A Playable Evolutionary Interface for Performance and Social Engagement

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Abstract. An advanced interface for playable media is presented for enabling both musical performance and multiple agents' play. A large format capacitive sensing panel provides a surface to project visualizations of swarm simulations as well as the sensing mechanism for introducing human players' actions to the simulation. An evolutionary software interface is adapted to this project by integrating swarm algorithms to playable interface functionality with continuous auditory feedback. A methodology for using swarm agents' information to model sound synthesis is presented. Relevant feature extraction techniques are discussed along with design criteria for choosing them. The novel configuration of the installation facilitates a unique interaction paradigm that sustains social engagement seamlessly alternating between cooperative and competitive play modes.

Keywords: evolutionary interface, agents, swarms simulation, sound model, interactive, playable media, social engagement

1 Introduction

Advances in novel interfaces present a vast range of playable configurations for human players. Contemporary users and players adapt to the advances in many areas of engagement from the use of mobile phones to the play of games. Performance and artistic venues are one of the forefronts of advancing interface technologies. Experimental design of interface configurations can facilitate interactive *playability* in a media experience, an alternative to standard gameplay. Beyond the artistic achievement for look and feel, design must pursue meaningful interaction that sustains interest beyond initial attraction to the novelty of an interface and its artful constellation. An ongoing challenge for designing interactive media installations is their affordance of sustained engagement with systems and other players beyond their initial attraction. The present project inquiry is to identify and integrate the elements to sustain play and social engagement without extensive rules, scenarios, and explicit valorization mechanisms that big budget games offer. We introduce playable media with two novel interfaces, one physical and the other a software-based play interface. For this paper we focus on the latter. The play scenario involves no winning or losing and there is no overarching goal dictating state transitions during play. The installation adapted an evolutionary algorithm into an interface function. Preliminary exploration of playability uses this interface configuration for group collaborative play. We refer to the project as *Wayfaring Swarms*.

1.1 Play Scenario

The Wayfaring Swarms play table is a rectangle of 36 inches by 48 inches, providing access for up to four players at one time. Using capacitive sensing the table surface can measure multiple players' hand positions. Players are invited to interact with swarm agents, which are animated graphics of small colored particles projected onto the table surface from above. Figure 1 illustrates the experimental infrastructure. Synthesized sounds are generated using algorithms that model musical patterns and transitions, and interactions with swarms cause changes in sound patterns. The swarm agents' dynamic properties exhibit emergent group behavior. Players may cooperatively gather agents or steer agents away from other players. The play surface displays a simple graphic map for a play sequence, a serial presentation of predefined play sections. Each section defines a swarm and accompanying sounds. Players simply play with each section and at some point they must decide to move on. Social interactions develop around this process.

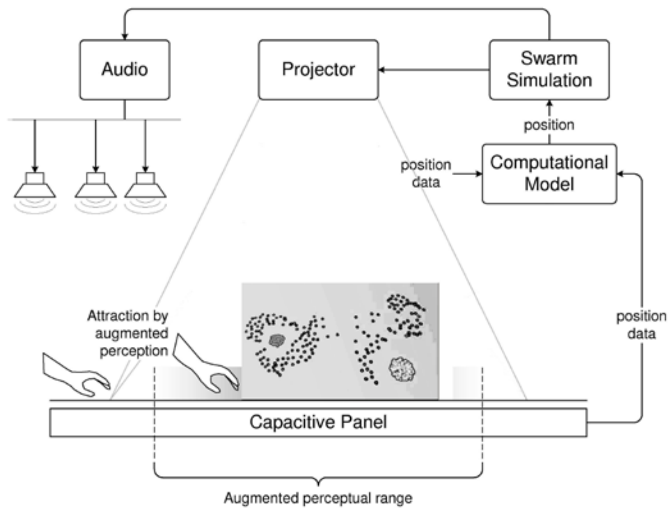

Figure 1: Wayfaring Swarms playable system configuration

This simple play scenario is yet non-trivial for novice players as the play involves some learning curve to become attending listeners. Progression through the sequence of play sections is controlled by players using a simple signal of two hands pressed in a specific area of the capacitive panel. Players' determining when to change sections becomes either an awkward moment of unilateral action or an engaged consensual moment among players. Players can take new positions around the table, or leave and return without disrupting the interface functions.

The remainder of section 1 presents background and prior work. Section 2 introduces the original simulation and our modifications to enhance playability. Section 3 presents methodology for swarm feature extraction for application to sound models. Section 4 presents methodology for developing sound models to enrich play experience. Section 5 concludes with a narrative of informal observations projecting a future research scenario.

1.2 Background

Wayfaring Swarms advances an evolutionary interface as a viable application for sustained engagement for players. This interface implements a "breeding" model to generate a new swarm combining features of two existing swarms. The model is applied in relation to biological research for understanding social behaviors of the kind known as flocking behavior [1]; one of the simplest behaviors seen in nature revealing social and collective dynamics. It is described as self-organizing because the collective behavior is governed by a set of simple rules applied to each agent and there is no centralized control agent. It is also observed as exhibiting emergent behavior as its evolving patterns are unknown to each agent and there is no high level prescription dictating the resulting complexity. Mathematical modeling of swarms has been implemented in numerous versions and applied to many areas of study. The model usually combines Reynolds' "boids" algorithm [2] and a self-propelled particle model [3]. These two methods combined make an excellent application to interactive and evolutionary play scenarios. While the boids algorithm provides microstructure of global patterns, the self-propelled particle model provides a lively oscillatory quality, and more importantly, an opportunity to introduce a high-level agent into the system, such as a human-controlled agent, as an influencing force to the global dynamics of swarms. This type of high-level influence evokes swarm behavior such as encountering predators [4], and provides a means to introduce human energy into the interactive pathway of swarm dynamics (see section 2.2).

