Swarm Intelligence: A Novel and Unconventional Approach to Dance Choreography Creation

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Abstract

Swarm intelligence (SI) is a class of Artificial Intelligence (AI) algorithms inspired by the collective behavior of social insect colonies. At its core lies the property of self-organization, namely, the emergence of spontaneous order from the local, decentralized interactions of relatively simple agents. Beyond its traditional AI and engineering applications, among which Swarm Robotics stands out, SI principles have found resonance in the artistic field. However, the link between SI and creativity—the driving force of all artistic processes—has not yet thoroughly explored. This paper aims to bridge the gap between Swarm Intelligence and artificial creativity in the context of dance choreography creation. To this purpose, this paper proposes a starting approach for the automatic generation of dance choreographies for artificial agents driven by Swarm Intelligence mechanisms, along with the presentation of a paradigmatic case study.

Keywords

Swarm Intelligence, Dance Choreography, AI Creativity, Dancing Agents

1. Introduction

The natural world has always been a source of inspiration for designing (groups of) intelligent artificial agents, i.e., endowed with interesting cognitive capabilities. Swarm intelligence (SI) is the epitome of the close connection between biological and artificial systems when the emergence of collective intelligence from groups of simple agents is looked for [1]. Indeed, social insect colonies—bees, wasps and termites—carry out collective activities such as foraging, nest building and cooperative transport despite their simplicity and limited cognitive capabilities [2]. The colony as a whole shows a much higher level of intelligence and complexity than each individual insect that makes up the colony. The explanation for this complex collective behavior, despite individual simplicity, lies in the principle of *self-organization*. It is the collective efforts and multiple direct and indirect interactions among the relatively simple lower-level components that enable the emergence of structures at the global level and, in turn, the ability to perform complex tasks, far beyond the capabilities of the individual component.

The outstanding properties of self-organizing insect colonies—such as distributed computation, fault tolerance and scalability—have provided inspiration for engineering applications. Indeed, engineers are intrigued by the prospect of designing artificial systems capable of exhibiting these properties. One of the successful incarnation of SI principles in engineering is Swarm Robotics [3]. In this field, robots are usually equipped with limited computational, sensing and action capabilities, and the designer (human or artificial) tries to find the local rules of control that guide the robot behavior and its coordination with the other robots in order to orchestrate the self-organization of the whole swarm and thus achieve the desired collective behavior [4, 5, 6, 7]. A swarm operates autonomously, without following a leader robot or the instructions of a centralized entity. Typical tasks in swarm robotics are: pattern formation, aggregation, cooperative transport, coordinated movement and self-assembly, just to name a few.

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Not only scientific disciplines, but also the humanities and arts have been influenced by the metaphor of social insect colonies [8]. The fairy tale “The Snow Queen” written by Hans Christian Andersen in 1844, tells of a swarm of snowflakes resembling colonies of bees that ultimately leads, in Kay’s imagination [1], to the emergence of a female figure, the snow queen indeed. The process that leads to the appearance of the snow queen described by the writer follows SI principles: the multiplicity of snowflakes and their swirling movements produce a higher-level organized structure that cannot be ascribed to individual snowflakes.

Brandstetter [8], again, reports two noteworthy examples of the application of swarm metaphor in human-created dance choreography. A first exemplification of the swarm phenomenon in dance can be found in the “ Waltz of the Snowflakes” in the classical ballet “The Nutcracker”. Another dance choreography that reifies SI principles can be found in the contemporary play entitled “Verosimile” by Thomas Hauert [2].

Despite the numerous applications and remarkable properties of SI, the connection between SI and (artificial) creativity remains largely unexplored. In the SwarmArt project [9, 10], some attempts have been made to combine these two disciplines. However, although SI models are used as basic building blocks, the creative process is mostly left to the human observer. SI models and evolutionary algorithms have been combined to design artificial agents capable of self-organizing into choreographed swarm patterns. Participants, through video interaction, are directly involved in the interactive installations in a collaborative creative feedback loop: the swarm installation constantly detects the human’s position and directs its movement toward him/her.

