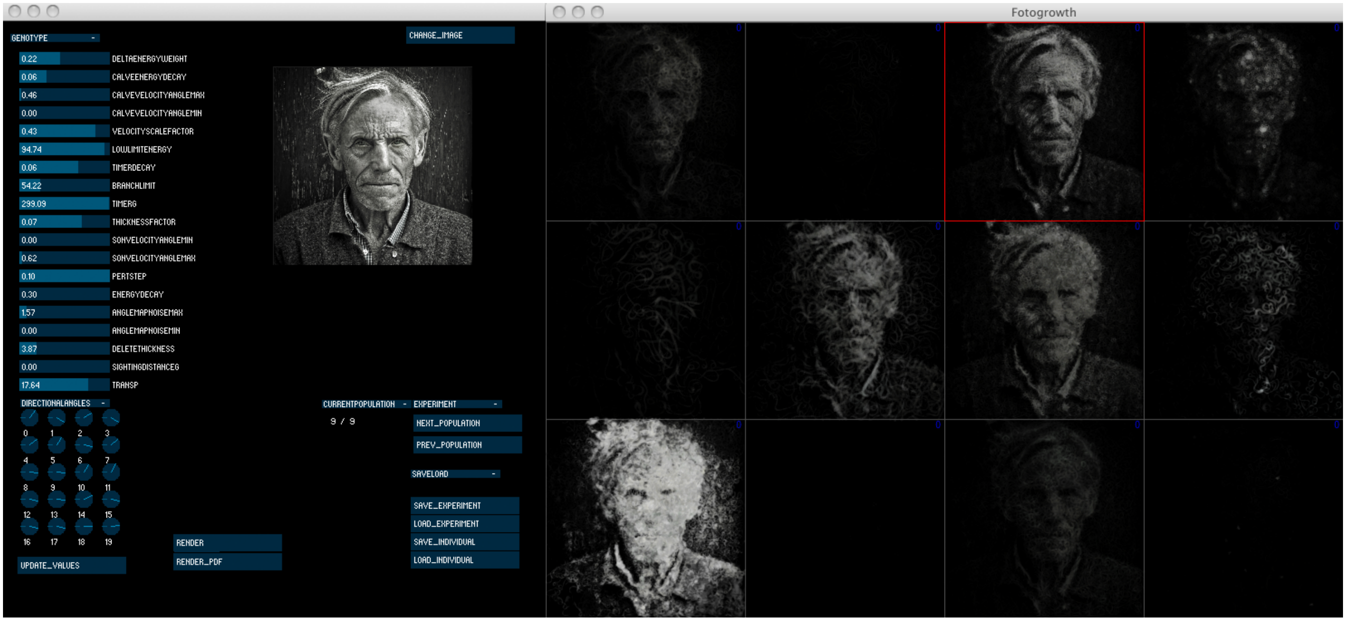

Figure 1: Screenshot of the graphic user interface. Control panel on the left and current population of ant paintings on the right.

2. For each ant:

   (a) Update the ant's energy following formula 1;

   (b) Update the energy of the environment;

   (c) Place ink on the painting canvas;

   (d) If the ant's energy is bellow the death threshold remove the ant from the colony;

   (e) If the ant's energy is above the reproduction threshold generate an offspring; The offspring assumes the color of the position where it was created and a percentage of the energy of the progenitor (which loses this energy); The offspring inherits the velocity of the parent, but a perturbation is added to the angular velocity by randomly choosing an angle between $descvel_{min}$ and $descvel_{max}$ (both values are species' parameters); Likewise, the deposit transparency is inherited from the progenitor but a perturbation is included by adding a randomly choosen a value between $dtransp_{min}$ and $dtransp_{max}$;

   (f) Update ant's position following formulas 2 and 3;

3. Repeat since 2 until no living ants exist;

Steps (b) and (c) require further explanation. The consumption of energy of the environment is attained by drawing on the living canvas a black circle of size equal to $energy * cons_{rate}$ of given transparency. $cons_{rate}$ and $cons_{trans}$ are parameters of the species. In previewing mode ink is deposited on the paining canvas by drawing a circle of the color of the ant – which is attributed when the ant is born – with a size given by $energy * deposit_{rate}$ and of given transparency. $deposit_{rate}$ is a species parameters, the deposit transparency is a parameter of the ant.

3.2 Evolutionary Engine

An interactive GA is used to evolve the ant species' parameters. The genotypes are tuples of floating point numbers which encode the parameters of the ant species. The size of the genotype depends on the experimental settings. Table 1 presents an overview of the encoded parameters. We use a two point crossover operator for recombination purposes and a Gaussian mutation operator. We employ tournament selection and an elitist strategy, the highest ranked individuals proceed, unchanged, to the next population.

