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Aesthetic Agents: Swarm-based Non-photorealistic Rendering using Multiple Images

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Abstract

The creation of expressive styles for digital art is one of the primary goals in non-photorealistic rendering. In this paper, we introduce a swarm-based multi-agent system that is capable of producing expressive imagery through the use of multiple digital images. At birth, agents in our system are assigned a digital image that represents their 'aesthetic ideal'. As agents move throughout a digital canvas they try to 'realize' their ideal by modifying the pixels in the digital canvas to be closer to the pixels in their aesthetic ideal. When groups of agents with different aesthetic ideals occupy the same canvas, a new image is created through the convergence of their conflicting aesthetic goals. We use our system to explore the concepts and techniques from a number of Modern Art movements. The simple implementation and effective results produced by our system makes a compelling argument for more research using swarm-based multi-agent systems for non-photorealistic rending.

Categories and Subject Descriptors (according to ACM CCS): Computing Methodologies [I.2.m]: Artificial Intelligence—Miscellaneous

1. Introduction

Both artists and computer scientists have looked to nature as a source of inspiration. One naturally inspired area of research for both disciplines is the study of artificial life. Artificial life is an interdisciplinary field that includes researchers from biology, chemistry, physics, computer science, and mathematics, as well as philosophers and artists [AK05]. At its core, artificial life research involves the creation of software, hardware, and wetware (e.g. biochemical) models based on real or hypothetical living systems. In this paper, we model the natural phenomenon of swarm intelligence using a multi-agent system (MAS) for the creation of artistic works.

The creation of artistic works using a swarm-based MAS has been previously explored. However, the majority of past research has adopted a colour-based painting approach i.e. agents paint a blank digital canvas with predetermined or randomly chosen colours. To date, there has been very little research that utilizes digital images as a source for creating digital paintings and the research that has been done was primarily concerned with feature extraction.

We build upon previous efforts through our investigation of a swarm-based MAS that utilizes multiple images for the production of expressive artistic works. Although easy to implement, our system is capable of producing varied and complex images that are the emergent result of millions of simple interactions. Our results demonstrate the power of emergence and naturally inspired algorithms for use in non-photorealistic rendering (NPR).

We proceed as follows: in Section 2, we provide a brief introduction to NPR, autonomous agents, swarm intelligence and swarm painting. In Section 3, we detail the implementation of our swarm-based MAS. In Section 4, we discuss the artwork produced by our system. Finally, in Section 5, we make our conclusions and suggest areas for future research.

2. Background

Our system uses autonomous agents to model swarm intelligence for the purpose of non-photorealistic rendering – a category of research we will refer to as *Swarm Painting*.

2.1. Non-photorealistic rendering

Where traditional computer graphics has focused on photorealism, NPR looks to artistic styles such as painting, drawing, animated cartoons, and technical illustration as inspiration. In addition to its expressive qualities, NPR can offer more effective means of communication than photorealism by adopting techniques long-used by artists e.g. emphasizing important details and omitting extraneous ones [GG01].

2.2. Autonomous Agents

An agent can be defined as “anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors” [RN95]. An *autonomous* agent is an agent that can operate independently and is capable of controlling its actions and internal state [WJ95]. Agents can be grouped into two general categories: *cognitive* agents and *reactive* agents.

Cognitive agents have an explicit symbolic understanding of their environment and can be seen as an extension of symbolic AI techniques. An example of a cognitive or *intentional* model is BDI-architecture. In a BDI-based model the beliefs, desires, and intentions of an agent forms the basis of their reasoning process [Rao91].

Reactive agents are specified by their behaviour i.e. how they react to perceived stimuli in their environment. In a reactive agent model, rules map perceived input to effectual output that is generally executed immediately. Purely reactive agents have no internal history or long-term plans, but choose their next action solely upon the current perceived situation.

Each model has its advantages: cognitive models provide more powerful and general methods for problem solving; reactive models are faster and capable of producing complex emergent behaviour from simple sets of rules [BD94].

2.3. Swarm Intelligence

Individually, social insects such as ants and termites appear to behave in a simple, almost random fashion. However, when a colony’s collective behaviour is examined complex and seemingly intelligent global behaviours emerge [BTD*97]. Initially, it was assumed that the insects were either communicating in an undiscovered fashion or that each individual had some kind of internal representation of a global plan. However, research in the biological sciences has determined that the behaviour is in fact the result of individuals working autonomously with only local information.

