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# ARTIFICIAL CREATIVITY WITH KINETIC DRAWING SYSTEMS BASED ON STOCHASTIC MOTION

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*This paper presents a kinetic drawing system (KDS) as the virtual motor oriented component of a system for visual creativity (VCS) modelled on stochastic motion based on variations of random walk algorithms. The starting point for this approach comes from the real world where natural collective stochastic motion of inanimate particles leads to aggregations of visual structures which are interesting from an artistic standpoint. The main idea of the current research is to integrate such random walk based stochastic motion into a framework governed by visual design principles and steer resulting form-aggregations into emerging visual designs that evolve continuously producing new compositions. The proposed system is based on loosely modelling Brownian motion and the phenomenon of diffusion limited aggregation.*

**Keywords**: artificial creativity, visual creativity, kinetic drawing, random walk, drawing agent, visual composition, visual design, artificial ecosystem, virtual environment, interactive drawing, autonomous drawing

## 1. Introduction

This paper presents a kinetic drawing system (KDS) developed as part of an artificial creativity system for visual arts. The purpose of the overall system is to autonomously or interactively produce visual content that resembles natural forms organized in compositions that are meaningfully structured and aesthetically valuable. The artificial drawing is ensured at lower perceptual level in the system by drawing agents in stochastic motion loosely modelling the process of diffusion limited aggregation (DLA) carrying out visual composition concepts generated at higher hierarchical level. The kinetic drawing system presented in this paper is the virtual motor oriented component of the artificial creativity system.

There is previous work using particle motion and phenomena such as DLA as real life models for developing various forms of computational art. A simulation to exemplify the process is offered by the *xmountains* program by Steve Booth [1]. This provides a good example of DLA simulation clarifying the natural process inspiring the present research, but *xmountains* has no aesthetical

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principles integrated in any form in its simulation. The existence of toxiclibs library for Java and Processing facilitates the implementation of DLA simulations in these programming languages. A DLA process simulation is also available with the NetLogo [2] programming language. These libraries and simulations show a general interest in computational recreation of natural phenomena. The libraries facilitate the simulation of DLA through simplified models, but implementations based on these libraries do not organize these structures by visual composition principles. Interesting examples of artistic fractal sculptures computationally developed with toxiclib library are in the work of Lomas [3]. In general, his work explores artistic values that can be developed from simulations of natural phenomena. Lomas focused on the development of one sculptural form in each application by controlling the accumulation of millions of particles in random movement. Other pieces of Lomas' works focus on simulating morphogenesis processes leading to sculptural forms of extreme complexity having aesthetical value. The main difference from our approach is that one sculptural form is generated by each application while the focus of KDS is placed on the creation of visual compositions that integrate simulations of multiple three dimensional structures that evolve into new ones while their overall arrangement evolves into new valid designs. There are numerous other computer models that simulate developmental programs in plants and other natural structure formation processes, but these are outside the scope of creating aesthetic artificial structures starting from simulations of particle diffusion in fluids.

Our approach is different from these examples as our simulation is only to a limited degree based on the DLA phenomenon. Specifically, instead of using a locked seed as the starting point for developing fixed structures, we use launching sites with loosely defined boundaries for developing structures that evolve in time. This approach also draws on processes in creative cognition that require loosening rules within knowledge systems to make room for unexpected associations and combinations leading to the development of new and valuable knowledge [2][3][4].

## 2. Kinetic Drawing with Random Walk Systems

The inspiration for using random walk algorithms as a basis for modelling a variant of KDS comes from the real world where natural collective stochastic motion of inanimate particles or living organisms leads to aggregations of visual structures which are interesting from an artistic standpoint [1][7][8][9][10][11]. By integrating motion based on random walk algorithms into a general framework governed by visual design principles, traces of agents' motion can be steered into organized visual designs that continuously restructure themselves into new designs. A large number of compositional variations are produced in the process. Due to this large variety of compositions and the level of complexity involved in operating with many design elements, such visual compositions can never be produced in very large numbers by the human artist alone. However, the artist can actively interact with the KDS to influence convergence towards desired visual form aggregations. The KDS system can produce valuable results working interactively, autonomously, or combining the two working modes.