Current techniques inspired by artificial intelligence are successfully applied to reproduce human behavior, such as written and spoken language, autonomous driving and facial recognition just to name a few examples. However, in the field of creativity and particularly in the performing arts—although there are notable exceptions especially in dance with robots [11, 12, 13, 14, 15] and in music generation [16, 17]—these approaches suffer from a lack, or partial lack, of novelty and improvisation in relation to and in agreement with (syntactically and semantically) the human performance they are supposed to replicate. These aspects prove to be of paramount importance for the success and good evaluation of a performance, whether performed by humans or artificial agents. This is where swarm intelligence inspired techniques can play an important role, given their aforementioned properties and their tendency towards self-organization, which surprises even the most experienced human designer.

In particular, automatic dance creation is a field of AI application in which we need to study and analyze emergent behaviors in groups of agents that need to globally follow the rhythm of the music by build common positions, but also to coordinate the behavior of the single agent by (e.g.,) avoiding mistakes in the dance routine. For these reasons, this paper aims to bridge Swarm Intelligence and artificial creativity in the context of dance choreography creation. So, this work proposes a new starting approach for the automatic generation of artificial agent choreography driven by swarm intelligence.

This article is organized as follows: Section 2 discusses the motivations why the creative process of artificial dance choreography could benefit from the principles of swarm intelligence; Section 3 describes the general scheme for automatic choreography generation along with a paradigmatic case study under development; finally, Section 4 highlights open issues and the future direction of the outlined approach.

2. Motivation

Many works on creativity and artificial intelligence [18, 19], emphasize the concepts of novelty and surprise in the creative idea creation process. We argue that artificial systems employing Swarm Intelligence principles, while not symbolic, have the potential to generate creative outcomes. Indeed, multi-agent systems driven by SI models can autonomously explore—in a way that is unpredictable in every fine detail—the space in which they are located and, at the same time, give rise to emergent and

[1]Kay is the little boy friend of Gerda, the main protagonist.
[2]https://zoo-thomashauert.be/en/projects/19/verosimile

self-organizing higher-level structures not present in the initial components of the system, and thus new and possibly not envisaged by one who is observing the system's dynamics.

Dance is a complex performing art whose basic concept is movement, either improvised or codified by a choreography. Whether improvised or prepared, the movements or their ensemble are the more appreciated by the audience the more creative they appear to their eyes. In addition, it is usually performed with musical accompaniment. For these reasons, it is an optimal application domain for testing Swarm Intelligence principles and the automatic generation/evaluation techniques that will act upon them.

However, just as from an engineering perspective Swarm Intelligence does not aim to faithfully mimic the dynamics of insect colonies, but is rather interested in understanding the general mechanisms that generate collective behavior in insects, SI in choreography creation does not aim to replicate the creation process adopted by choreographers in the art of dance, but offers novel possibilities and a different perspective to the creative process itself, under a different perspective.

Some dancing projects[3] performed by human dancers, embody and exemplify perfectly the possibilities that SI can unlock in the field of performing arts. It can confer to performances properties such as improvisation and the emergence of novelty, properties that are notoriously difficult to confer through classical artificial intelligence techniques in the field of creativity. These properties can be appreciated in the 'Verosimile project' video [4], that is one of the aforementioned projects, and the sequence of screenshots captured from it and shown in Figure 1. Through the dance and music used, the relationship and the interplay between individual and group is highlighted. The seemingly random and oscillatory movements of performers gradually synchronize in time and space and result in recognizable spatial figures such as lines and circles. *All this takes place without the presence of a leader to follow or commands provided by the choreographer.* Voluntary and involuntary movements, such as errors, are amplified or dampened by the group of dancers, and the visual result is continually unpredictable to the observer. Indeed, the viewer of this dance, like one who observes social insect colonies, witnesses the transition from the "apparently" uncoordinated dynamics of individual dancers to the formation of coherent group structures.

