Sleep Paintings by Artificial Ants

Peintures du sommeil par des fourmis artificielles

Carlos M. Fernandes[1]

[1] LARSyS: Laboratory for Robotics and Systems in Engineering and Science, University of Lisbon, Portugal, cfernandes@laseeb.org

ABSTRACT. This paper provides technical and conceptual information on a swarm art project called *Sleep Paintings*. The project consists of a series of colour images generated by an ant-based clustering algorithm operating with sleep data sets extracted from electroencephalogram (EEG) signals. The algorithm was originally proposed for clustering and classification and is described by a simple set of equations that model the local behavior of artificial ants (data samples) in a way that, when travelling on a heterogeneous 2-dimensional lattice of vectors, they form clusters of similar data samples, while changing the vectors of the environmental lattice. The 2-dimensional colored abstract sketches of human sleep described in the paper result from the visualization of the lattice.
KEYWORDS. swarm art, generative, artificial ants, ant algorithms, data analysis, sleep.

Introduction

Swarm art is a term used to describe artworks or ornamental objects that are entirely or partially generated by artificial intelligence models with swarming behavior and emergent properties 0. The concept is a particular case of broader creative practices that bridge art, science and technology, usually described by terms like *generative art* or *digital art*.

Sleep Paintings is a swarm art project that consists of a series of coloured drawings generated by an algorithm whose working mechanisms are inspired by the communication strategies of eusocial insects 0. To create the images, the algorithm uses data from polysomnography signals, like electroencephalograms (EEG), recorded from a series of human subjects with and without sleep disorders. Each image is therefore a kind of visual representation of corresponding patient's sleep.

The algorithm is called KANTS 0 0 and was developed with the objective of analyzing large sets of correlated data: i.e., KANTS is basically a clustering and classification algorithm. Here, we use it exclusively for creative purposes. The data consists of 3-dimensional vectors extracted from sleep EEGs. Following a set of simple rules, the data samples move and self-organize on a grid that we may call, within this context, a *digital canvas*. In order to communicate with each other and attract similar data, the samples change the vectors of the canvas's regions that they visit, making them more similar to the vector they represent. The result is a visual representation of sleep.

Algorithm

KANTS is a population-based algorithm. The population consists of data samples (called *ants*) that move on a grid where each cell is mapped to a vector of real-valued variables. The dimension of the grid's vectors is the same as the data samples. While moving through the grid, the ants change the values of the vectors so that they tend to be more similar to their own values. At the same time, each ant is attracted to areas of the grid where the Euclidean distance between its data sample and the environmental vectors in that particular section is minimized. If the algorithm is properly tuned 0, the population self-organizes into clusters of similar samples. KANTS is a clustering algorithm.

As stated above, the artificial ants of the KANTS algorithm communicate via the environment, while changing that same environment. In nature, this process of communicating through the environment is known as stigmergy 0. Natural ants, for instance, use a chemical substance that they secrete, called pheromone 0, to attract mates, signal danger or provide clues to other ants about a specific location. In KANTS, the pheromone is the grid vector's values. Hence, the grid of vectors is a kind of *pheromone map*, shaped by the ants throughout the whole process.

In our exploration of KANTS as a swarm art tool, the maps are used for generating 2-dimensional colored images in the RGB system. The vectors are directly translated to the R, G, and B values (three-variable data samples are used here, which makes it easy to translate the values into RGB images, but other forms of translating vectors to RGB can be devised). Since the ants tend to cluster, thus changing the values in that region, it is expected that the pheromone map, after a certain number of iterations, shows non-random patterns.

The algorithm works as follows.

The grid vectors are initially set to random values uniformly distributed in the range $[0, 1.0]$. Then, the ants are randomly placed on the grid (after their vectors are also normalized within the range $[0, 1]$). In each iteration, each ant is allowed to move to a different cell of the habitat and modify that cell's vector values. The ants movements are described by sing equations 1 and 2, taken from Ant System 0.

$$w(j) = \left(1 + \frac{\sigma}{1 + \delta\sigma}\right)^{\beta} \quad [1]$$

$$P_{i \to j} = \frac{w(\mathrm{j}).\,\mathrm{r}(\mathrm{j})}{\sum_{j \in M} w(\mathrm{j})} \quad [2]$$

Equation 1 measures the relative probability of moving to a cell j with pheromone density σ. The parameter β ($\beta \geq 0$) is associated with the osmotropotaxic sensitivity, recognized by Wilson 0 as one of two fundamental types of an ant's sensing and processing of pheromone and related to instantaneous pheromone gradient following. In other words, parameter β controls the degree of randomness with which the ants follow the gradient of pheromone.

