# Ecosystem Dynamics for Creative Image Generation

Stefan Bornhofen, Andréa Machizaud, Vincent Gardeux

L@ris, EISTI, Avenue du Parc,
95011 Cergy-Pontoise Cedex, France

**Abstract**

Artists are constantly exploring new methods which innovate or enhance the esthetic value of their works. Over the last few years, there has been a growing interest in applying the swarm paradigm to generative art, i.e. in designing decentralized systems where mobile agents collaborate on the creation of an emerging piece. In this context, the present paper discusses the artistic potential of a generative ecosystem featuring resource chasing and consumption. We argue that the introduction of an energy budget to the agent model not only allows the user to partially control the creation process, but also to enrich the overall visual experience, by mapping the energy level of the agents to artistic dimensions such as line width or color.

**Keywords**

Generative Art, Ecosystem Art, Swarm Intelligence, Artificial Life

## 1 Introduction

Generative art is one of the most fascinating blends between art and science. It covers any practice "where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art." (Galanter, 2003). The key ingredient in this process of artistic creation is a generative system which provides an automated method for producing complex output. The output exhibits stylistic invariants, but also diverse and unpredictable facets, due to interactions between the system components and a number of parameters involved. The artistic quality of each piece remains to be assessed by the user.

Typical examples for this approach are creations by fractal algorithms (Draves, 2005; Lutton et al., 2003), cellular automata (Ashlock and Tsang, 2009) and L-systems (Bornhofen and Lattaud, 2006; McCormack, 2004). The present paper focuses on the creation of images, yet generative art applies to many other forms including music, 3D sculpture or animation.

The use of swarms has also been studied in this context, by modeling agents that collaboratively work on an emerging piece of art (Aupetit et al., 2003; Greenfield, 2005). Inspired by the behavior of ants, the agents deposit colors on a canvas and follow simple rules of motion and reaction to the colors they encounter, just like real ants move and react to pheromones. However, these agents do not possess other life-like characteristics such as growth, metabolism or reproduction.

More recently, those dynamics have come into focus. It has been suggested to borrow ideas from natural ecosystems for creation in generative art (Dorin, 2008; McCormack, 2007). In these "creative ecosystems", artificial agents not only interact with one another and with their environment, but also complete a life cycle and potentially evolve. The approach raises a number of interesting questions about which ecosystem mechanisms are most useful for creative design and how they can be adapted to generative art. As one of the pioneering results in this field, it has been shown that niche construction can considerably increase the diversity and the heterogeneity of artistic output (McCormack, 2010).

The present paper extends this line of research and explores the artistic potential of a generative ecosystem with resource chasing and consumption. We focus on the fundamental impacts of these dynamics on the final images and suggest what their contribution for generative art could be. In the next section, the ecosystem model is briefly introduced. Several basic experiments of image generation are described and discussed in section three. Section four highlights three examples of practical application. Section five concludes the paper and presents the perspectives on the approach.

## 2 Model description

The presented model takes its inspiration from existing studies on swarm based generative art (McCormack, 2010): artificial agents move and reproduce in a two-dimensional continuous environment, leaving a trail as they roam around. The environment can be considered as a canvas, and the trails are lines that progressively compose an image. The image is complete when there are no more agents in the environment.

As a complement to the previous work, we add a simplified energy management to the agent model and explore its potential for esthetic image generation. In particular, we focus on the following dynamics: food chasing and ingestion as well as agent size and coloration depending on its energy level. In the above cited work, the agents die when they cross an existing trail. This constraint has been lifted and replaced by death through starvation, i.e. total energy loss.

## 2.1 Agent

The current state of an agent is described by

- *location*: the position of the agent in the environment;
- *velocity*: its speed and orientation. In the scope of this paper, speed is constant during an agent's lifetime;
- *curvature*: the rate of curvature of the movement. A curvature of zero signifies a straight line;
- *energy*: a positive real number denoting the energy budget which is consumed by movements. The energy level can be increased by absorbing resources from the environment. If it falls below zero, the agent dies;
- *covColor*: a covering color which changes according to the color of the ingested resources. The overall agent color is a blend between the covering color and the genotypic primary color (see below).