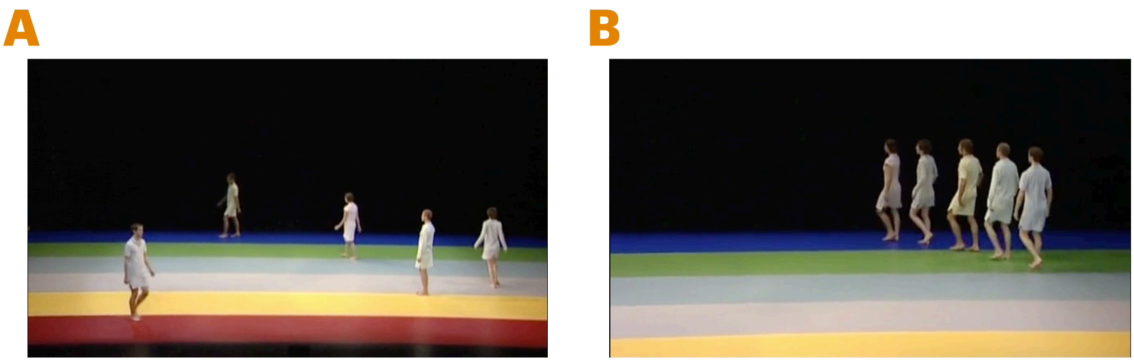

Figure 1: Two screenshots from the video of the dance performance performed as part of the Verosimile project. The figure **(A)** represents a moment in which the dancers move randomly, while **(B)** depicts a moment in which a dynamic and coherent group structure emerges.

To sum up, the motivations behind the combination of Swarm Intelligence and dance choreography in artificial systems are summarized below.

[3]https://zoo-thomashauert.be/en/projects
[4]https://vimeo.com/44176946

1) Unconventional Approach to Dance. The adoption of the principles of Swarm Intelligence for choreographies creation represents an innovative and unconventional methodology in dance and can bring a breath of fresh air to this art. In addition, it can fulfill the role of inspiration for human dancers and choreographers, expanding the boundaries of traditional human creative thinking and inviting new perspectives of artistic expression. Indeed, that of swarm dynamics represents a whole *new artistic language* that has yet to be explored. An example of the potential of a human swarm performing a choreography in the spirit of "the whole is greater than the sum of its parts" is the performance made by the group "Murmuration" [5]. Swarms of artificial agents can take on the role of dynamic dance figures and abstract shapes reminiscent of certain dance step sequences.

2) Complexity from Simplicity. Swarm Intelligence exploits the production of complex self-organizing behaviors from simple agents. For choreography design in artificial systems, self-organization is an appealing property. At the same time it poses new challenges and difficulties, especially in automatic evaluation of swarm behavior. Indeed, in addition to the difficulty arising from the evaluation of what is creative or not, self-organization is by its very nature elusive and not easily captured or controlled. In dance, the *decentralized coordination* nature of insect colony provides a whole new perspective for choreographers, allowing them to explore new avenues and move away from traditional norms.

3) Collaborative Feedback Loop. Users/observers can actively participate in the simulation of the dancing swarm, thus becoming full-fledged dancing composers. Indeed, they can initiate a collaborative feedback loop with the evolving choreography, influencing the process of creating the choreography itself, which in this way would become extemporaneous, unrepeatable and story-dependent. In addition, the aesthetic perception of swarm dynamics can have a new declination as *visual art*, thus falling into the realm of science-inspired art installations, such as the Swarm Art project. In the context of visual art, musicians could also visually test the "impact" of their musical composition through interactive simulations. Indeed, music can perturb the choreography of agents, causing a dynamic reorganization of the swarm during the unfolding of the musical track.

4) Alternative to Classic AI Techniques. Automatic dance design using the principles of swarm intelligence represents a radical paradigm shift from what is now the state of the art in AI and creativity, mostly addressed through symbolic techniques [12]. With SI, the focus will not be on the fine planning of movements and constraints to be met by the individual, but on the local rules that govern agent-dancers and the effects of these on the whole swarm. SI-based approach is proposed as an alternative to symbolic AI techniques and, where applicable, as a complementary technique to them.