Parameter δ ($\delta \geq 0$) defines the sensory capacity $1/\delta$, which describes the fact that each ant's ability to sense pheromone decreases somewhat at high concentrations. This means that each ant eventually moves away from a trail when the pheromone reaches a high concentration.

Equation 2 models the probability of an ant moving from cell i to a specific cell j that belongs to the Moore neighborhood (M) of i: $P_{i \to j}$, defined after a discretization of time and space, is the probability of moving from cell i to j; $w(j)$ is given by equation 1 and $r(j)$ is set to 1 if the cell j is within the Moore neighborhood (with range $r1$) and 0 otherwise. The pheromone density σ in equation 1 is defined as the inverse of the Euclidean distance $d(\vec{v}_a, \vec{v}_c)$ between the vector carried by ant n $\vec{v}_{an}$ and the vector in cell (i, j) at time-step t, $\vec{v}_{cij}(t)$ – see equation 3. That is, the shorter the Euclidean distance is, the more *intense* is the pheromone level.

$$\sigma = \frac{1}{d(\vec{v}_{an}, \vec{v}_{cij}(t))} \quad [3]$$

With these rules, ants tend to travel to cells that are mapped to vectors which are "closer" to their *own* vector. The ants update the vector in the cell where they are currently on, plus the vectors in the cell's Moore neighborhood (with a user-defined range $r2$) according to equation 4, where $\overline{D}$ is the average Euclidean distance between the data vector and the environmental vectors in its Moore neighborhood. This is the equation that modifies the environment and, ultimately, generates the images.

$$\overrightarrow{v_c}(t) = \overrightarrow{v_c}(t-1) + \bar{D}(\overrightarrow{v_a} - \overrightarrow{v_c}(t-1)) \quad [4]$$

The grid vectors are all evaporated in each time-step. Evaporation is done by updating the vectors with Equation 5, where $k \in [0{,}1.0]$ (usually a small value, in the range $[0.001, 0.1]$) is the evaporation rate and $\overrightarrow{v_{\iota c}}$ is the vector's initial state (at $t = 0$). Basically, the evaporation step "pushes" the vectors towards their initial values.

$$\overrightarrow{v_c}(t) = \overrightarrow{v_c}(t) - k.(\overrightarrow{v_c}(t) - \overrightarrow{v_{\iota c}}) \quad [5]$$

Finally, a probably test restricts the movement of the ants: an ant only moves if a random value uniform.ly distributed in the range [0,1] is above a probability value p:

$$p = (1/neigh)^2 \times d(neigh) \quad [6]$$

where $d(neigh)$ is the averaged Euclidean distance to the neighbors and $neigh$ is the number of ants in the neighborhood (Moore with range 1). If there are no ants in the neighborhood except the ant itself, $d(neigh) = 1$. This rule promotes the immovability of ants adjoining similar ants. The pseudo-code of the algorithm is given by Algorithm 1.

Algorithm 1: KANTS

1. Initialize an array $N \times M \times d$ with random values in the range [0, 1], where $N \times M$ is the size of the habitat and d is the dimension of the data samples
2. Store n data samples in an array of size $n \times l$, $ants[n][l]$, where l is the number of variables of the vectors.
3. Distribute the ants randomly on the environment.
4. For each ant do:
    5. Update habitat (grid) vectors: apply equation 4 to the vectors in the Moore neighborhood (range $r2$) of the ant.
    6. Determine $neighbors$ (number of ants in neighborhood, with range 1), average distance to neighbors and average distance to the neighboring cells.
7. For each ant do if random[0,1] < p (p is defined by equation 6):
    8. Compute $P_{i \to j}$ for each possible destination cell (not occupied and within the Moore neighborhood with range $r1 = (0.5 \times N)/neighbors$).
    9. Decide where to go by *roulette wheel* selection. Move to selected cell.
10. For each cell in the environment evaporate pheromone: apply equation 5 to the vector in the cell.
11. If stop criteria not met return to 4.

Sleep Paintings

Sleep is a state of reduced and filtered sensory and motor activity, within which there are different stages, each one with a distinct set of associated physiological and neurological features. The correct identification of these stages 0 is very important for the diagnosis and treatment of sleep disorders. However, sleep classification is not completely standardized. Usually, sleep experts make the classification by visual methods, i.e., they analyze the signal and then, according to its patterns in a specific time period, they decide in which stage the patient was in that precise period. However, such method is time-consuming and prone to errors. Hence, it is very important for biomedical sleep research to devise methods to extract the proper information that is later used for classification.

