COMPOSING WITH SWARM ALGORITHMS – CREATING INTERACTIVE AUDIO-VISUAL PIECES USING FLOCKING BEHAVIOUR

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ABSTRACT

In this paper, methods and concepts for algorithmic musical composition with flocking algorithms are discussed. Taking three pieces from an exhibition as examples, the strategies for building the specific relationships between each swarm-system and its musical results are shown. General considerations about the structures of self-organising systems and their potential for shaping musical dynamics as well as about adaptive and interactive behaviours in an installation-context follow. The central aspects of a low-level unified algorithmic thinking in artistic processes are made evident and further scenarios for the organisation of flocking systems and the application to algorithmic musical composition are developed. Finally, some details are given about the technical tools that were used in the implementations.

1. INTRODUCTION

The transformation of algorithms and simulation techniques from the fields of theoretical biology and artificial life into generative mechanisms for musical creation provides a vast and fruitful terrain for artistic experimentation. [8][9][10] The adaptation of flocking simulations for the creation and control of algorithmic music constitutes a paradigmatic example of such a transfer. [2][3][4] Even in their simplest form, dating back to the seminal work by Craig Reynolds [12], these self-organized multi-agent systems can give rise to a range of emergent phenomena, which can be exploited for musical creation. Consequently, flocking simulations prove to possess a great appeal for musicians and numerous examples of swarm-based music have been created. [5][6][7][16][17] In most of these examples, the flocking simulation employed is (almost) identical to Craig Reynolds' original "Boids" system. Since that flocking simulation was not designed with any musical application in mind, a significant part of the effort in the creation of the swarm based piece needs to be invested into establishing a meaningful mapping between the simulation's properties and the musical results. We believe that by shifting the focus of the musical creation away from the mapping issue towards the design of the flocking simulation itself, the mapping challenge is diminished and the diversity of the musical possibilities is increased. In this publication, we try to elucidate this claim by describing three implementations of swarm based music pieces.

2. BACKGROUND

The transposition of an abstract model, such as the flocking algorithms, into musical forms poses a set of interesting challenges. Any computational model of natural phenomena such as flocking behaviours represents a mathematical abstraction of reality. The result of this abstraction involves several aspects that are relevant for artistic applications of the model. The properties and behaviours of the natural system have to be stripped down to a level of generality, that allows their creative reconfiguration into an artificial phenomenon. This could for example embody a musical idea. Yet, the process of abstraction also strips the natural phenomenon of its naturally perceivable characteristics. As a consequence, the computational model loses many of the perceivable qualities present in the original system and therefore is less constraining and facilitates the application of a much wider variety of musical strategies than the natural phenomenon. The almost unlimited number of possibilities for model customisation and transformation into music constitutes some of the main challenges of simulation-based computer music. The two research projects entitled ISO (Interactive Swarm Orchestra) and ISS (Interactive Swarm Space), which have been running for several years at the Institute for Computer Music and Sound Technology (ICST) of the Zurich University of the Arts provide an ideal context to study these issues. This research combines conceptual considerations, engineering developments and public disseminations in artistic venues. As part of the conceptual aspects of this research, we tried to define a set of fundamental correspondences between swarms simulations and musical algorithms that can help inform artistic strategies. As part of our engineering activities, we have developed an open-source programming library entitled “ISO Flock” that facilitates the creation of highly customized multi-agent simulations. Since then, this library has progressed into a flexible environment for real-time creation, configuration and modification of multi-agent simulations that can control a wide range of audio engines through OSC. [18] The main focus of the ISO Flock library lies on the generic definition of agent and environment properties and behaviours. Due to this generality, the library permits not only the implementation of ordinary flocking simulations, but can also be adapted to deal with a much broader range of phenomena, that may for example be used to implement physics simulations or even entirely fictitious systems. The flexibility of the ISO Flock simulation library is intended to encourage a creative methodology that situates the customisation of a multi-agent simulation directly within the musical composition process. With this approach, the characteristics of the multi-agent simulation are as much the reflection of a musical idea as would be the configuration of the audio engine and the definition of the mapping relationships.