## 2.2 Genotype

In addition to the phenotypic information which varies over time, the agent behavior is ruled by a set of constant genetic characteristics. At reproduction, the offspring inherits a copy of these values. Random mutations are not implemented for the simulations of this paper.

- *irrationality*: the degree of variation in the curvature. The higher this value, the more chaotic the movement, producing less predictable patterns;
- *fecundity*: the probability of producing a child agent per time step;
- *offset*: the offset angle of the children that separate from the parent agent;
- *divRatio*: the proportion of energy an agent allocates to its child at reproduction;
- *sensorRange*: the range of perception in the environment. An agent senses resources within this distance;
- *ingRange*: the maximum distance which allows ingesting food from the environment;
- *consumption*: the amount of consumed energy per covered distance;
- *agility*: the capacity to rapidly orient towards a target location for food chasing. The higher this value, the smaller the executed turning radius;
- *prColor*: the underlying primary color of the agent;
- *prStrength*: the relative strength of the primary color versus the covering color.
- *linSize*, *expSize*: a linear and an exponential parameter controlling the size of the agent for a given energy level.

## 2.3 Food chasing

The agents, also called grazers, possess a default moving behavior based on *curvature* and *irrationality*. As soon as a resource enters their perception range, they are attracted to it. In the scope of this paper, such resources are static and can be considered as food bits placed on the canvas. They hold a certain amount of energy (*fEnergy*) as well as a color (*fColor*) which acts on the agent's covering color.

When a chased food bit comes into ingestion range, the agent's energy level is increased by that of the resource, and the resource is deleted from the environment. The color and the size of the agent are updated according to the rules of the next section.

## 2.4 Coloration and size

The size of the agents, and accordingly the width of the trail they leave behind, follows the equation

$$size = linSize * energy^{expSize}$$

Note that if *expSize*$=0$, the line width does not depend on the energy level. When an agent feeds from the environment, its covering color updates according to the color and energy of the resource. The new covering color of a grazer ingesting a food bit is computed by

$$covColor = \frac{covColor * energy + fColor * fEnergy}{energy + fEnergy}$$

The agent trail is colored after its current overall color, which is a weighted mean of primary and covering color: the higher the energy level, the higher the influence of the covering color.

$$color = \frac{prColor * prStrength + covColor * energy}{prStrength + energy}$$

# 3 Basic studies

This section presents and discusses a gallery of images that emerge from the modeled ecosystem. We explore the basic dynamics of energy and color, i.e. the two phenotypic traits beyond spatial and motional information, and point out some major impacts on the artistic output.

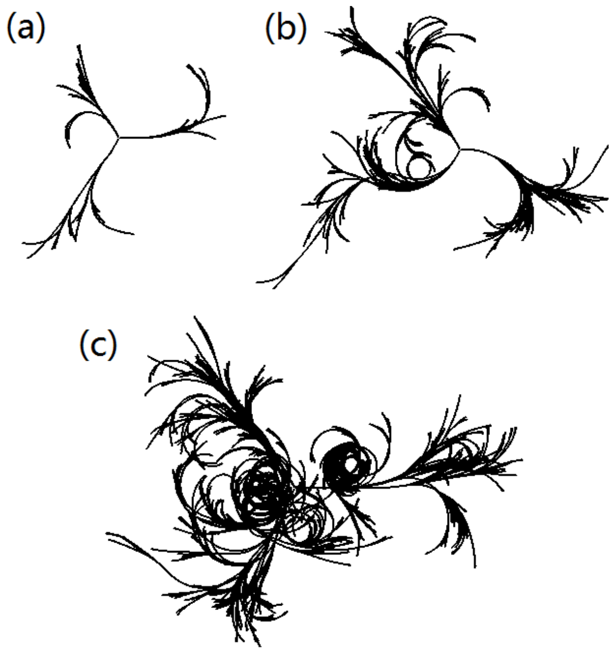


Figure 1: The importance of primary energy. Patterns created with an initial value of (a) 1000, (b) 5000 and (c) 15000