Hjorth 0 proposed a method for extracting three parameters from EEG signals. The first is a measure of the mean power representing the *activity* of the signal. The second, called *mobility*, is an estimate of the mean frequency. The third estimates the bandwidth of the signal and represents *complexity*. The main advantage of this method is its low computational cost when compared to others. Furthermore, the time-domain orientation of this representation may prove suitable for situations where ongoing EEG analysis is required.

Our choice of the Hjorth parameters is merely practical: the three variables can be directly translated into RGB values, generating the desired 2-dimensional representation of sleep. Other extraction methods and features have been used when testing KANTS as a possible clustering algorithm for an automatic classifying system. However, for the present work, we are only concerned with the visual patterns displayed by the environmental grid (or pheromone map) and the Hjorth features are well suited for this purpose. Another possibility is to compute the mean power of the EEG, electrooculography (EOG) and electromyography (EMG) signals and create also 3-dimensional data vectors.

Real data from five adult sane patients and babies were used. Each recording is approximately 8 hours long, divided into 30 seconds epochs. The EEG signals were analyzed and each epoch classified within one of the R&K classes 0 by a medical expert team. Then, the Hjorth parameters were extracted or the mean power of the EEG, EOG and EMG were computed and the files with the parameters corresponding to the EEG signals of each patient were created. Each vector is labeled with the class assigned by the experts. Since there are three parameters in the data set, the ants are described by $\vec{v}_a = (v_{a1}, v_{a2}, v_{a3})$.

Parameters ρ and δ are set to 32 and 0.2. These values are in the range of the parameter space that in 0 puts the system in the self-organized state. Parameters $r1$ and k were adjusted until the results were satisfactory (considering the subjective opinion of the author). Range $r2$ remained fixed ($r2 = 2$) through all the experiments. Finally, probability p in Equation 6 was set to 1.