3. THREE SWARM PIECES

In the context of an exhibition entitled "Milieux Sonores" which was curated by Marcus Maeder and shown in 2009 in the "Walcheturm" exhibition space in Zürich and in 2010 in the "Gray Area Foundation for the Arts" in San Francisco, a set of three interactive swarm based audiovisual compositions were created by the authors. [1] Each of the three compositions is based on a specific swarm simulation and a musical and visual composition, which are both controlled by that swarm simulation. The musical compositions are spatialised via a twenty speakers three-dimensional Ambisonic projection array. [13] Interactivity is provided via a touch-sensitive surface, which allows visitors to directly manipulate some of the simulated agents and thereby affect the swarm-based generative mechanisms that underlie the audio-visual compositions. The visual compositions are projected onto two of the pentagonal surfaces of the structure and fill the visitor's field of view. Each composition is structured into several stages that are characterized by distinct simulation behaviours and audio-visual aesthetics. They transition from one stage to the next according to a simple state machine mechanism that takes both the duration of a particular state and the current activity level in the visitor's interaction into account.
The main emphasis in the creation and exhibition of the three pieces is placed on the development of a specific and unique correspondence between the properties of each swarm simulation and its musical manifestation. At the core of each piece is a musical concept that guides the design of the flocking simulation, the musical composition and their mutual relationships. Similarly, each visual composition transforms an important aspect of the swarm simulation into a key element in the graphic language.

3.1. Impacts

Starting from a strongly interactive premise, the algorithm in this piece explores the possibility of a hierarchical field of relationships within several flocks, representative, in some ways of the interdependence within an ecosystem or food chain. On a second level the perceptually most significant events are extracted from the continuous flow of data of all the agent's motions and used as the fundamental impulses for the music. (See Figure 1.)
There are three types of entities present in the "Impacts" model: the first type of agent is the attractor. Its behaviour is fully dependant on the visitor's action since it can't move by itself but is displaced by the visitor's touch. The attractors' positions are constrained to a plane within the simulation's three-dimensional space in order to be coherent with the gestural interaction space. The agents of the secondary swarm react to the attraction forces of the first swarm and also influence their own kind. They themselves serve as attractors to the agents within the third swarm, which exhibits the same behaviours as the secondary agents but on a lower hierarchical level. The behaviours of the agents within the second and third swarms are based on the classic attraction, evasion, alignment paradigm [12], but are parameterized in such a manner as to create visually and musically interesting dynamic motion patterns.