3. Proposed approach

The approach we propose to address the problem of automatically creating dance choreographies for artificial agents guided by Swarm Intelligence principles, is summarized in Figure 2. Below, we describe each macro-phase of the proposed approach.

Music Track. As mentioned in the previous sections, a dance choreography is based on a sequence of (human) movements that play along with, highlight and emphasize the musical track played. Therefore, the first module of the choreography generation process is represented by the music track choice. The song will perturb the autonomous dynamics of the swarm of artificial agents, causing its continuous dynamic reorganization. This can bring out metastable spatio-temporal shapes/patterns of the swarm of agents that resemble—to the eyes of human observers—some elementary but essential forms of dance choreography.

[5] https://murmuration-lespectacle.com/en/americas-got-talent-2/

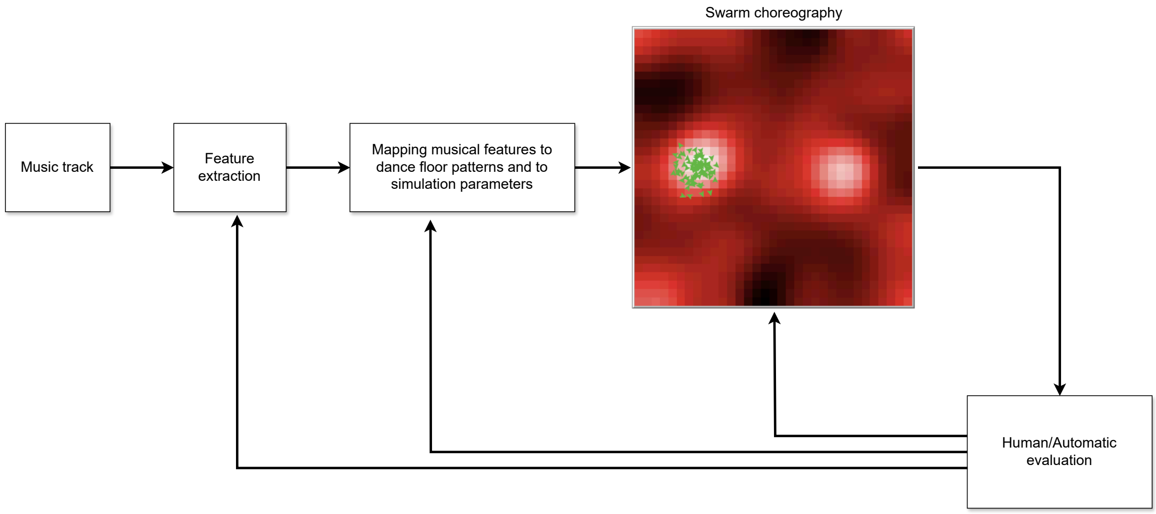

Figure 2: Schema of the relationships between the macro-phases of the proposed approach.

Features Extraction. The feature extraction phase refers to the process of transforming the data contained in the selected music track into numerical features, in a format suitable to be processed by the subsequent stages of the approach. This first involves the identification and extraction of musical characteristics such as melody, harmony, rhythm, tempo (i.e., the BPM value), dynamics, structure and ornaments of the musical composition. This component then involves the computation of composite, derived and pre-processed musical features, based on previously extracted information. An example of composite features are those calculated by applying Information Theory measures to the notes that compose each bar. As can be seen from the scheme of the approach, the parameters of this module can be subject to adjustment and refinement based on the evaluation given by human or automatic evaluators.

Features Mapping. The feature mapping component refers to the process that produces the set of rules that binds the extracted (composite) musical features to the simulation parameters that regulate the agents' dynamics. These rules act on the parameters of Swarm Intelligence models, thus changing the agents' local rules and consequently their macro-properties. In addition, they can act on the environment in which the agents are immersed and act. In the latter case, by analogy with dance, we can say that they act on the characteristics of the dance floor. The dance floor, in turn, modifies the observable emergent properties of the swarm.