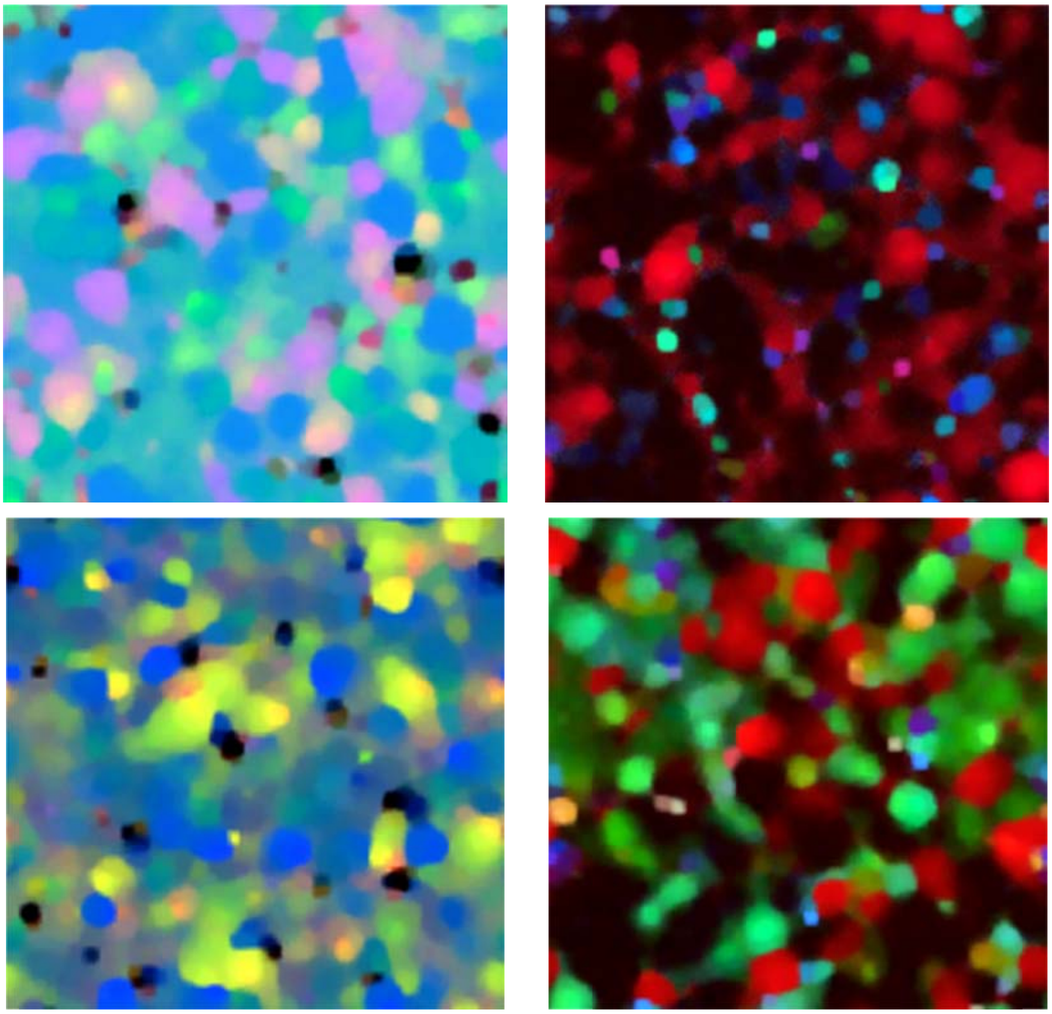

Fig. 1. *Images generated by sleep data of four different patients*

The algorithm stops after 50 iterations and the environmental lattice at $t = 50$ is used to generate the images in the RGB format. Each set of values is stored in 200×200 arrays, each one being the source for creating an RGB image.

KANTS habitat size is set to 200×200. Given the size of the data sets, the suggested ratio between grid size and number vectors 0 generates images too small to be properly visualized and valued. Therefore, input files of each patient's data with 10 copies of each sample were created. Some of the results are in Fig. 1.

It is clear that each night's data set generates unique drawings, even if there are common features to all of them. However, each one shows unique patterns and major differences are also observed, namely in the dominant color of the drawings. These colors are related to the dynamics of the sleep and distribution of sleep stages.

Sleep data showed to be an alluring raw material for swarm art. Since the ants tend to cluster, thus changing the values in the clustering region, it is expected that the pheromone map, after a certain number of iterations, shows non-random patterns, like a kind of a fuzzy patchwork. In addition, the stochastic nature of the process and the size and range of the data samples, make these *sleep signatures* unique, not only for each patient, but also for each night's sleep. The resulting *pherogenic* paintings not only represent an interesting imagery related to human sleep, but can also be a basis for a conceptual framework for artists and scientists to work with.

For long, sleep was a mysterious state that science and philosophy tried to study and interpret. In addition, dreams, an inseparable feature of the human sleep, added a mystic aura to this physiological state. Having the opportunity of generating representations of a night's sleep with a novel bio-inspired and self-organized algorithm is surely inspiring. Furthermore, the whole process is based on a kind of distributed creativity, i.e., the drawings are in part generated by the person/patient, since the data samples shape the environment, and in part created by the swarm and its local rules, from which global and complex behavior emerges. Our proposal to *Art&Science in Evolutionary Computation* is to collect and present several sleep paintings in a large grid, as shown in Fig. 2.