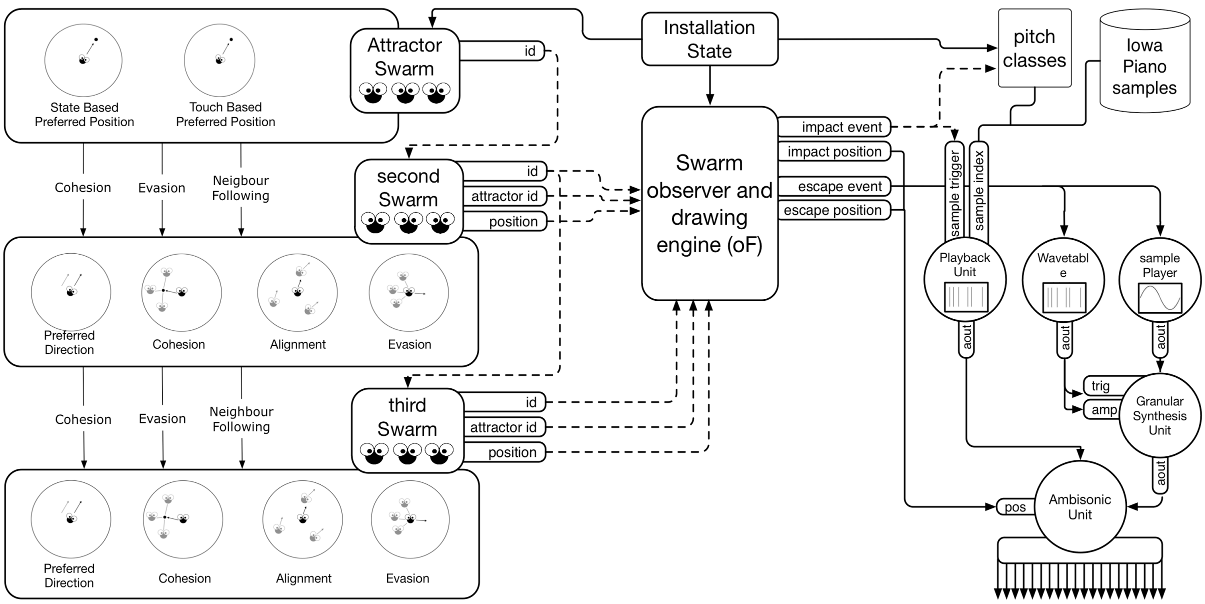

Figure 1. Schematics of the swarm music piece "Impacts". The hierarchy of the swarm simulations is depicted on the left side. The intermediate mapping stage performs the analysis of swarm behavior and generates the control events and data for the musical engine, which is shown on the right.

Figure 2. Flowspace installation showing the flock and visualisation for "Impacts".

The main feature extracted from this behaviour is selected for its expressive qualities. As the title of the piece implies, the impacts or (near)-collisions between agents are used to generate the discrete events that form the main part of the musical "Gestalt" of the composition. An earlier working title of the piece was swarm-piano, as these discrete events are rendered with normal piano samples. [15] The occurrences of this key moment within the perceptual scope of a single agent are made musically apparent by triggering the sound event. The reciprocal of the proximity event is the moment when the farthest point on the escape tangent from the point of impact is reached. This again emphasizes a key moment from the perspective of a single agent and triggers a second type of event. In the true spirit of emergent structures, the mixture of all of these events alone is what generates the texture of sounds, which is characteristic of this piece. The overall condition of the musical domain reflects the state of the entire model, where no global control is applied neither to the individual entities nor to the sound producing algorithms.

The music consists of a background layer of Ambisonic ambience recorded with a "Soundfield" microphone in the Notre Dame cathedral in Paris. This is reproduced on the 20-channel dodecahedral speaker array, which forms the installations space. The individual collision events in the swarm simulation trigger piano samples on impact and a granular echo of the same pitch when the escape point is reached. A simple state machine that tracks the level and duration of user interaction controls the choice of pitches: the higher the level of interaction, the more active the entire swarm simulation becomes and the richer and more dissonant the pitch-set will be. The pitches are grouped into eight groups, one for each agent in the primary attractor swarm. The second and third swarm contain 32 agents each and are assigned to different pitch registers. The secondary swarm activates the lower register and the higher pitches reflect impacts and escape points for the third swarm. Since the note-events are spatialised according to the position of the generating agents, these pitch clusters are perceivable as being located in certain sectors of the surround field. The granular shadow notes create a cloud on the trails of the agents after each impact. Since they get repeatedly triggered during the escape starting from an impact until they reach the largest spatial displacement, a noticeable perceptual widening of the pitch-space occurs. Finally the spatial positions of the swarm agents are stretched from low Euclidian positions higher onto the surround sphere in order to make height information perceptually more apparent. This is necessary as a consequence of the fact that the agents of the second or third swarm will seldom gain great height, since the primary attractors only evolve on the ground plane of the simulation space.

The visualisation re-interprets the idea of impacts and escape points by tracing them into overlapping dynamically changing Delaunay triangulations and furthermore shows widening and fading concentric circles around the points of impact end escape. (See Figure 2.)

3.2. Flow

In the second example piece, the musical idea centres on the establishment of periodically changing agent-neighbour relationships that are rendered audible with rhythmical musical structures.