One way that collective intelligence can emerge is through *stigmeric* interaction. Stigmergic interaction refers to spontaneous, indirect coordination between individuals that occurs when the effect of an individual on the environment can influence the actions of others [TB99]. An example of this is the pheromone trail that an ant creates on the way back to the nest after it has found food. The pheromone trail attracts other ants who reinforce the trail with their own pheromones. Pheromones fade over time so once a food source is exhausted the trail to it disappears. This seemingly simple heuristic is so effective that it has been utilized to solve a number of combinatorial optimization (CO) problems, including the well-know traveling salesman problem [DG97].

Swarm-based algorithms have a number of properties that make them successful at solving certain types of problems. They are *versatile* – the same algorithm can be applied with minimal changes to solve similar problems, *robust* – they keep functioning when parts are locally damaged, and *population-based* – positive feedback leads to autocatalytic or ‘snowball’ effects [RA00].

2.4. Swarm Painting

Swarm Painting refers to swarm-based multi-agent systems in which a group of software- or hardware-based ‘painter agents’ move and deposit paint or change pixel colour values on a real or digital canvas. Swarm painting can be divided into two main categories: colour-based swarm painting and image-based swarm painting.

2.4.1. Colour-based

To date the majority of Swarm Painting systems have adopted a colour-based painting approach. In a colour-based approach, agents paint a blank digital canvas with predetermined or randomly chosen colours. The majority of colour-based swarm painting researchers utilize an ‘ant and pheromone’ model. In this model, a colony of virtual ants move and deposit paint on a canvas based on the distribution of virtual pheromones. Research using this approach has investigated a number of different methodologies including robotics [Mou02], genetic algorithms [ABM*03], single [Urb05] and multiple [Gre06] pheromone systems, consensus formation [Urb06] and mimicry [Urb07].

2.4.2. Image-based

Another approach to swarm painting is to use an existing digital image as a reference for painting. The use of image files for NPR is a subfield within NPR called non-photorealistic rendering from photographs (NPRP).

The concept of using a digital image as a habitat for a colony of virtual ants was first published by Ramos at the 2nd International Workshop on Ant Algorithms (ANTS 2000) [RA00]. In Ramos’ model, the grey level intensity of pixels in a digital image creates a pheromone map that virtual ants are attracted to. Ants deposit paint as they move and the trails they leave form a sketch-like image that contains salient features of the original image. Ramos’ primary interest was in image processing and not the creation of artistic works. In fact, the majority of research utilizing digital images as a habitat for swarm-based multi-agent systems has been concerned with non-artistic image processing tasks such as image segmentation, feature extraction, and pattern recognition.

There are a couple of notable exceptions. Semet used a digital image habitat and artificial ant model as an approach to non-photorealistic rendering [SOD04]. In Semet's system, a user interactively takes turns with an artificial ant colony to transform a digital photograph into a stylized image. Semet's model was successful in creating a variety of stylistic effects including painterly rendering and pencil sketching. Another example is Schlechtweg et al. who used a multi-agent system to do stroke-based NPR using a set of input images that each contained different kinds of pixel-based information e.g. depth, edges, texture coordinates [SGS05].

In addition to the use of a single image as a source for NPR, multiple images or video frames have been used to achieve a number of artistic styles including cubism [CH03], pen and ink drawings [BSMG04], interactive video [BHS*07], rotoscoping [CRH05] [HZF10], and animation [LMS06].

3. Aesthetic Agents

Our system expands on previous research by using multiple images in conjunction with a swarm-based MAS for NPRP. Although our system references digital images for colour information it does not treat them as a habitat or environment. Instead, agents in our system are assigned a digital image that represents their *aesthetic ideal*. Accordingly, we refer to them as *Aesthetic Agents*.

On the surface, the behaviour of *Aesthetic Agents* does not seem to be stigmergic since the aesthetic ideal that agents are assigned can be seen as a global goal. However, the existence of *multiple competing global plans* produces images that are not the goal of any individual agent. Therefore, images produced by our system are the emergent result of local interactions since agents are not aware of each others goals or the image that will result from their interactions.