For KDS purposes within the visual creativity system (VCS), we implement artificial drawing as a model of natural diffusion based on stochastic motion confined to a predetermined frame of reference as defined by the picture plane. This motion is further constrained by embedding into the virtual world composition rules manifested through the interactions between drawing agents and the artificial environment. This approach allows producing visual designs that emulate natural structures such as clouds, rivers, aggregations of celestial bodies in cosmic space and more. The generated artificial structures are in continuous development reorganizing themselves along directional lines of visual tension, centers of visual attraction/repulsion distributed along the structural skeleton of the given frame of reference [13]. While the lines and centers of visual tension are not directly visible on screen, they induce a design structure in the drawing space functioning as an invisible reference field through which visual compositions are generated. We start with simulations of Brownian movement in a two-dimensional space with drawing agents in irregular motion that is not directly under the influence of forces. The integrations of such models of motion with design principles in the generation of visual output are discussed in this paper for several applications.

## 3. Formal Framework for the KDS with Random Walk Drawing Agents

Heuristic techniques employed in the development and testing of the KDS rely on the intuitive probabilistic framework of classical random walk as formalized by Spitzer. Being illustrative from the perspective of our interest in generating drawings by tracing agent motion paths, we can describe the random walk as a trajectory developed by successively adding random variables, which are independent and have identical distribution [1] [14]. This allows developing and empirically evolving a model that loosely simulates Brownian motion in a two-dimensional space with an estimated probability of recurrence and self-similarity. The system produces random discrete fractal structures resembling natural forms. The discrete property is important because it allows the necessary freedom for steering the form aggregation into a very large range of possible visual designs. Heuristic experiments used for testing the visual creativity system with random walk KDS are based on a two-dimensional recurrent random walk class with the state space limited to the pictorial field and drawing agent motion in incremental steps along x and y axis within this bounded state space. This is a typical case of recurrent random walk for which, in the framework defined by Spitzer [15], the following property is satisfied:

$$G = \frac{1}{1-F} \tag{1}$$

with the interpretation that: (a) when $F=1$ then $G=+\infty$ meaning that in the case of a recurrent random walk the number of returns to the same point is unlimited; (b) when $G=+\infty$ then $F=1$ meaning that when multiple returns to the same point in the state space are unlimited then the random walk is persistent or recurrent. In relation (1) above, we have $F=F(0,0)$, $G=G(0,0)$, with $F_n(x,y)$ being the probability function that estimates the chance to reach for the first time the point $y$ in $n$ steps when starting from point $x$ at time $0$ and $G_n(x,y)$ being the probability function that estimates the number of times a random walk can reach point $y$ when starting from point $x$ during time $n$. Both $F_n(x,y)$ and $G_n(x,y)$ are functions of the same type as the transition function $P_n(x,y)$. For any points $x,y \in \mathrm{Z}^d$ we have:

$$F_0(x,y) = 0, \tag{2}$$

$$F_1(x,y) = P(x,y), \tag{3}$$

$$F_n(x,y) = \sum_{x_i \in \mathrm{Z}^d - \{y\}, i=1,..,n-1} P(x,x_1)P(x_1,x_2)....P(x_{n-1},y), \quad \text{for} \quad n \ge 2 \tag{4}$$

For $n \ge 1$ and any $x,y$ in $\mathrm{Z}^d$, it is demonstrated [15] that the probability function $F_n(x,y)$ has the following properties:

$$F_n(x,y) = F_n(0,y-x) \tag{5}$$

$$\sum_{k=1}^{n} F_k(x,y) \le 1 \tag{6}$$

$$P_n(x,y) = \sum_{k=1}^{n} F_k(x,y) P_{n-k}(y,y) \tag{7}$$

For any points $x,y \in \mathrm{Z}^d$ and $n \ge 0$ the function $G_n(x,y)$ is defined as follows:

$$G_n(x,y) = \sum_{k=0}^{n} P_k(x,y) \tag{8}$$

and has the following property:

$$G_n(x,y) \le G_n(0,0) \tag{9}$$

If we consider F and G to be the limits of respectively $F_n(0,0)$ and $G_n(0,0)$ then we have:

$$G(x,y)=\sum_{n=0}^{\infty}P_n(x,y)\leq\infty \tag{10}$$

$$F(x,y)=\sum_{n-1}^{\infty}F_n(x,y)\leq 1 \tag{11}$$

$$G_n(0,0)=G_n,\quad G(0,0)=G \tag{12}$$

$$F_n(0,0)=F_n,\quad F(0,0)=F \tag{13}$$

with the above terminology based on the F and G limits being at the basis of relation (1) on which hypotheses of our experiments rely.