The simulation implements two types of flocks: a primary flock that consists of eight agents whose predominantly static properties are responsible for the existence of stable spatial patterns, and a secondary flock consisting of 50 highly mobile agents that gives rise to continually changing spatial patterns. The stable neighbourhood relationships among the agents in the primary flock establish a network of interconnected force lines to which agents from the secondary flock respond. This response consists in an initial attraction towards and subsequent tangential acceleration along the closest of the interconnected lines. As a result, the agents of the secondary flock tend to settle into one or several cyclical trajectories that cause them to encounter agents from the primary flock in a periodical fashion. (See Figure 3.)

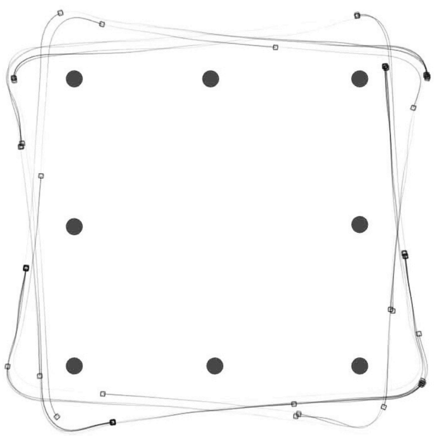

Figure 3. Still image of the swarm simulation for the swarm music piece "Flow".

When the secondary agents approach the primary agents, their movement becomes affected by a magnetic force that acts over a short distance and whose direction and strength depends on the magnitude and sign of the two agents' respective "charge" properties. The periodicity of the secondary agents' repetitive encounters with the primary agents forms the basis for the creation of the rhythmical structures in the emerging musical piece. The rhythmical sound events consist of sine waves that are combined via granular synthesis. These grains are triggered whenever an agent of the secondary flock gets sufficiently close to an agent in the primary flock. The duration, fundamental frequency, harmonic frequencies and amplitude of the sine waves contained within these grains depend on the position of the primary agent, the distance between primary agent and secondary agent and the secondary agent's velocity and jerk. (See Figure 4.) The acoustic spatialisation of the grains is determined by the position of the primary agent. The rhythmical structure and melodic motive of the triggered sounds is fairly stable as long as the primary agents maintain their positions and the secondary agents have settled into a particular cyclic movement. Otherwise the acoustic texture of the triggered sounds is very sensitive to perturbations in the secondary agents' response to the magnetic force effects. The relationship between the static and dynamic flocks leads to the emergence of the musical motifs on two temporal levels, within the short time frame of an individual sound's texture and within the longer time window of the rhythmically recurring line.
The influence of the visitor's interaction with the touch sensitive surface occurs on two levels. As an immediate effect, the visitors can manually change the positions of the primary agents and thereby alter the rhythmic sonic lines that result from the appearance of the secondary agents' adapted cyclic movements. As a more indirect and long-term effect, the visitor's activity levels are gradually accumulated and until they trigger changes in the overall state of the musical and visual piece. This state affects the regularity of the cyclical trajectories and the strength and distance of the magnetic force effects. This is achieved by changing the properties of several behaviours of the secondary flock: the strength of the neighbour line-following behaviour, the strength of the vertical acceleration behaviour, and the strength and distance of the magnetic interaction behaviour. The combination of these changes alters the probability and stability of the rhythmical patterns and the amount of fluctuation in the texture of the individual sound events.

3.3. Membranes

In this example, the relationship between the swarm simulation and sound generation technique is characterized by a conclusiveness, which stems from the fact that they are both based on a model of the same physical phenomenon: the behaviour of interconnected springs.
As in the "Flow" example, the flocking simulation consists of two types of flocks, a primary mostly stationary flock and a secondary mobile flock. The secondary flock implements a mass-spring system. Here, the agents represent point masses that are connected to their neighbours via elastic springs. When left undisturbed, the interconnected springs form a stable network that pushes the secondary agents into an even distribution across the simulation space. (See Figure 5.) In this situation, small random movements of the secondary agents only minimally perturb the network. The stable network state can be disrupted by the repulsive effect of agents in the primary flock. As the secondary agents evade the primary agents, some of the connected neighbours move beyond the breaking distance of the springs. Consequently, these springs are