Aesthetic Agents are born in a toroidal digital canvas i.e. a 32-bit ARGB (Alpha Red Green Blue) bitmap image. Agents occupy a single pixel within the digital canvas and are invisible i.e. only their effect on the digital canvas is seen. When an agent is born it is assigned a 32-bit ARGB bitmap image that represents its aesthetic ideal. *Aesthetic Agents* are both reactive and autonomous. They are capable of 'sensing' the colour value of the pixel they occupy and those immediately surrounding them (Moore's Neighbourhood) and can modify the value of the pixel they occupy.

To initialize our system we create n agents, where n is the number of input images, and assign each agent one of the images as its aesthetic ideal. Only one agent for each aesthetic ideal is required since the offspring of agents are assigned the same aesthetic ideal as their parent. In our experiments we spawned our initial agents either in the centre of the digital canvas, *c(width/2, height/2)*, or at random locations *c(random(width), random(height))*. For each iteration of the system, agents perform the following actions:

1. **Sense Colour & Move**
   Aesthetic Agents can move 1 pixel per iteration. The direction an agent moves in depends on its movement mode. In *random* mode an agent randomly chooses one of its eight neighbouring pixels to move to. In *greedy* mode an agent moves to the pixel that is the most different from their aesthetic ideal. Difference is based on the euclidian distance between the RGB values of the pixels an agent can sense in the digital canvas and those in the agents ideal image. When the movement mode is set to *random*, *Aesthetic Agents* can only sense the colour of the pixel they currently occupy. When the movement mode is set to *greedy* agents can sense the pixel they occupy and those immediately surrounding them.
   In *greedy* mode images tend to converge more rapidly since agents focus their manipulations on the pixels that can be affected the most. In addition, the rate of canvas coverage (the percentage of the digital canvas that has been modified by agents) tends to increase as agents are attracted to areas of the canvas that have not been manipulated. The digital canvas is toroidal in nature so if an agent moves outside the bounds of the canvas it will reappear on the opposite side.
2. **Express Aesthetic Ideal (Modify Pixel)**
   For this action an agent modifies the colour value of the pixel it currently occupies to be closer to the colour value of the same pixel in its aesthetic ideal. This is achieved through the interpolation of the RGB components in the pixel they occupy in the digital canvas *c(x, y)* with the pixel at the same location in the agent's aesthetic ideal *i(x, y)*. The amount of interpolation is based on a preset interpolation variable between the value 0.0 and 1.0 where 0.0 is equal to the first number, 0.1 is very near the first number, 0.5 is half-way between, etc. For example, if the interpolation variable is 0.1 (10%), the RGB colour value at *c(x, y)* is (0, 0, 0) and the RGB value at *i(x, y)* is (100, 50, 200) then the pixel at *c(x, y)* will be changed to (10, 5, 20) by the agent.
3. **Reproduce**
   Agents reproduce asexually when their *fertility level* (which increases by one each time an agent expresses its aesthetic ideal) is greater than or equal to its *proliferation value*. Fertility levels are reset after a new agent is spawned. Asexual reproduction results in a new agent being born at the same location and with the same aesthetic ideal as its parent. Agents continue to reproduce until a preset static or dynamically determined maximum population is reached. In our experiments we were able to set the maximum global agent population to ~50,000 before the computational overhead started to have a visible ef-

fect on rendering. The maximum global population size is dependent on both the computer hardware that the system runs on as well as any software-based optimizations that have been implemented e.g. bit-shifting for efficient access to ARGB colour values.
In static populations agents are *runtime immortals* i.e. they persist until the program exits. In systems with dynamic population sizes, agents are culled if the new maximum population size is smaller than the current population size.

4. Experiments in Swarm Painting

In our initial experiments, we were interested in creating a system that would dynamically transform one image into another – a process referred to as *morphing*. We found the simplest way to achieve a morphing effect was to set the image that we wanted to transform as the digital canvas and to add an agent that had the target image as its aesthetic ideal. Since offspring are born with the same aesthetic ideal as their parents a population of 'like-minded' agents soon emerges and transforms the environment into the target image. This worked as expected, but we decided it would be more interesting if we had an agent population for each of the images. This would allow the morphing transformation from one image to another to happen in either direction e.g. from image A to B, or B to A. Furthermore, it gave us the ability to dynamically control the amount of morphing between two or more images by simply changing the population sizes of the competing groups of agents. Although, our experiment was successful in producing a dynamic morphing effect, we found it to be quite crude – more like the early cross-fading techniques used in film and not the convincing and seamless morphing effects produced by modern optical flow-based approaches [HS81].