The possibilities for implementing mapping rules range from simple hand-coded mappings to general and versatile machine learning models such as neural networks. The latter possibility is also the most interesting, as it offers the possibility of combining machine learning models and automatic design. Indeed, automatic procedures, such as evolutionary algorithms, can act on the parameters of machine learning models to improve the choreography produced by swarms, also considering the result produced by the evaluation phase.

Swarm Choreography. This is the module where the dance choreography of the agents takes place, i.e. where the dynamics of the group of agents driven by Swarm Intelligence models unfolds. This will be the component to which the (human) observer will turn his attention, observer who may have the opportunity to actively interact with the agent's simulation, in the spirit of the "collaborative feedback loop" concept. The overall dance choreography is the product of superposition of the *(i)* autonomous dynamics of each agents, *(ii)* the autonomous dynamics of the dance floor and *(iii)* the perturbations arising from the music track, which act on the parameters of both the agents and the dance floor.

Dance Evaluation. Determining criteria for objectively assessing dance choreography is a challenging task [13]. There are examples of metrics for evaluating the qualitative aspects of human dance choreographies, such as [20], but being a new topic nothing has yet been proposed for artificial dancing agents. As can be noted by the scheme in Figure 2, this phase involves both automatic and human evaluations of the produced dance choreography. At present, indeed, an aesthetic evaluation of human is indispensable for an evaluation of the degree of creativity achieved by an artificial system. For automatic evaluation, one can draw inspiration from the metrics used as objective functions for evaluating robots in classic Swarm Robotics tasks, cohesion, separation, coverage and clustering measures are just a few examples. The feature extraction and mapping components can be tuned according to human and automatic evaluations on the creative level and aesthetic enjoyment of the choreography; this influence is represented by the arrows that originate from the dance evaluation block. The arrow from the latter block to the swarm simulation component deserves special attention, because, as already mentioned, an observer can act directly on the simulation of the agents, and thus on the choreography: thus initiating a creative loop in which the observer is influenced by what the swarm produces and, in turn, acts to modify its dynamics in order to make it more aesthetically pleasing.

3.1. A Paradigmatic Case Study

Here we present the paradigmatic case study that we are developing to test the proposed approach. Although the case study is still under development, some of the main modules of the approach have already been implemented and can therefore provide a means to begin evaluating the effectiveness and feasibility of the proposed approach. In the following sections, therefore, we will review the technologies employed and the design choices we made concerning the creative process mediated by the swarm intelligence algorithms.

3.1.1. Technologies

Given the requirements imposed by SI algorithms—swarms of agents, direct and environment-mediated interactions, etc.—and our need to rapidly prototype new ideas and mechanisms, we chose NetLogo [21] as modeling environment. It has the ability to quickly simulate different types of multi-agent system models and a programmable environment, which takes the form of a 2D or 3D grid, in which basic SI concepts, such as food sources, can be mapped naturally. More, it offers a simple graphical interface that allows the observer to interact with the simulation. Lastly, it is open source and it offers interoperability with other languages (e.g., Python).

With regard to the implementation of the first module, we chose to use MIDI files as the format for music tracks. MIDI files offer a symbolic musical notion easily interpreted with the help of libraries in all major programming languages.

As for the feature extraction phase, the library *Mido (MIDI Objects for Python)* [6] was used. In more detail, at the state of the art in the development of the case study, based on the time information and time signature of the selected piece of music, we divided the information contained in the MIDI file into bars (i.e., segments of time defined by a certain number of beats, also called measures). Thus, for each beat that composes the music track we can keep track of, for example, the number of notes and the volume at which they are played. After that, this information can be processed to construct, as mentioned in the previous section, composite musical features. Examples of composite features are those derived from applying the Shannon entropy of the notes in each beat or their average volume; these can then dynamically control the parameters of the SI algorithms and the characteristics of the environment in which the agents will perform their dance choreography. In this way, this process creates a swarm of agents that follows the dynamical specificities of the song, such as intensity, pauses,

[6] https://mido.readthedocs.io/en/stable/

melody and rhythm, notoriously of high impact for a human observer. Overall, therefore, it will help the creative process to create a dance choreography that matches the emotional dynamics characteristic of the selected song. Finally, during the simulation of the choreography, the music track is played using the *Pygame* python library [7].