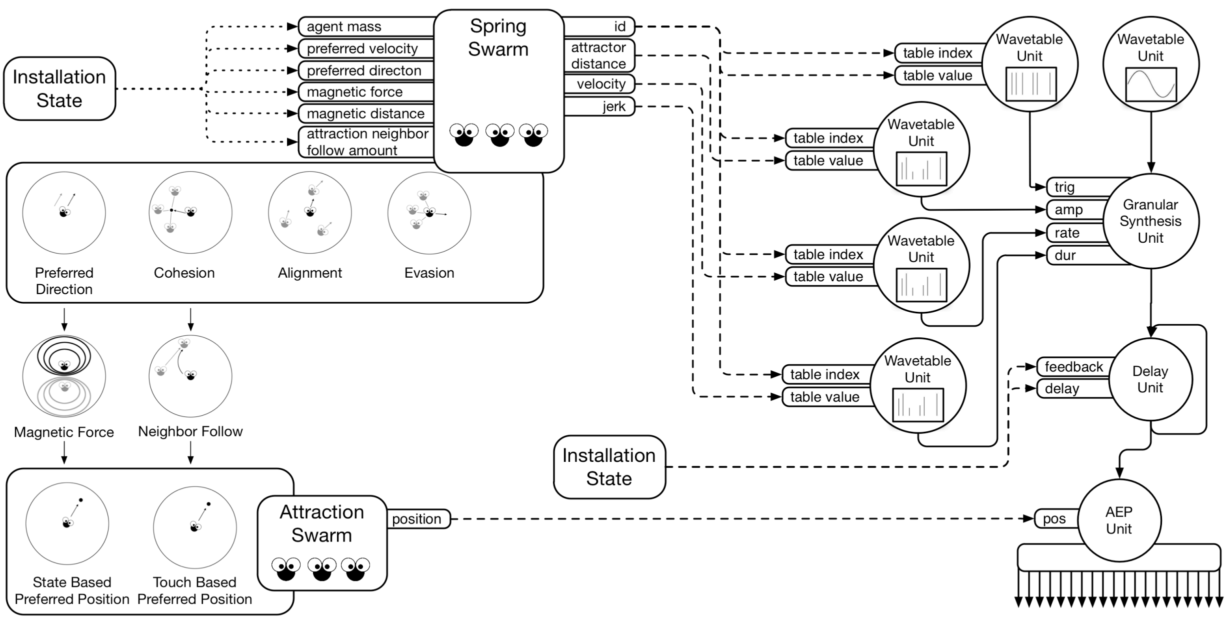

Figure 4. Schematics of the swarm music example entitled "Flow". The characteristics of the swarm simulation are depicted on the left side. The musical architecture is shown on the right. The dsp chain is shown a solid arrows. The mapping relationships between the swarm simulation and the music engine is depicted as dashed arrows.

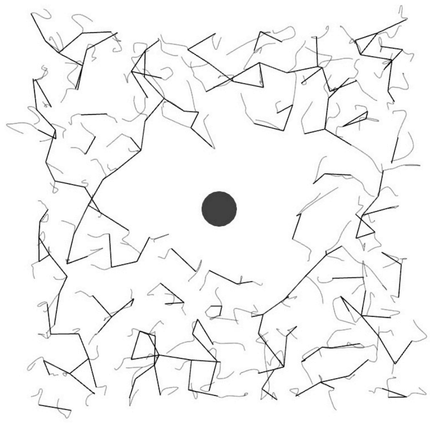

Figure 5. Still image of the swarm simulation for the swarm music piece “Membranes”.

removed from the simulation. New springs are formed whenever two secondary agents that haven't yet reached their maximum number of spring connections get sufficiently close to each other.