## 4. Integration of Simple Random Walk KDS with the VCS

As briefly explained in §1, the visual creativity system is structured on two main hierarchical levels. The lower hierarchical level is where drawing agents sense the environment and take action that translates into movement with traces of that motion creating the visual output from the system. This represents the KDS, which is the virtual motor component of the VCS. At this hierarchical level in the VCS, agents move and take decisions locally. The influence of local decision making at individual agent level bears seemingly little importance in content creation as designed visual compositions. This is the low level perceptual system of the VCS. Visual concepts are developed at higher hierarchical level where the aggregations of visual elements generated by the KDS is controlled. Embedding a certain structure in the artificial environment is an important part of controlling visual composition creation. This is based on drawing agents reactions to the artificial environment with the effect that the overall agents' motion is steered towards form aggregations from which visual designs emerge gradually. Visual concepts are implemented in the VCS through the visual aggregation and fading (VAF) module. The VAF module is inspired by the diffusion limited aggregation (DLA) process, which is related to Brownian motion. The DLA process is, in principle, the process by which particles in Brownian motion cluster in a frozen structure starting from a static seed particle, to which more and more particles attach gradually growing the seed into complex fractal forms. Examples of such DLA growth in nature are coral reefs, crystal growth, cloud formation etc. The VAF module, which is loosely inspired by the DLA process, is not generating fixed visual structures in the pictorial field, but instead it generates trends in structure formation at macro level at varying temporal and spatial scales.

The DLA process and its simulations produce fixed volumetric forms in three-dimensional space, while the VAF module works on a bi-dimensional space loosely forcing random walk agents into KDS areas of high recurrence rate. The formation of such areas of high recurrence is initiated by random walk agents' collision events with the frame of reference, which we estimate that are sure to happen in finite time even when the size of the picture plane is very large in the positive domain of the state space. Such events determine two main results. First, a decrease of contrast is applied throughout the entire pictorial field, which we describe as fading. Fading may be of varied intensity depending of the collision site and on the agent itself, different agents having different properties. Second, the random walk agent abruptly jumps into areas of high recurrence. Instead of converting the landing location into a locked seed as with the DLA process, the agent continues to move freely. However, the landing locations are randomized, but limited to certain bounded areas in the random walk state space defining the KDS high recurrence areas. The loose definition of the high recurrence areas within the drawing space is handled so that their distribution within the pictorial filed is in accordance with visual composition principles and in accordance with potential visual tensions that may develop along the structural skeleton of the given frame of reference as described by [13]. The result is an artificial form of DLA with mobility, spatial expansion, and with a number of visual properties described in more detail in [16]. In addition, these high recurrence areas, while limited in their expansion, have undefined boundaries and the agent is free to leave it as a result of its unhindered stochastic motion. Visually, the high recurrence areas appear in the visual output as areas of higher trace density where forms are constructed by the system.

VAF module emulates some aspects of the adaptive regression process in creative cognition as described in existing research [4][5][6]. This can be summarized as a pre-conscious state that catalyzes unusual combinations and associations of mental structures when restrictions grounded in memorized knowledge are relaxed. Therefore, the composition principles are manifested as weak VAF rules and the system can easily and randomly depart from them, while forms generated through the random walk movement make possible the creation of a large range of structures. At macro level, we expect to see a generative process producing systematically bi-dimensional compositions in continuous change. Details related to the implementation of a fading system that creates the illusion of aerial perspective and depth perception, as well as aspects related to the selection of the agent unit form and its relation to step size are described in more detail in [16]. In conclusion, the VAF module is based on probabilistic intuition grounded in the general formalization of the random walk algorithms.

## 5. Hypothesis and Experiments Design

Heuristics used for testing the visual creativity system with random walk KDS are based on a two-dimensional recurrent random walk class with the state space limited to the pictorial field and drawing agent motion in incremental steps along x and y axes within this bounded state space. This is a typical case of recurrent random walk for which property (1) is satisfied. Based on this, we assume that returning to a given point in the space is highly probable within reasonable time. Therefore, it can be expected that interactions within the frame of reference at defined sites will initiate the VAF re-launching of drawing agents periodically into KDS areas of high recurrence. Our hypothesis is that this behavior underlies the system's ability to generate visual compositions in continuous change converging towards structures organized by design principles. In spite of the fragmentations of the random walk, we assume that the self-similarity and scaling properties of discrete fractals are preserved as an agent most often draws uninterrupted following a random walk path for a long time before launching the VAF module.