3.1.2. Design of Choreography Creation Process

The design phase of the choreography creation process focuses mainly on two components: the environment in which the agents will move and the algorithms that will guide the agents' movements.

The dance floor concept—i.e., the environment in which the agents-dancers move—has been modeled as a dynamic fitness landscape whose changes will follow the salient (extracted) features of the song. Its local maxima—i.e., the food sources in swarm intelligence terms—represent significant spots for agents' choreography. Therefore we use the food sources as "focal point of attraction" [9, 10] for the agents. To implement the dance floor with its food sources, a real value was assigned to each patch that constitutes the 2-D NetLogo world and colored accordingly. A composition of food sources, in turn, represents a dance basic choreographic pattern [8]; examples of implemented food sources patterns are shown in Figure 3**(A)**. At the end of each bar of the musical track, the pattern of food sources changes. Considering the entire duration of the music piece, this results in a sequence of patterns that form the entire dance choreography for the agents to follow. At present, the food source pattern at the end of each bar is chosen in a random fashion, but in the long-term the pattern will be chosen according some features of the song. As the configuration of the dance floor changes over time depending on the characteristics of the music track, an additional parameter controlling the memory of the particle performance became necessary. Memory—complementary to the introduction of noise—has a twofold aims: (i) allows particles to adapt to changed dance floor, and (ii) not to settle down on possible local maxima and look for more promising spots.

Regarding the basic movement mechanisms that guide the agents, we chose to combine contributions from different algorithms. For now, agents are guided to patches with higher values, i.e., food sources, by Particle Swarm Optimization (PSO), taking into account the global and local optimal position of the swarm[22, 23]. At the same time, they dynamically aggregate following the principles of the Ant Colony Optimization algorithm [24, 25]. For this purpose, we introduced an additional vector representing the attraction to the pheromone trace. Each particle continuously leaves a pheromone on the patches and can sniff it out and follow it, at a parameterized variable distance. In addition, we implemented an agent-dance floor interaction that take the form of consumption of the values assigned to the patches, see Figure 3**(D)**. Particles continuously consume the dance floor and, from the point of view of dynamical systems theory, perturb the possible metastable state achieved, thus causing the need for particles reorganization.

The code of the developed NetLogo application along with some demo videos in which one can appreciate the dance dynamics emerging in an initial prototype of this system can be found at the following link (https://github.com/mbraccini/Swarm-intelligence-dance-choreography). By observing the emergent choreographies of the particles of this first prototype, the following macro-behaviors and properties can be appreciated: *(i)* the tendency to aggregate on food sources, dividing the population into different clusters whose characteristics are dynamically determined by the simulation parameters, and in turn, by the musical features; *(ii)* flexibility, which takes the form of the richness of the bouquet of qualitative behaviors the SI algorithms allow particles to express; *(iii)* robustness, as even if perturbed, the particles tend toward the food source patterns, thanks to the introduced memory and noise components; *(iv)* thanks to the introduced mapping between the musical features and the simulation parameters, the visual impression that the movement of the particles actually follows the musical one; *(v)* so, in general, a tendency towards self-organization modulated by the musical features, self-organization that will be

[7] https://www.pygame.org/news

[8] The performance of 15,000 drones creating a moving Chinese dragon (https://youtu.be/ycCtRWL8MCI?si=TapTdwFpLAlRK-6f) served as inspiration for the idea of using the composition of food sources as the basic choreographic movement of the agents' dance.