Nonetheless, there were other aspects of the system we found compelling. When interpolation values are low e.g. 0.0-0.05, the morphing effect is subtle i.e. the transformation happens in increments that are too small to be noticeable. However, when interpolation values are higher e.g. 0.05-1.0, the activity of the tens of thousands of agents transforming the image becomes perceptible. From an aesthetic perspective, viewing complex processes like this can have a mesmerizing or even *sublime* effect on the viewer – something akin to the experience that one can feel when looking at the ocean or watching a fire. This aesthetic quality is referred to by Dorin as *computationally sublime*, a notion derived from Kant's concept of the mathematically sublime [Dor05]. In addition, when interpolation values are higher, the activity of the agents never ceases since pixels converge to and fluctuate between *n* different colour values, where *n* is the number of competing aesthetic ideals. Aesthetically, this creates a kind of *living painting* that remains in constant flux.

Furthermore, we noticed that when interpolation values are high (>0.05) that the images produced by our system have a painterly quality to them. This quality is produced by the softening of edges and blending of details caused by the interpolation of pixels from different images. *Figure 1* illustrates the effect of different interpolation values on output of the system. We decided to investigate this phenomenon further using concepts and techniques from a number of Modern Art movements as inspiration for our experiments.

Montage

Since our system uses multiple images the most obvious visual technique to explore was montage. *Montage* (French for 'putting together') is a composition made up of multiple images. The technique played an important role in many Modern Art movements including Bauhaus, Dada, Constructivism, Surrealism, and Pop Art. To create a montage we simply take *n* images and assign each one to a different group of *Aesthetic Agents*. *Figure 2* shows a montage made of an image of a skull, a lotus flower, and dice.

Figure 2: *Montage created by assigning different groups of Aesthetic Agents an image of a skull, a lotus flower, and dice.*

Impressionism

Impressionism was a late 19th century art movement based on the work of a group of mostly Paris-based artists including Monet, Pissarro, Manet, Sisley, and Renoir. Some of the characteristics of Impressionist paintings include small, visible brush strokes, an emphasis on light and colour over line, a focus on the overall visual effect instead of details, and a relaxed boundary between the subject and background [Ste09]. To explore these techniques we set different pictures of the same subject matter as the aesthetic ideals to different groups of *Aesthetic Agents*. Our intention was to try to combine similar elements of the same subject matter into an abstracted form. *Figure 3* shows an example in which five groups of agents are given five different images of daffodils.

Figure 1: *Demonstration of the effect of different interpolation values. Interpolation values from left to right are 0.01, 0.1, 0.9*

Figure 3: *'Aesthetic ideals' (left images) for five different groups of Aesthetic Agents and the output (right image) their interaction produces.*

Cubism

Cubism was an art movement in the early 20th century pioneered by Picasso and Braque. In Cubist artworks subjects are deconstructed and re-assembled in an abstracted form that often depict the subject from a multitude of viewpoints [EH04]. To explore this technique we took photographs of the same subject from different angles and assigned the different perspectives as aesthetic ideals to different groups of *Aesthetic Agents*. *Figure 4* shows the result of this technique and the increasingly abstract effect created as more angles and images are added.

Futurism

Futurism was an artistic and social movement founded in Italy in the early 20th century by Filippo Tommaso Marinetti. The Futurists admired speed, technology, youth and violence, the car, the airplane and the industrial city – all that represented the technological triumph of humanity over nature [McK10]. To the Futurists we lived in a world of constant motion, an idea that manifested in their painting technique:

> On account of the persistency of an image upon the retina, moving objects constantly multiply themselves; their form changes like rapid vibrations, in their mad career. Thus a running horse has not four legs, but twenty, and their movements are triangular [Mar10].

To explore this Futurist concept we took successive images of a subject in motion and set the images as the aesthetic ideals for different groups of *Aesthetic Agents* (see *Figure 5*).

Figure 5: *Image created from successive frames of a subject in motion.*

An issue that arises with this technique is that the more images you use the more the moving subject is blended into the background. This creates an interesting visual effect when using a small numbers of frames (three were used in our example output) but a subject starts to completely disappear as more frames are added. Furthermore, the non-moving parts of the image remain photorealistic. One way to get around this is to combine the translation of the camera (like in our Cubist inspired experiments) with the movement of the subject. *Figure 6* demonstrates a sample output using this hybrid approach.