Experiments are meant to provide enough data for estimating during a reasonable time the system produces results as assumed in our hypothesis. Different experiments allow evaluating how the size of the state space and the amount of time correlate in reaching a great variety of visual compositions. Some of the experiments allow the system to evolve autonomously while other experiments use a combination of autonomous and user driven drawing and compare the results. For the current group of heuristics, we are interested in experimenting with various sizes of the bounded state space, various drawing agents' sizes, different numbers of drawings agents in the system, autonomous and or interactive convergence towards comprehensible designs, and various durations of experimental runs. We asses if the resulting distributions of forms converge towards aggregating into visual compositions that are valid from design standpoint and if such convergence occurs consistently in a reasonable time span. In order to keep the experiments independent from the performance of a given work station, we evaluate the duration of each experiment based on the number of steps in a run rather than based on the run duration.

## 6. Experiments with Single Random Walk Drawing Agent KDS

The first experiment with single random walk agent KDS is based on the system working autonomously (Fig. 1). The important settings for this experiment are as follows: (a) the frame size is 1000 x 600 pixels; (b) the agent is an ellipse with diameters: 15 pixels and 20 pixels; (c) total number of steps: 6,523,4000 (29 hours 57 minutes); (d) images are sampled at every 100th step; (e) total number of samples: 65, 234 images. The VAF module uses sections of the sides of the drawing space as collision sites that initiate new starts in various high recurrence areas distributed around four centers of visual balance in the pictorial field. Selected images from clusters of compositions sampled in temporal order are presented in Fig. 1. The analysis of the sets of composition clusters (Fig. 1) with only one step per cluster, shows a clear system tendency to aggregate drawing traces in emerging visual designs that are organized in accordance with design principles. Although there is certain degree of similarity between compositions in the same cluster, each composition is different. Similarity between compositions within the clusters is mostly due to the transitioning process from one form into another in slow incremental fashion. However, the overall system leads in time towards new compositions. It is interesting to note that the system works successfully ensuring depth perception, non-repetitive distribution of aggregated structures in the pictorial field, and ensuring decluttering along time. Multiple runs of the same heuristic consistently produced similar results with an extremely large number of composition variations.

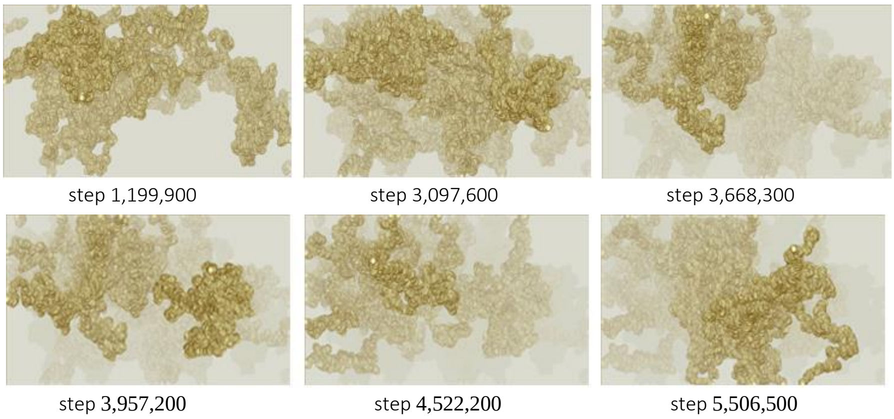


Fig. 1. Autonomous KDS with single random walk drawing agent, version 3; autonomous run of 6,523,4000 steps; agent: ellipse, diameters: 15 pixels and 20 pixels; unit size steps; frame size: 1000 x 600 pixels; still images sampled at every 100$^{th}$ step for a total of 65,234 images.

The second experiment based on single random walk KDS is summarized in Fig. 2 and combines autonomous and interactive working modes. The important settings for this experiment are as follows: (a) the frame size is 600 x 1200 pixels; (b) the agent is a rectangle of 15 x 25 pixels; (c) total number of steps: 1,812,9000 (21 hours 14 minutes); (d) images are sampled at every 300th step; (e) step size is unit size (f) total number of samples: 6.036 images. These settings show that the resolution is increased by 20% in comparison with the previous two experiments. The aspect ratio of the frame of reference is changed to acquire vertical orientation. The size of the drawing agent is fixed and slightly larger than in the first heuristic. Drawing agents change color and transparency in interactive mode to keep track of user interventions.