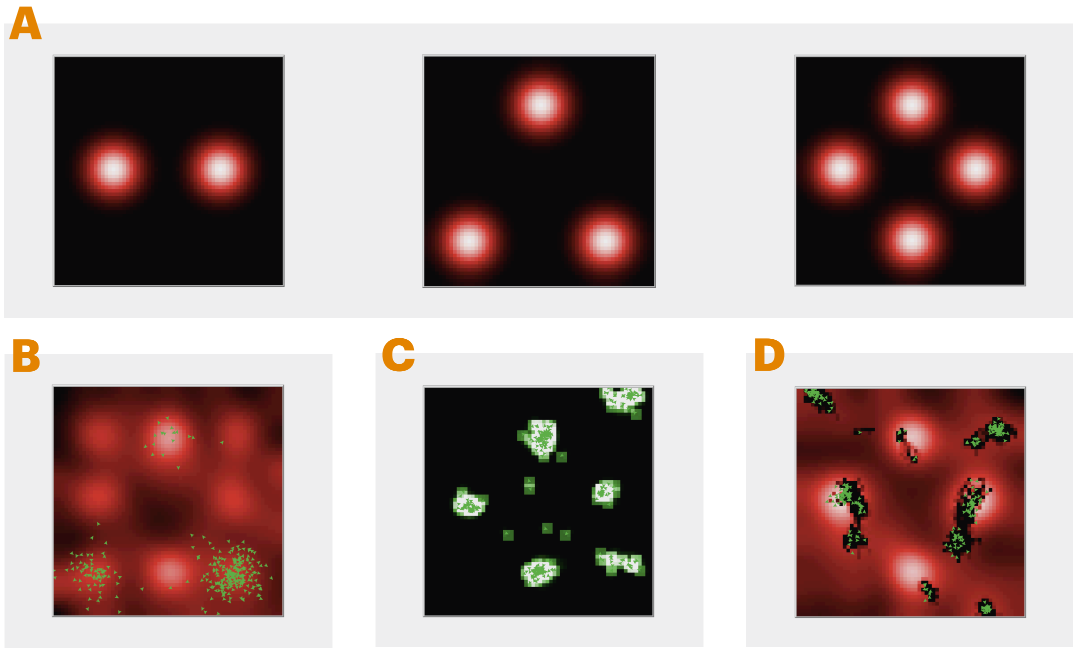

Figure 3: Representation in the 2-D NetLogo world of the basic concepts and mechanisms implemented in the case study. **(A)** Three kinds of basic choreographic patterns implemented in the case study, each of which is a composition of the swarm intelligence concept of food sources. Each food source is represented as a circle in a red-to-white gradient. **(B)** Representation of the dynamics generated by the mechanism governed by the Particle Swarm Optimization algorithm. **(C)** Type of agents' behavior produced by the Ant Colony algorithm. **(D)** Representation of the mechanism of consumption of the dance floor by agents.

subject to automatic design and automatic and human evaluation in the future.

4. Conclusion & Future Works

In this paper, we first presented the reasons why Swarm Intelligence can play an important role in generating creative works and thus dance choreographies. Secondly, we proposed a methodological approach for the creation of dance choreographies for multi-agent systems guided by the mechanisms underlying SI. Finally, we tested the proposed approach on a paradigmatic case study making use of the NetLogo modeling environment and agents mainly driven by the basic principles of the PSO and ACO algorithms.

Future work will be devoted to adding further SI mechanisms, with the aim of creating a bouquet of possible basic behaviors upon which automatic design techniques can act to create increasingly creative and complex agent choreographies. In addition, an attempt will be made to automate the choice of the parameters of the mechanisms that regulate the movement of the agents and the dance floor based on objective and subjective (coming from the human observer) performance evaluation criteria. The definition of objective dance performance evaluation criteria is an open issue that deserves further investigation, partially addressed in [11] for scenarios involving dancing robots. About the cooperation between the observer and the choreography creation process (human-in-the-loop), we also allow the observer to dynamically alter the parameters of the simulation to continuously influence the aesthetic performance of the choreography.

Finally, similar to robotic contexts involving online adaptation, special attention must be paid to the quality of the execution of the choreography as it is performed [26]. Indeed, dance is a highly dynamic process that requires, as a result of the observer's perturbation, either a rapid return to the execution of the current choreography or the emergence of a novel ensemble of choreographic movements that accommodate the perturbation itself.

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