The musical algorithm employs the non-linear model of a physical spring as basis for sound synthesis. [11] Each of these acoustic springs corresponds to a spring in the secondary flock. The movement of the secondary agents drives the excitement of the acoustic springs. The acoustic spatialisation of the springs' audible excitement is determined by the centre position of the spring. When the secondary flock has settled into a stable spring network, the excitement of the acoustic springs is very weak. This type of excitement creates a diffuse acoustic texture. When a new spring is created, a corresponding acoustic spring is instantiated and becomes audible via a strong but brief impulse excitation. A similarly strong and brief excitation is triggered, whenever an agent spring and the corresponding acoustic spring are destroyed. As a consequence of these behaviours, the musical result is a combination of a diffuse musical background and discrete bright sound events that take place in direct correlation with the occurrences inside the swarm simulation. (See Figure 6.)

As in the "Flow" example, the visitors can interact with the piece by both directly changing the position of the primary agents and affecting the state of the musical installation via their accumulated activity. The correspondence between interaction and musical outcome is directly perceivable since the changing position of the primary agents causes the disruption and recreation of springs. These spring events are clearly visible in the graphical display of the swarm simulation on the touch surface and are also clearly audible in the musical result. The overall activity state in the installation affects the mass and movement of the secondary agents, as well as the stiffness, rest length and breaking length of the springs. These gradual changes alter the loudness of the sustained but weak spring oscillations and affect the occurrence, intensity, and distortion of the impulse sounds.

4. DISCUSSION

The description of the three swarm based pieces serves as an illustration of some of the musical possibilities that arise when creative decisions are applied not only in the design of the audio generation techniques and the mapping schemata but especially in the customisation of the swarm simulations. Each of the three pieces is based on a particular musical core idea that links the design of the swarm simulation, the swarm-to-music mapping, and the specific controls of the musical processes. The "Impacts" example establishes a correlation between hierarchically dependant swarm agents' collision events

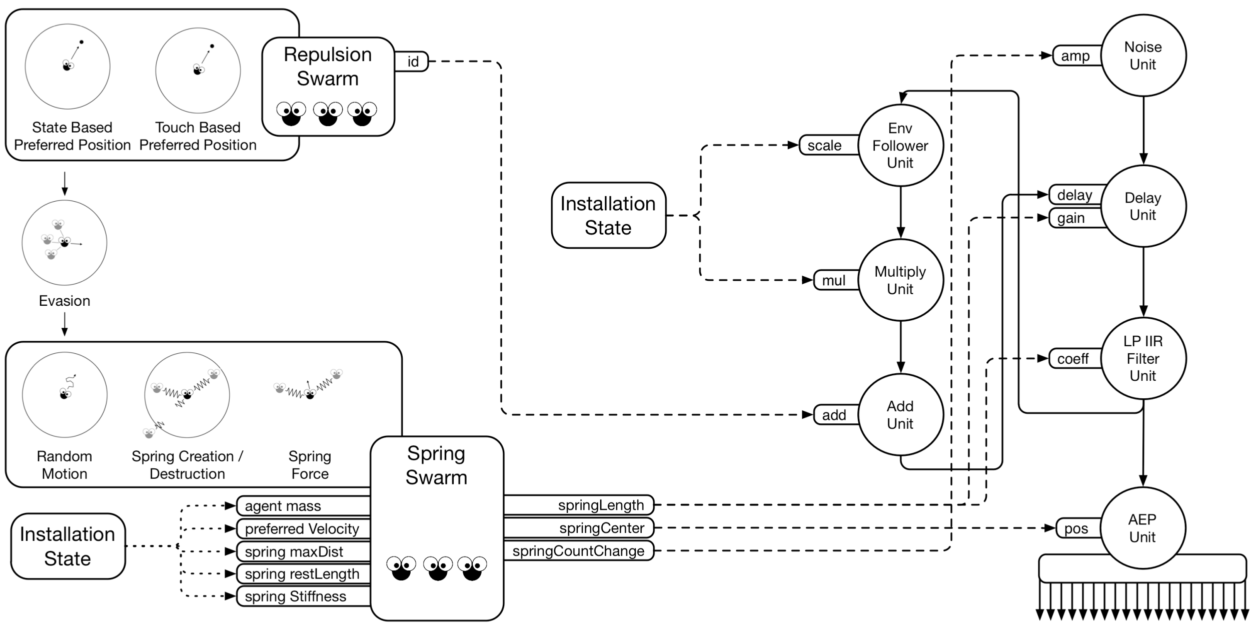

Figure 6. Schematics of the swarm music example entitled “Membranes”. The swarm simulation is shown on the left, the musical architecture on the right and the mapping relationship in between.