Figure 6: *Image created using successive frames of a subject in motion in conjunction with camera translation.*

Abstract Expressionism

Abstract Expressionism was a post-World War II art movement that is characterized by spontaneity, emotional intensity, and an anti-figurative abstract aesthetic [Irv70]. It was the first American movement to achieve global influence and was largely responsible for shifting the centre of the Western art world from Paris to New York City. Some notable painters of this style include: Jackson Pollock, Willem de Kooning, Mark Tobey, Mark Rothko, and Barnett Newman. Since we had discovered that increasing the number of competing aesthetic ideals in our system leads to increased abstraction we simply needed to use more images to create completely abstracted imagery. We found in general that around ten images is sufficient to remove all of the figurative details from a set of input images (see *Figure 7* for an example).

The above examples demonstrate the importance of image selection to achieve a particular effect with our system. Although, some of the effects (e.g. Abstract Expressionism) can create interesting results from random image input, others like Montage require more mindful selection to achieve good results e.g. have figurative elements remain intact and still-readable.

5. Conclusions and Future Work

In this paper we expanded upon previous research that utilized swarm-based multi-agent systems for NPRP through our use of multiple images. We successfully implemented a system that is easy to implement, versatile, and capable

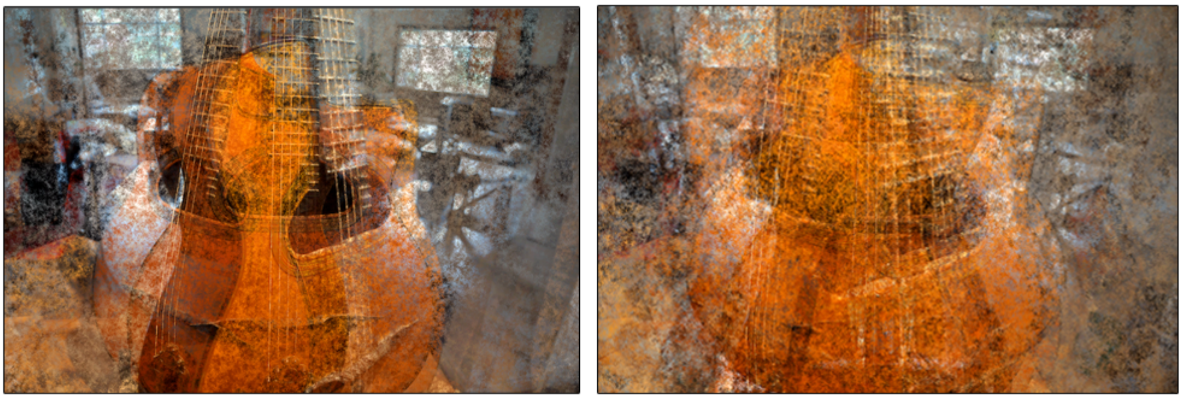

Figure 4: *Images created by assigning Aesthetic Agents three (left image) and six (right image) images of a guitar from different angles.*

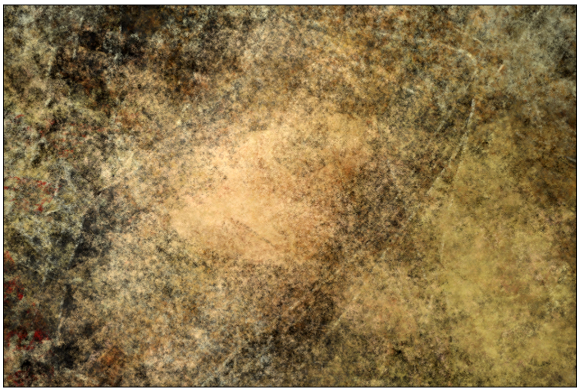

Figure 7: *Abstracted image made from ten different images of a reclining nude figure.*

of producing novel, high-quality artistic renderings. In doing so we demonstrated the power of biologically inspired models and metaphors to create new forms of artist expression. Furthermore, the simple implementation and effective results produced by our system makes a compelling argument for more research using swarm-based multi-agent systems for non-photorealistic rending.