3.3 Preview and Rendering Modes

We use scalable vector graphics in both preview and rendering modes. This allows the generation of resolution independent ant paintings, which, to the best of our knowledge, is a novel feature of our approach. As previously stated, in preview mode, the ants draw circles while they move. In rendering mode the ants behave similarly in every way. However, when the painting is finished, the trail of each ant is converted into a single line of variable width. This is attained by calculating external tangents to each pair of consecutive circles drawn by the ant, drawing polygons among these points and performing a shape union between all circles and polygons belonging to the same trail. In Fig. 3 we present a graphical portrayal of this process.

The differences between preview and rendering modes are usually not visible on screen, however, they have a significant impact when the artworks are printed or at high zoom rates. Fig. 4 highlights the differences.

It is also important to notice that the color of an ant is determined at birth, thus the ants may carry this color to areas of the screen that possess different colors in the original image, making the ant paintings further deviate from the original image (see Fig. 7). As a consequence of this

Table 1: **Parameters encoded by the genotype**

Name	#	Comments
$gain$	1	scaling for energy gains
$decay$	1	scaling for energy decay
$cons_{rate}$	1	scaling for size of circles drawn on the living canvas
$cons_{trans}$	1	transparency of circles drawn on the living canvas
$deposit_{rate}$	1	scaling for size of circles drawn on the painting canvas
$deposit_{transp}$	1	base transparency of circles drawn on the painting canvas
$dtransp_{min}$	1	limits for perturbation of deposit transparency when offsprings are generated
$dtransp_{max}$	1	
$initial_{energy}$	1	initial energy of the starting ants
$death_{threshold}$	1	death energy treshold
$birth_{threshold}$	1	generate offspring energy threshold
$descvel_{min}$	1	limits for perturbation of angular velocity when offsprings are generated
$descvel_{max}$	1	
vel	1	base speed of the ants
$noise_{min}$	1	limits for the perlin noise generator function
$noise_{max}$	1	
$initial_{positions}$	$2*n$	initial coordinates of the n ants placed on the canvas
$sensory_{vectors}$	$2*m$	direction and length of the m sensory vectors
$sensory_{weights}$	$2*m$	direction and length of the m sensory vectors

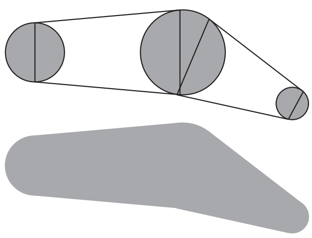

Figure 3: On the top, three circles belonging to the same trail and the polygons produced by tracing lines between the points of the external tangents to each consecutive pair. On the bottom, the shape resulting from the union of the three circles and two polygons

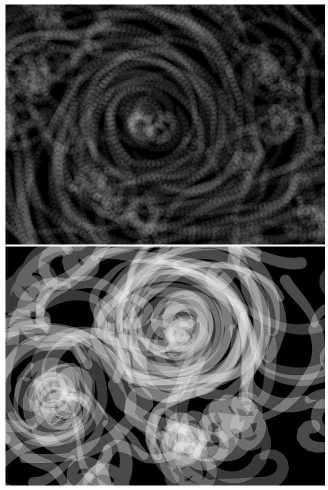

Figure 4: Details of images produced in preview(top) and rendering (bottom) modes depicting the differences in the rendering of the ants' trails.

coloring method, trails of progenitor ants become interlaced with those of descendants.

4. EXPERIMENTAL RESULTS

The results presented in this section were obtained by conducting a series of informal experiments with the following experimental setup: Population Size = 15; Tournament size = 3; Crossover probability = 0.9; Mutation Probability = 0.1 (per gene); Initial Position of the ants = center of the canvas; Initial number of ants = 1. Thus, when the drawing stage starts each ant specie is represented by a single ant. However, due to the abundance of energy this ant tends to generate offspring quickly. The length of each evolutionary run varied, typical runs had 30 to 40 generations.

The analysis of the experimental results of evolutionary art systems, specially user driven ones, is subjective by nature. As such, more than presenting measures of performance that would be meaningless when considering the goals of our system, we aim to:

1. Convey the overall feeling of the user experience when working with photogrowth through the presentation of different steps of the evolutionary process;

2. Highlight the different types of imagery that can be evolved with the system;

3. Show that the application of the same individual (ant colony) to different input images produces stylistically similar renderings;

In Fig 5 we present snapshots of the 1st, 2nd, 20th and 40th population of a typical evolutionary run. As it can be observed, most of the individuals of the initial population fail to portray the input image. In the second population, the percentage of images that depict the input image significantly increases. Nevertheless, the overall quality of the images is relatively low, in the sense that they do not convey the aesthetic preferences of the user. In the 20th population we observe the emergence of elliptical and organic ant trails

Figure 5: On the top row, snapshots of the 1st and 2nd populations of an evolutionary run. On the middle row, the 20th population. On the bottom row, snapshot of the 40th population.