and the triggering of individual piano notes. The “Flow” example links periodic repetitions in the spatial distributions of agents with rhythmical patterns. The “Membranes” example employs models of physical springs both for the swarm simulation and the sound synthesis technique in order to create a perceptual and aesthetic proximity between the two.

4.1. Specific Strategies

For all three pieces, we created a distinct swarm simulation that matches a particular musical idea. Despite of this, the resulting swarm simulations still share many properties with the time-honoured "Boids" model. The individual agents remain highly simplified objects that do not possess any form of anatomy nor maintain any form of adaptive behaviour or internal dynamics. The spatial and temporal properties of each swarm are predominantly dependent on neighbourhood forces such as attraction, repulsion and alignment among its agents. Nonetheless we believe that each swarm simulation successfully captures a unique combination of agent characteristics, swarm behaviour and musical results.

The following elements emphasize those musical elements that best express our specific compositional strategy on the simulation, mapping and musical levels:

– By observing the activity of those behaviours, which are dependent on very close proximity relationships between neighbouring agents, discrete events can be extracted. These discrete events can be exploited in the mapping strategy and the musical algorithm.

– Continuous changes in agent parameters on the other hand can easily be mapped to equally continuous changes in musical parameters.

– As an extension of the original swarm concept, it can be useful to not only endow agents with properties that are shared by the entire flock, but also to give the agents individually distinctive traits. Thus the combination of shared and unique agent properties serves the purpose of balancing the perception of homogeneity and individuality in the musical "Gestalt".

– The simulation of multiple interdependent swarms with distinct behaviours influences the creation of musical patterns on different temporal scales. Swarms that settle into stable spatial arrangements control equally stable musical structures, whereas highly mobile swarms may generate more dynamic and brief musical forms.

– The spatial dynamics and coherence of flocking agents lends itself to control of the periphonic positioning of musical elements. By establishing a clearly perceivable causal relationship between the position of the visitor’s touch gesture, the agents’ spatial distribution and the spatialisation of the resulting musical events, the basis for an intuitive interaction is created.

4.2. General Structure and Dynamics

Swarm simulations offer an exemplary application of a model building approach that focuses not so much on the accurate reproduction of a specific natural occurrence but rather tries to identify general, underlying principles of organisation for an entire category of phenomena. In particular, this approach explores how principles of self-organisation influence the emergence of qualitatively different characteristics on a higher structural level. A musical engagement with the principles and capabilities of swarm simulations enables the exploration of these algorithmic systems in order to serve as a form-generating process in composition.

The difference between artificial intelligence and artificial life agents lies in the learning and adaptation capabilities of the former and the emergent, bottom-up local rules that lead to expression of complex overall "Gestalts" by the latter. When using flocking algorithms for musical compositions, the challenge lies primarily in finding a set of simple agent rules and behaviours that can generate as much musical potential as possible.

The selection of the behaviours on the one hand generates the overall structure of the flock; the weighting of the different behaviours on the other hand determines the current dynamics of the simulation. At the beginning of the compositional method lies the recognition of a structural similarity that is shared by a particular swarm simulation and an intended musical process. The awareness for such a similarity informs the design of the behavioural characteristics of the swarm and the composition of the musical algorithms. These should be implemented simultaneously in order to reflect each other. The implementation of the mapping relationship between the flocking algorithm and the musical processes however, follows as a consequence of the previous choices. This compositional strategy works well in the case of non-adaptive swarm simulations and swarm-music relationships. Although these types of pieces are only capable of expressing a limited aesthetic range, they manage to convey a musical idea quite clearly.