Figure 1 shows a series of simulations where the initial agents are seeded with different energy levels. In these simulations, *prStrength*=*expSize* = 0, meaning that neither color nor line width depends on the agent's energy. It can be observed how increasing starting values lead to more complex patterns. As a matter of fact, all agents coming into existence during the creation process inherit a fraction of the primary energy which has originally been supplied to the environment. The user may act on this parameter to control the overall length of lines drawn on the canvas, and therefore the density of the final image.

By defining *expSize*>0, the agent's energy level is mapped to size and consequently to line width. The second series of images focuses on this visual effect. Just as in the previous runs, no resources are added to the environment, so that all agents rapidly die of starvation. The samples of Figure 2 show how the progressive energy loss of the agents implies a thinning of the lines. Moreover, it can be seen that the proportion of energy ceded to offspring has an influence on the overall appearance of the image. Even splits design rather balanced patterns, whereas uneven divisions lead to the emergence of a master branch with secondary filaments.

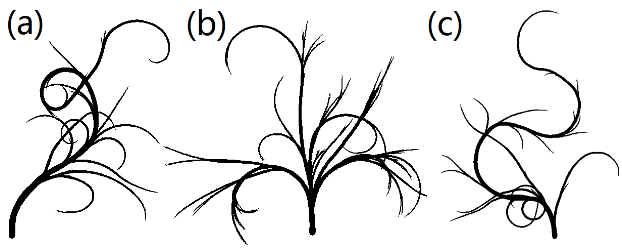


Figure 2: Emergence of main branches. Patterns created with a division ratio of (a) 0.1, (b) 0.5 and (c) 0.9

The next experiment highlights the possibilities of mapping the agent's energy to color. Due to printing limitations, the presented examples only use gray shadings. Figure 3 displays two images generated by swarms of agents with a positive *prStrength*. In the left image, the agents have a black primary and a white covering color. In the right image, the properties are inverted. Since the agents lose energy as they roam around, their primary color gradually predominates, which produces interesting fade effects. Agent coloring clearly enriches the space of generable images and offers new ways of artistic exploration with the ecosystem.

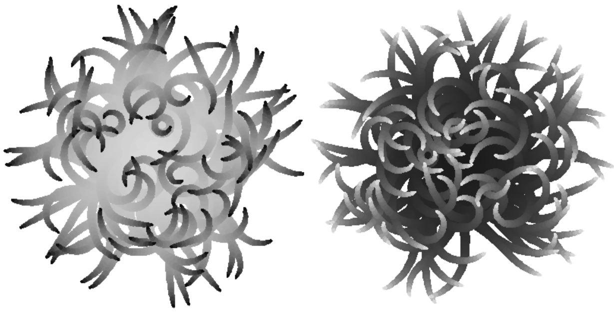

Figure 3: Energy loss leading to fade effects

The concept of food chasing can be used to control the agent's drive during the image generation. In order to illustrate this idea, the two images of Figure 4 simulate swarms realeased in an environment featuring two food bits. As a result the agents are attracted to the targets, but their ingestion range has been set to 0, so that they cannot catch it. Note that some agents in the lower left and the upper right corners are situated in such a way that both food bits are outside their sensor range and adopt their default behavior.

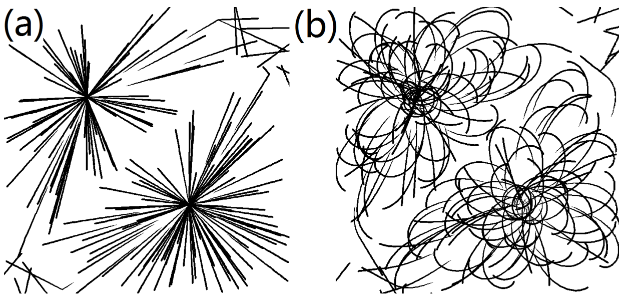


Figure 4: Food serving as attractor. Patterns created with an agility of (a) 1 and (b) 0.07

# 4 Applications

Three concrete examples have been designed to illustrate the artistic potential of the previously studied behaviors in more complex environments.