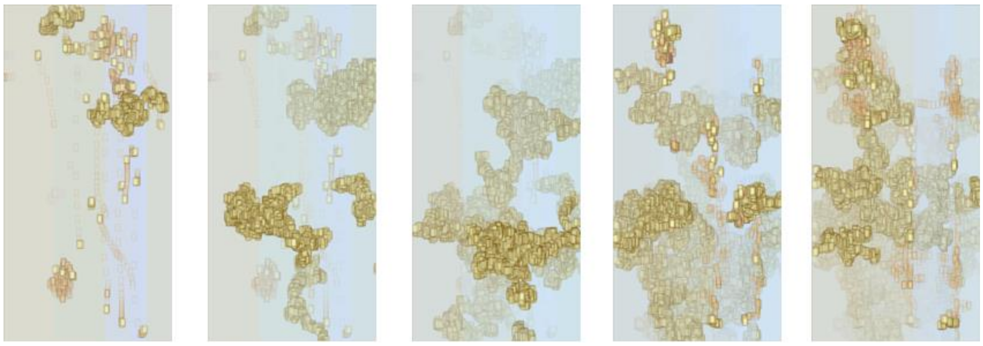


Fig. 2. Interactive KDS with single random walk drawing agent, version 6; sampled compositions generated autonomously between steps 5,700 and 513,600; number of steps for this run: 1,812,9000; total number of samples: 6,036 sampled images; agent: rectangle with sides 15 pixels and 25 pixels; unit size steps; frame size: 600 x 1200 pixels; still images sampled at every 300$^{th}$ frame.

As in the previous case, the VAF module uses sections of the sides of the drawing space as collision sites to re-launch random walks in high recurrence areas. Sampled images show consistency in the system tendency to aggregate drawing traces in accordance with aesthetic requirements. The convergence is much faster with user interactions and remains very consistent, but slower in autonomous mode. Like in the previous experiment, we note that the system ensures depth perception, non-repetitive distribution of aggregated structures in the pictorial field, and consistent decluttering in time of the pictorial field. Reliable results were produced for multiple runs of the same heuristic.

## 7. Experiments with Multiple Random Walk Drawing Agents KDS

We describe two heuristic experiments with multiple pseudo-random walk drawing agents and user interactive drawing input for parts of the experiments.

The first experiment (Fig. 3) is based on a KDS with five drawing agents. Compositions are generated with user interaction and/or autonomously. A change in the agent color to orange-ochre tint occurs when drawing is driven by the user. The important settings for this experiment are as follows: (a) the frame size is 1200 x 1200 pixels; (b) the agent is a rectangle of 15 x 25 pixels; (c) the total number of steps is 2,238,300 (17 hours 57 minutes); (d) images are sampled at every 300th step; (e) total number of 7,463 frames were sampled.

The heuristic was run in two parts, with the first part being run for 424,500 steps and the second part being run for 1,813,8000 steps. The 7,463 still images were collected from the combined two parts of the experiment. Fig. 3 shows a cluster of compositions sampled during the second part of the heuristic experiment and are presented in temporal order. Sampled images show that new compositions responding to visual design principles are emerging from the heuristic on a continuous basis and faster when multiple agents are used even when the resolution is larger. This is true when the system runs autonomously or with user interaction. User interaction may speed the process. Therefore, the starting assumptions are satisfied. We notice that the agent size, which is proportionally smaller in relation to the frame of reference than in previous experiments, seems to allow for a more refined look of the visual output.