4.3. Adaptation and Interaction

In order to increase the diversity without sacrificing the particularity of the musical result, an external mechanism for the alteration of the swarm and music characteristics can be added. As is the case in the three examples described in this paper, such an external mechanism may be implemented as a finite state machine. The interaction with a viewer can act as a disturbance or as a new impulse for an otherwise stable state. An interesting aspect of the interactive situation is the fact that human behaviour interferes with the emergent swarm behaviour and begins to form a meta-system, that might exhibit different states than the purely closed world of simulation.

4.4. Further Ideas

It would be very interesting to explore how altering or expanding some of these classical swarm simulation properties can extend the musical possibilities of swarms. What follows are ideas for a few fundamentally different types of flock-music relationships:

– By drawing from a musical landscape metaphor, a swarm-music relationship could be implemented in which it is not the agents themselves that control the musical processes but rather the properties of an artificial environment. This environment is changed via the agents' activities, for example by stygmergic interactions (environmental communications).

– Agents can be endowed with adaptive traits that change within different time frames (physiological, learning, evolutionary) and thereby drive the evolution of a musical piece on different time scales.

– A swarm simulation could incorporate some aspects of multi-agent simulations that model the diffusion of cultural trends or political opinions. Such a simulation may give rise to musical patterns in which consensus-based dominant motives emerge from initially very diverse musical elements.

– A two-way relationship between the swarm simulation and the musical results could be established by endowing agents with the capability to perceive aspects of the acoustic output. As a consequence, the agents would respond in such a way that certain quantifiable musical criteria would be optimized.

5. TECHNICAL DETAILS

The realisation of the three swarm music examples is based on custom hard- and software developments that have been made in the context of the two research projects "Interactive Swarm Orchestra" and "Interactive Swarm Space". Part of the projects' results is a set of open-source software libraries, which were specifically developed to facilitate musical and artistic applications of swarm simulations. The swarm simulations for the three different examples are based on the "ISO Flock" library. The audio for "Impacts" is implemented in Max/MSP whereas "Flow" and "Membranes" employ sound synthesis algorithms implemented with the "ISO Synth" library. Two of the three applications for the visual rendering of the swarm simulations are implemented using the "ISO Visual" library. All of these libraries are readily available from the project website. [19] The visualisation and swarm analysis tool for "Impacts" as well as the finger tracking and the master state software are implemented in openFrameworks. [20] The master state software is in charge of managing the different installation states and acts as a communications hub between the simulations, tracking software and audio engines. Inter-application communications are based on the OpenSoundControl [18] protocol.

On the hardware side, the aluminium dodecahedron structure that supports the placement of the 20 speakers was specifically developed and built for this installation. The touch detection system is camera based and employs an infrared diffuse illumination setup. [14] The touch sensitive area consists of a textile surface with an acrylic plate underneath to provide mechanical support. The textile is transparent to infrared light and acts as a screen for the video display. A camera and two infrared light sources are placed on the back of the installation. For the rear-projection, three ultra short-throw projectors are placed on the outside of the dodecahedron.

6. CONCLUSION

The simultaneous design of swarm simulations and musical algorithms for the creation of interactive pieces is a fortunate case of coinciding concepts and methods. Most musical applications of flocking algorithms start from a well-known static flocking behaviour and adapt or merely map the musical algorithm retroactively to the information generated by the simulation. In this paper we show that a more concise form of relationship is possible. A generic flocking simulation environment, which permits the expression of varying degrees of complexity, is combined with a development of algorithms for both domains. These are based on one unified concept. The normally essential task of designing a powerful mapping to mediate between two separate systems becomes insignificant in comparison to the union achieved by conceptually joining the systems in the early stages of the design process. The three pieces we discuss serve to illustrate our methods and show how an extended link between swarm and music algorithms can be achieved in practise.

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