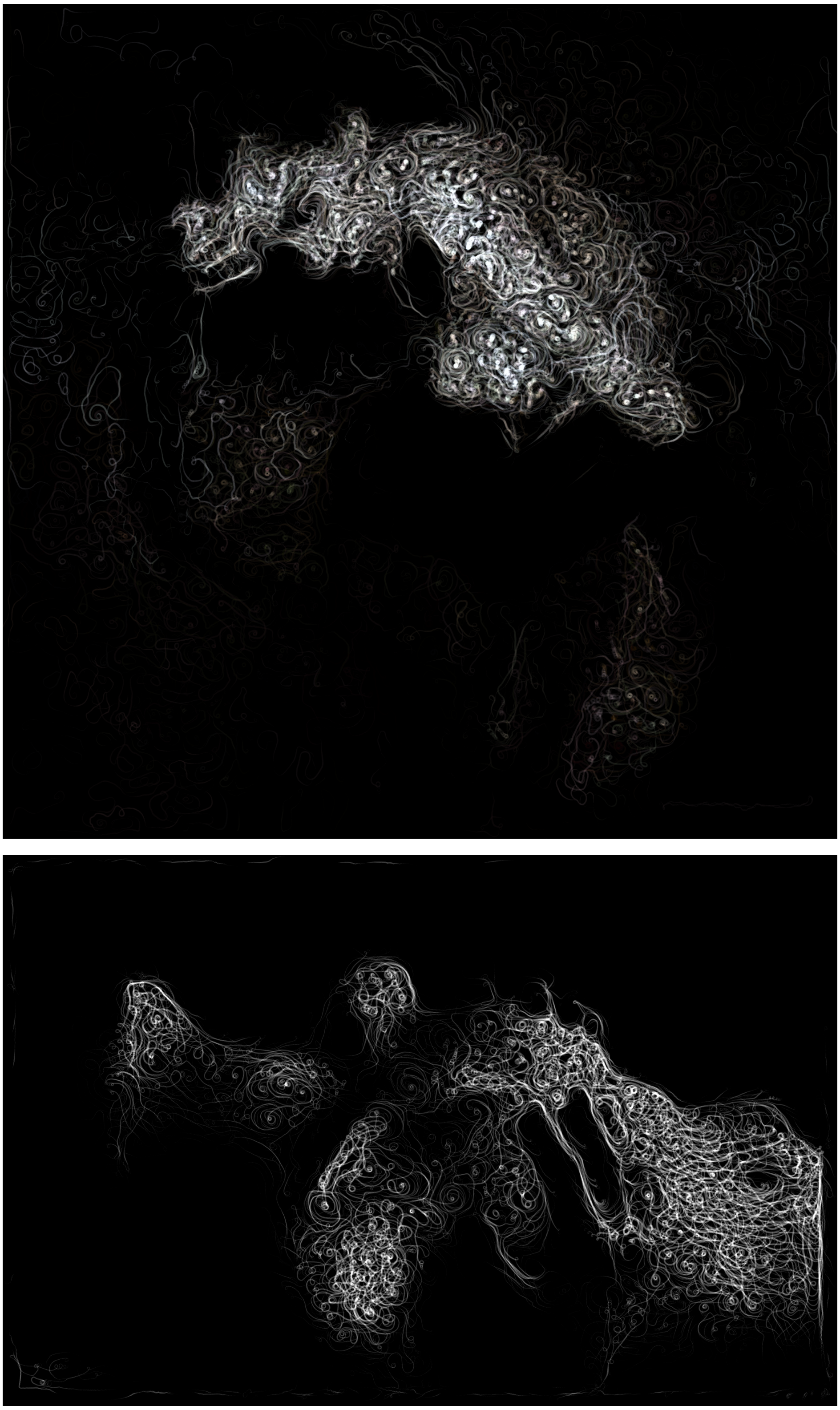

Figure 6: NPRs of two different images using the same evolved ant species.

(e.g., 3rd and 9th images of this population), a trait that will be favored by the user in subsequent runs. The 40th population presents an wide variety of images of contrasting line widths and trail curvature scales. The organic ant trails that emerged on the 20th population are still present on most of these images (although in some cases this is only observable at higher resolutions). At this generation we also observe the emergence of "abstract" portrayals of the original image (see figure 14th of this population). Progress from this point onwards tends to be slow and unsteady since, like in other interactive evolutionary art approaches, the user tends to often rewards novelty, resulting in frequent changes of selection criteria.