We created our system using a swarm-based MAS, but we are certain that similar results could be produced using another programming methodology. Which begs the question, why use a swarm-based MAS methodology? To answer this we will adopt McCarthy's justification of *intentional* systems that "although a certain approach may not be *required* – it can be *useful* when it helps us to understand and think about systems where a mechanistic explanation is difficult or impossible" [WJ95]. As computer systems become increasingly complex we will need more powerful abstractions and metaphors to explain their operation. This is particularly true in the case of modelling *emergent* phenomenon.

The dynamic nature of our swarm painting system makes it easily extendable to interactive applications. At the time of this writing we are working on a series of interactive installations in which agents are born and populations dynamically change based on input from real-world physical sensors.

In the future we would like to endow our agents with more more biologically inspired attributes and behaviours. More complex movement, feeding, and reproduction strategies will be investigated. In addition, we can extend our current model of an 'aesthetic ideal' to go beyond the colour values of pixels in a target image. Future agent's aesthetic ideal could be be based on other visual elements such as contrast, brightness, and saturation or an agent could have a geometric bias towards creating certain shapes. To explore our system we used a number of Modern Art movements as inspiration for our experiments. Future work will explore the innate and unique qualities of our system. Finally, we would like to create *Aesthetic Agents* that inhabit a 3D world. Groups of agents could be given different 3D models as their aesthetic ideal to create emergent sculptures. Other *Aesthetic Agents* could add *living textures* to the 3D forms.

References

[ABM*03] Aupetit S., Bordeau V., Monmarche N., Slimane M., Venturini G.: Interactive evolution of ant paintings. In *Evolutionary Computation, 2003. CEC '03. The 2003 Congress on* (2003), vol. 2, pp. 1376–1383 2

[AG01] Aftanas L. I., Golocheikine S. A.: Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalised attention: high-resolution EEG investigation of meditation. *Neuroscience Letters 310 (1)* (2001), 57–60.

[AK05] ADAMATZKY A., KOMOSINSKI M.: *Artificial Life Models in Software*. Springer-Verlag New York, Inc., Secaucus, NJ, USA, 2005. 1

[ANW*01] AZARI N. P., NICKEL J., WUNDERLICH G., NIEDEGGEN M., HEFTER H., TELLMANN L., HERZOG H., STOERIG P., BIRNBACHER D., SIETZ R. J.: Neurocorrelates of religious experience. *European Journal of Neuroscience 13 (8)* (2001), 1649–52.

[BD94] BUSSMANN S., DEMAZEAU Y.: An agent model combining reactive and cognitive capabilities. *Intelligent Robots and Systems '94. 'Advanced Robotic Systems and the Real World', IROS '94.Proceedings of the IEEE/RSJ/GI International Conference on 3* (1994), 2095–2102 vol.3. 2

[BHS*07] BOYD J., HUSHLAK G., SAYLES M., NUYTTEN P., JACOB C.: SwarmArt: Interactive Art from Swarm Intelligence. *Leonardo*, vol. 40, no. 3. 3

[BSMG04] BARTESAGHI A., SAPIRO G., MALZBENDER T., GELB D.: Nonphotorealistic rendering from multiple images. *Image Processing, 2004.ICIP '04.2004 International Conference on 4* (2004), 2403–2406 3

[BTD*97] BONABEAU E., THERAULAZ G., DENEUBORUG J.-L., ARON S., CAMAZINE S.: Self-organization in social insects. *Trends in ecology evolution 12*, 5 (1997), 188. 2

[CH03] COLLOMOSSE J. P., HALL P. M.: Cubist style rendering from photographs. *IEEE Transactions on Visualization and Computer Graphics 9*, 4 (2003), 443–453. Compilation and indexing terms, Copyright 2010 Elsevier Inc. 3

[CRH05] COLLOMOSSE J., ROWNTREE D., HALL P.: Stroke surfaces: Temporally coherent artistic animations from video. *IEEE Transactions on Visualization and Computer Graphics* (2005), 549. 3

[DG97] DORIGO M., GAMBARDELLA L. M.: Ant colony system: A cooperative learning approach to the traveling salesman problem. *IEEE Transactions on Evolutionary Computation 1* (1997), 53–66. 2

[Dor05] DORIN A.: *Enriching Aesthetics with Artificial Life*. Artificial Life Models in Software. Springer-Verlang, New York, 2005, pp. 415–431. 4