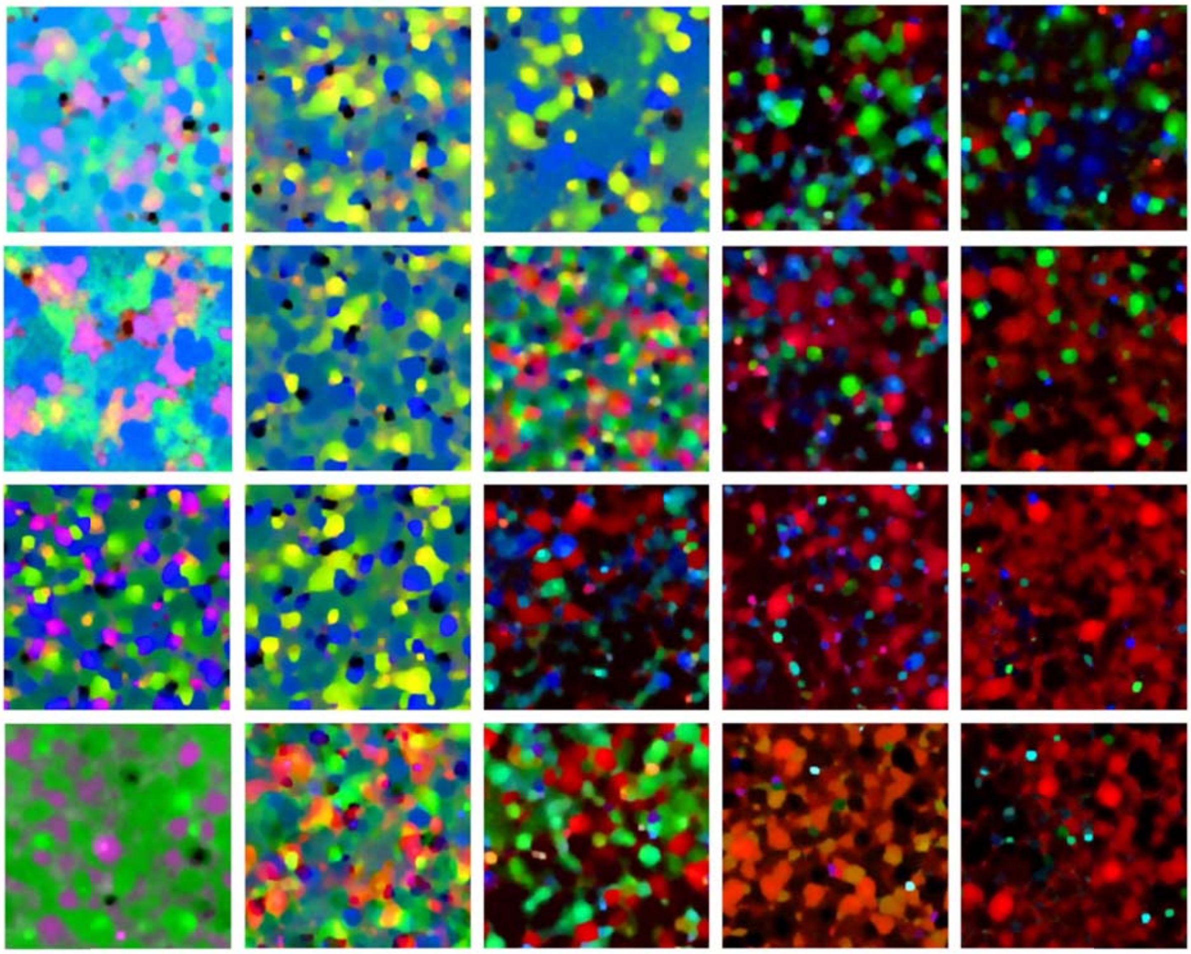

Fig. 2. *Sleep Paintings by Artificial Ants, 2017*

Conclusions

KANTS is an ant-based algorithm for data clustering and swarm art. The algorithm generates clusters of data samples by letting those samples (ants) travel through a heterogeneous environment. The ants communicate via the environment and modify it. The idea is to use the resulting environment (pheromone maps) to create 2-dimensional color representation of data sets. Previously, this concept has been used to create *Abstracting the Abstract*, for which chromatic information from historical abstract paintings was used to feed the algorithm and generate reinterpretations of those same paintings – see Fig. 3. *Abstracting the Abstract* received positive feedback from the community, winning the 2012 *Evolutionary Art, Design and Creativity Competition* of the *Genetic and Evolutionary Computation Conference* 0.

This paper describes another swarm art experiment with KANTS. In this case, sleep EEG data are used. The resulting images are aesthetically interesting, with dynamic patterns and colors that spread through the canvas in a balanced way. They also have the interesting characteristic of being unique representations of a night's sleep. Furthermore, they are the result of a distributed creativity, between the sleep patient, the person that tunes the algorithm and the swarm.

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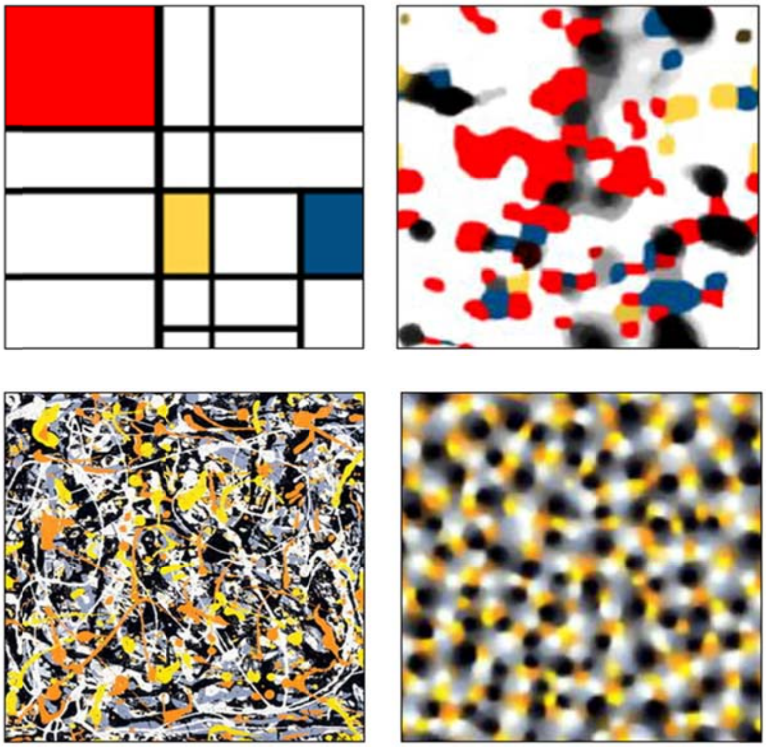