Fig. 6 presents the results of applying the same evolved ant species to two different images. As it can be observed the distinguishing traits of the ant colony are preserved, resulting in renderings that share stylistic characteristics.

In Fig. 7 we present two color images produced by different ant species to highlight the range of imagery that can be produced by photogrowth. The top image explores the use of thick organic lines of varying width to produce an abstract rendering of the original image. The bottom image is composed of thiner lines which become more intertwined. Both images take advantage of the coloring approach – the color of the ants is determined at birth – to transport the color of a region of the image to surrounding areas. This effect is particularly noticeable in the bottom image.

5. CONCLUSIONS

We presented photogrowth, a novel evolutionary approach to the production of NPRs of input images. The distinguishing characteristics of the system rest on the evolution of the sensorial organs of the ants, on the production of a scalable vector graphics output and on the rendering engine which represents the ant trails through continuous lines of variable width. The experimental results illustrate the range of imagery that can be produced by the system and demonstrate its adequacy for the production of large-format artworks.

Future research will focus on: (i) the improvement of the efficiency of the rendering engine – the production of an artwork in rendering mode can take from hours to days – which can be easily attained through parallelization since each ant trail can be independently processed; (ii) the development of automatic fitness assignment schemes. For this purpose, and considering the nature of our painting algorithm, we are particularly interested in the use of statistics of the behavior of the ants to assign fitness [5] and in the combination of this approach with ones that take into account the complexity and fractal dimension of the produced artwork (see e.g. [12]).

6. ACKNOWLEDGMENTS

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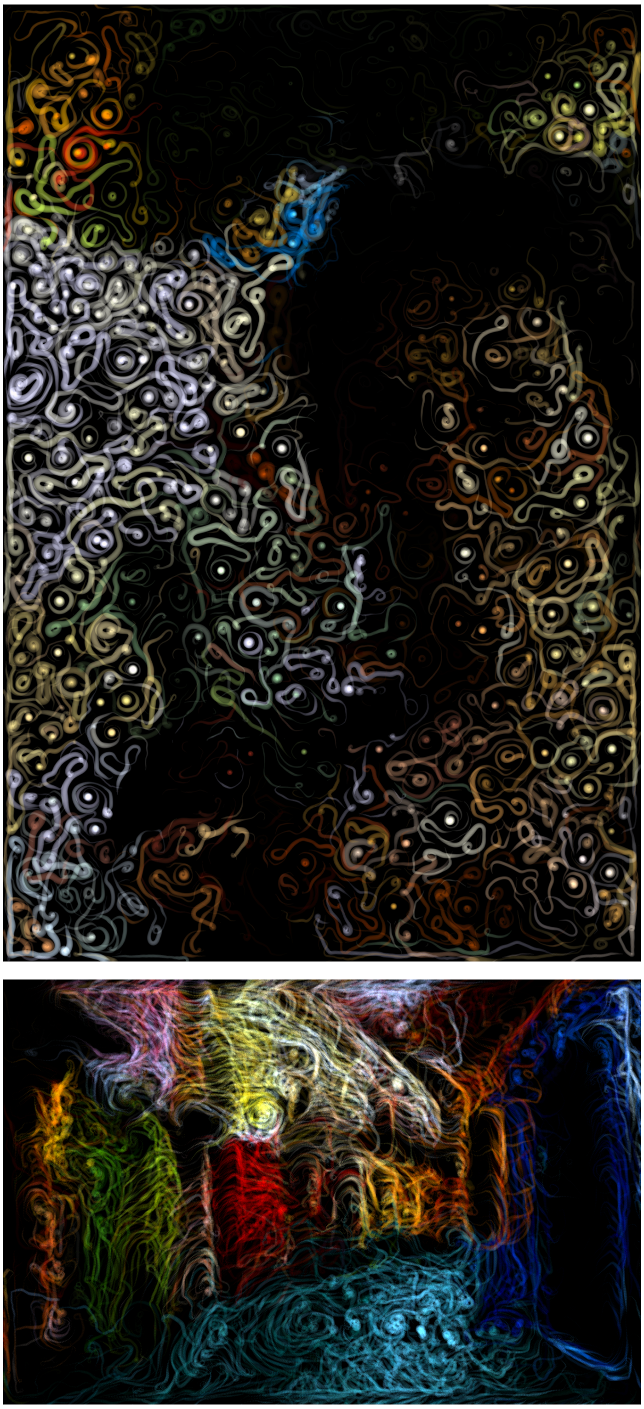

Figure 7: Examples of evolved color images.

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