[EH04] EINSTEIN C., HAXTHAUSEN C. W.: Notes on cubism. *MIT Press Journals*, 107 (2004), 158–68. 6

[GG01] GOOCH B., GOOCH A.: *Non-Photorealistic Rendering*. A. K. Peters, Ltd., Natick, MA, USA, 2001. 2

[Gre06] GREENFIELD G.: On evolving multi-pheromone ant paintings. In *Proceedings of the 7th Conference on Short and Medium Span Bridges* (2006). 2

[HS81] HORN B. K. P., SCHUNCK B.: Determining optical flow. *Artificial Intelligence 17*, 1-3 (1981), 185–203. 4

[HZF10] HUANG H., ZHANG L., FU T.-N.: Video painting via motion layer manipulation. *Computer Graphics Forum 29*, 7 (2010), 2055–2064. Compilation and indexing terms, Copyright 2010 Elsevier Inc. 3

[Irv70] IRVING S.: *Abstract Expressionism. The Triumph of American Painting.* Pall Mall Press, London, 1970. 6

[LMS06] LUO Y., MARINA L., SOUSA M. C.: Npar by example: Line drawing facial animation from photographs. *Computer Graphics, Imaging and Visualisation, 2006 International Conference on* (2006), 514–521. 3

[Mar10] MARINETTI F. T.: Futurist painting: Technical manifesto., April 1910. 6

[McK10] MCKEVER R.: Back to the futurism. *The Art Book 17*, 1 (2010), 66–7. 6

[Mou02] MOURA L.: *Swarm Paintings*. Architopia: Art, Architecture, Science. Institut d'Art Contemporaine, 2002, pp. 5–24. 2

[RA00] RAMOS V., ALMEIDA F.: Artificial ant colonies in digital image habitats - a mass behavior effect study on pattern recognition. In *Proceedings of ANTS 2000 - 2nd International Workshop on Ant Algorithms* (2000), et al Dorigo M., (Ed.), Ant Colonies to Artificial Ants, pp. 113–116. 2

[Rao91] RAO A. S.: Modeling rational agents within a BDI-architecture. *Principles of Knowledge Representation and Reasoning* (1991), 473–484. 2

[RN95] RUSSEL S. J., NORVIG P.: *Artificial Intelligence. A Modern Approach*. Prentice Hall, Upper Saddle River, NJ, 1995. 2

[SGS05] SCHLECHTWEG S., GERMER T., STROTHOTTE T.: RenderbotsâĂŽ A multi-agent systems for direct image generation. *Computer Graphics Forum 24*, 2 (2005), 137–148. 3

[SOD04] SEMET Y., O'REILLY U. M., DURAND F.: An interactive artificial ant approach to non-photorealistic rendering. In *Proceedings, Part I* (Berlin, Germany, June 2004), Genetic and Evolutionary Computation - GECCO 2004. Genetic and Evolutionary Computation Conference, Optimization Machine Learning Group, INRIA Futurs, Orsay, France, Springer-Verlag, pp. 188–200. 3

[Ste09] STERN J.: The arrival of french impressionism in america: California's golden years. *American Artist 73* (2009), 12–16. 4

[TB99] THERAULAZ G., BONABEAU E.: A brief history of stigmergy. *Artificial Life 5*, 2 (1999), 97. 2

[Urb05] URBANO P.: Playing in the pheromone playground: Experiences in swarm painting. *Applications of Evolutionary Computing, EvoWorkshops 2005: EvoBio, EvoCOMNET, EvoHOT, EvoIASP, EvoMUSART, and EvoSTOC LNCS 3449* (2005), 527. 2

[Urb06] URBANO P.: Consensual paintings. *Applications of Evolutionary Computing, EvoWorkshops 2006: EvoBio, EvoCOMNET, EvoHOT, EvoIASP, EvoInteraction, EvoMUSART, and EvoSTOC LNCS 3097* (2006), 622–632. 2

[Urb07] URBANO P.: Mimetic variations on mimetic stigmergic paintings. *Proceedings of EAÃŢ07, Evolution Artificielle, 8th International Conference on Artificial Evolution LNCS, 4926* (2007), 278–290. 2

[WJ95] WOOLDRIDGE M., JENNINGS N.: Intelligent agents: theory and practice. *Knowledge Engineering Review 2(10)* (1995), 115–152. 2, 7