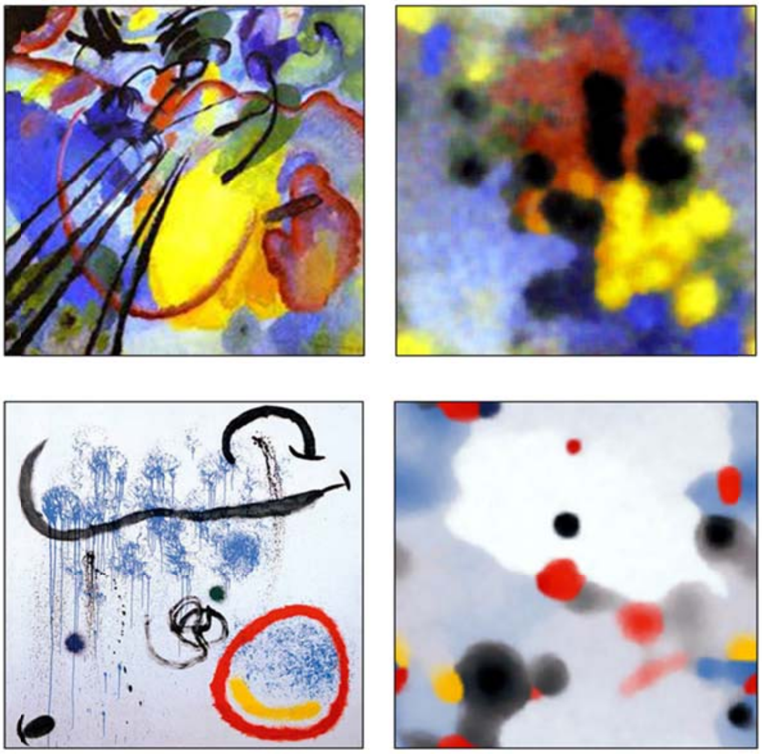

Fig. 3. *Abstracting the Abstract, 2012. From top to bottom (left): Mondrian's Composition in Red, Pollock's Number, Kandinsky's Improvisation, Miró's The Birth of Day III. On the right: corresponding images generated by KANTS.*

About the author

Carlos M. Fernandes was born in Luanda in 1973 and works and lives in Lisbon. He is a photographer and a research scientist. He studied photography at Ar.Co (1994-96), in Lisbon, and since 1996 he participated in several group and solo photo exhibitions. In 2009, Fernandes completed his PhD on bio-inspired computation and in recent years he has been bridging his research on artificial biological systems with his interest and practice in photography. In 2012, he won the *Evolutionary Art, Design and Creativity Competition* of the *Genetic and Evolutionary Computation Conference*. He published almost 100 scientific papers, in journals, books and conference proceedings.

His work was presented in art and science exhibitions, namely *I-S-T 95-75-15* (Lisbon, 2006), *Atlas* (Lisbon, 2007), *INGenuidades – Photography and Engineering 1846-2006* (Lisbon and Brussels, 2008), Inside [Art and Science] (Lisbon, 2009), *Da Cartografia do Poder aos Itinerários do Saber* (Coimbra, 2011) and *Ephemeros* (Lisbon, 2013). He published the photobooks *Kaluptein* (2001), *I-S-T 95-75-15* (2006) and *Quia in Inferno Nulla est Redemptio* (2009). Teaches photography and history of photography since 1996. Co-founder of *a Pequena Galeria*, photography gallery in Lisbon. Consultant for *P4*, art and photography dealers, in Lisbon.