The first example addresses the aspect of agent coloration. In Figure 5, a collection of black food bits has been placed in a predefined pattern representing the letters A-R-T. A number of agents is seeded to the left of each letter, with white primary and covering color. Moreover, they are "blind", i.e. *sensorRange*= 0, so that they cannot perceive resources and only follow their default behavior which is defined to be a fixed rightward run. As soon as the agents meet the deposited food, they start ingesting them and develop dark trails. When they quit the resource-rich region on the right hand side of the letter, they rapidly die of starvation. As an overall visual effect, the swarm redraws but somewhat blurs the original pattern.


Figure 5: Agents running across a predefined resource pattern

In the previous section, it has been shown that not only the color but also the moving direction of the agents can be influenced by food patterns. To demonstrate an application of this idea, black food bits have been laid out in a pattern which is similar to that of the previous simulation. Hovewer, this time the agents' sensor range is positive, so that they perceive and actively head for nearby resources. As soon as they start assimilating the deposited food, they produce visible lines. When no more resources are found in the environment, the agents adopt their default strategy, which is a straight forward march. Their trails constantly thin and finally disappear.

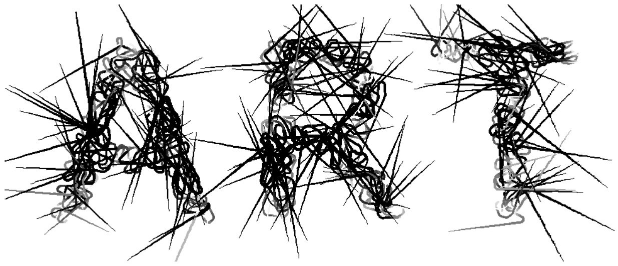

Figure 6: Agents grazing on a predefined resource pattern

Interestingly, the thinning of the lines due to energy loss can be likened to human brush strokes. Figure 7 illustrates this idea by a swarm of agents which, starting from a hand-crafted initial configuration, collectively draws a chinese character. Calligraphy is an artistic subspace within the space of all images that can be generated by the ecosystem. The sample painting suggests that, given a sufficiently convenient interface for the exploration process, the system may allow artists to discover imaginary calligraphic patterns or variations of existing ones.

Figure 7: Qun - the chinese pictogram signifying ”swarm”

# 5 Conclusion

We presented an artificial swarm system for generative art based on mechanisms observed in natural ecosystems. The key novelty of our approach is the introduction of energy and food chasing to the agent model.

A series of simulation runs allowed identifying the major dynamics of the system. In particular, the agent’s energy level is a changing phenotypic information which can be mapped to artistic dimensions such as line width and color and therefore enrich the visual experience. Despite its simplicity, the system produces output of great variety. Three applications suggested ways to leverage the observed properties of the artificial ecosystem. We demonstrated how a well-directed positioning of resources can harness the agents’ drive and allow the user to partially control the creation process.

In the scope of this paper, the agent reproduction did not involve evolutionary dynamics. This restriction was made in order not to blur the basic mechanisms of our model. As a future extension, it would be interesting to introduce genetic mutations, i.e. random variations in the child genotype. Evolutionary change would open new degrees of freedom which could be creatively exploited by the system. Moreover, the definition of distinct agent species would allow assessing the artistic value of predator-prey relationships, flight behavior and dynamic chase.

The presented work contributes to the construction of a toolbox of ecosystem features for creative image generation. In this sense, we participate in the vision of a new generation of generative art systems featuring ”intelligent brushes” (McCormack, 2010) which could be selected by the artist and applied on a canvas in order to produce pieces on the borderline between human inspiration and machine creativity.

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