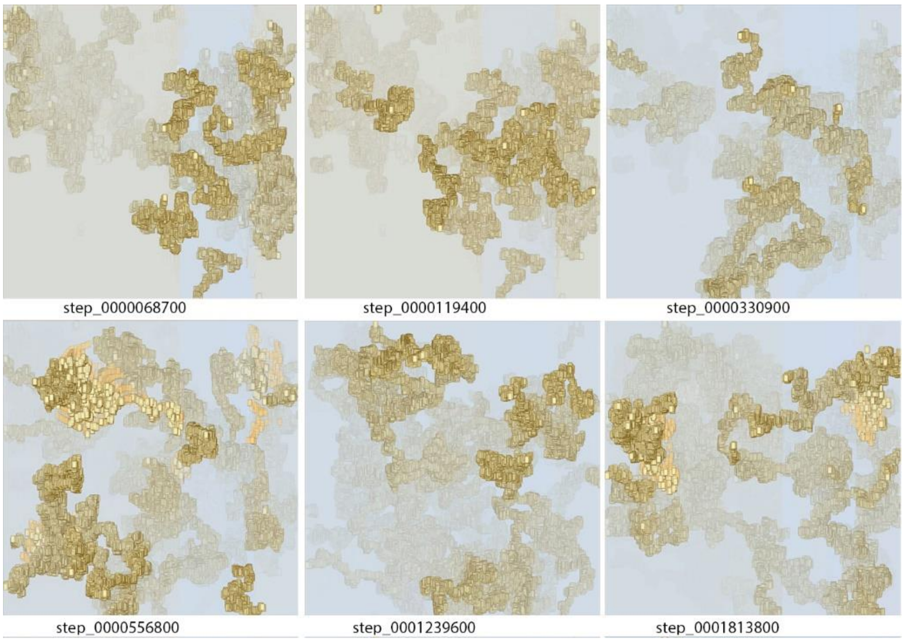


Fig. 3. Cluster of sampled compositions generated with KDS version 10; combined interactive and autonomous working modes; 5 random walk drawing agents; run of 1,813,800 steps; total number of sampled frames: 7,463; samples collected at every 300th step; agent: rectangle with sides 15 pixels and 25 pixels; unit size steps; frame size: 1200 x 1200 pixels.

Based on these results, it is of interest to run heuristic experiments based on a KDS with an increased number of agents and proportionally larger size of the agent in relation to the frame of reference. The second heuristic with multiple agents (Fig. 4) is, therefore, based on a KDS with 25 random walk drawing agents, with rectangular agent size maintained at 15 x 25 pixels. The resolution is reduced to 600 x 600 pixels, making the drawing agent relatively much larger in relation to the frame of reference compared to the previous experiments. This heuristic was run for 1,305,600 steps with still images sampled at every 300th frame for a total of 4,352 frames. The inspection of these images show that, contrary to our assumption of faster convergence, the autonomous KDS generates structures that do not converge towards compositions organized along design principles. Instead, the 25 drawing agents create too many sites of condensed structure development that work at comparable speed and visual intensity in the same time. This leads towards a rather uniform distribution of points of visual accent within the pictorial space making very difficult the development of compositions in accordance with design principles. The user driven heuristic can still produce interesting results with almost continuous input from the user.


Fig. 4. Sampled compositions generated autonomously by KDS version 11 with twenty-five drawing agents during a run of 1,305,600 steps; samples taken between steps 9,900-551,700 at every 300th step; total number of sampled compositions: 4,352 frames; agent: rectangle 15x25 pixels; unit size step; frame size: 600 x 600 pixels. This experiment shows that a large number of drawing agents is counterproductive and compositions generated by these settings may not respond to aesthetic requirements.

## 8. Conclusion

The experimental results show that autonomous or interactive single agent random walk KDS are very reliable for generating a large number of valid visual design compositions with resolutions in the range of 600x600 pixels up to 1200x1200 pixels within a reasonable time of approximately 25 hours on average. Minimal time must be allowed for the actual drawing process to take place in small step increments. KDS with multiple random walk drawing agents with a relatively small number of agents of about 15-18 agents, can produce faster convergence towards valid visual design compositions. This is not true for the case of systems with large number of random walk drawing agents. It is difficult to make a general recommendation for the maximum number of agents so that the system effectiveness is boosted up. This is because this number can be different for different system resolutions and agent sizes. If the size range is maintained around 1000 x 1000 pixels for the reference frame and around 20 x 20 pixels for the agent size as in the case of the set of heuristic experiments described in this paper, then we are able to recommend that the agent number should be limited to approximatively 5-10 agents for good results.

In summary, the visual creativity system with kinetic drawing based on stochastic motion provides a new way for autonomous or interactive production of large numbers of new visual designs. The system is very effective and reliable when used interactively to produce visual content. When working in interactive mode, this holds true even when the number of agents is relatively much larger. The important aspect is that, when working autonomously, the system provides a new paradigm for artificial creation of original visual content resembling natural structures. When working interactively, the systems provides a new medium for artistic expression based on a combination of user drawing and active system response resulting in the generation of forms that resemble natural structures, but with more visible human intervention.

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