1.3 Prior Work

Swarms and evolutionary algorithms are widely explored in areas of visual art and media, and developed to the extent of applications in commercial production including computer graphics, film special effects, and computer games, with use cases ranging from movements of crowds and armies to growth of vegetation-like scenic elements to genesis of game denizens (see Will Wright's *Spore*). Interactive art examples include works by Sims [5], Sommerer and Mignonneau [6], and McCormack [7]. The Wayfaring Swarms system is not applied in this tradition. Swarm visualization serves not for advanced visual arts content but for basic and extensible capacity for listening and enactive movements not unlike those of musical performers (see section 5). The perceived kinesthetic energy of performers is an important aspect of musical reception [8]. Rudolf Laban has similarly articulated this through the theory of effort applied to dance performance [9][10]. Musical instruments are refined and fit to the human scale: the detailed interactive gestures between performers and their instruments are very intimate, not visible to audiences. However those gestures are perceived through the corresponding tones as musical expressions [11]. Our previous works on enactive interfaces explore various novel configurations to "enlarge" performers' tone producing gestures to make them accessible to observers [12]. Consistent with the previous works, the current project prioritizes the design criterion: configure the system so that players' movements are clearly visible.

Wayfaring Swarms incorporates a touch free capacitive sensing panel. Leon Theremin originated capacitive sensing for music performance by direct touch-free tone control. The touch surface repertoire of interface paradigms opens other retrospective references to analog electronic interfaces with tone generators, such as systems constructed by Buchla [13] and Martirano [13], each of whom produced unique capacitive control surfaces and logic control gates for tactile transformation of sound synthesis. Following this line the Wayfaring Swarms interface engages upper body movements guided by human hands to interact with swarm agents projected on the playable surface. Unique from prior work, we introduce a layer of indirection from hand movements to tone control, through the swarm model. The interface also differs from the recently discontinued Lemur™ controller with animated physics-based graphic object trajectories. We are concerned not with graphic controllers but with 1) swarms' emergent patterns, and 2) many to many mapping design between swarms and audible features.

2. Wayfaring Swarms Overview

Sayama [14] developed the swarm simulation used in Wayfaring Swarms. Sayama's swarms are populated by agents exhibiting simple, semiautonomous movement rules in a continuous two-dimensional space. Each agent is assigned movement rules and a perceptual range for detecting the positions and velocities of other agents. Agents' awareness within their perceptual ranges determines individual position updates with only decentralized control. The simple kinetic interactions among agents result in spontaneous large-scale pattern formation.

2.1 Agent properties and evolutionary design of swarms

Swarm agents consult all other agents in their perceptual range at each discrete time step. Agents can instantaneously change velocity according to the following rules, adopted from Reynolds' "boids" system [1]:

Outside of an agent's perceptual range: Straying:

- Agents move randomly if there are no other agents within perception range.

Within an agent's perceptual range:

- Cohesion: an agent moves toward the average position of local agents
- Alignment: an agent moves towards the average velocity of local agents
- Separation: an agent avoids collision with local agents
- Whim: an agent moves randomly with a given probability
- Pace keeping: each agent approximates its speed to its own normal speed.

Table 1 from Sayama enumerates kinetic parameters used to simulate agent behavior. Each agent *i* is assigned a set of unique values to define its dynamic properties. The pixel is the atomic unit of spatial coordinates for agent position and movement. Tendency is an agent's rate of approximation of its current speed to its own normal speed. Maximum values were determined by Sayama heuristically and are arbitrary for implementation purposes. The total number of agents in a swarm is limited to 300.

Table 1. Kinetic parameters used to simulate agent behavior (explained in detail in Sayama [14])

Name	Min	Max	Meaning	Unit
R^i	0	300	Radius of local perception range	pixel
V_n^i	0	20	Normal speed	pixel step^{-1}
V_m^i	0	40	Maximum speed	pixel step^{-1}
c_1^i	0	1	Strength of cohesive force	step^{-2}
c_2^i	0	1	Strength of aligning force	step^{-1}
c_3^i	0	100	Strength of separating force	pixel^2 step^{-2}
c_4^i	0	0.5	Probability of random steering	—
c_5^i	0	1	Tendency of pace keeping	—

A set of these parameter values is referred to as a *recipe*. Multiple agents that share a common recipe are referred to as a *species*, and assigned a common color. Heterogeneous swarms are composed of multiple species. The emergent patterns of heterogeneous swarms are encoded in the agents' multiple sets of kinetic properties and the proportions of each recipe in the swarm. Sayama avoids automated fitness evaluation methods that would necessarily limit the diversity and novelty of potential outcomes. Evolutionary operators enable mutation of a single parent swarm by random re-sampling of up to 80% of the population size. Evolutionary design starting from two parent swarms will generate a new swarm by randomly determined ratios between all agents of both parents. The heuristic design process resembles musical improvisation, and is incorporated into the playability design of the Wayfaring Swarms system.

2.2 Creating a playable media configuration

We embedded Sayama's simulation in a software and hardware environment designed for playability. To extend playability as social interaction, a large format capacitive panel is used for touch-free, multi-player, multi-point control. The panels were developed by Philippe Jean of Les Ateliers Numériques [15] for use in live performances by Cirque du Soleil. The Swarm graphics are projected on this surface so that players observe the social formations of swarms and interact with them by hand movements. The capacitive panel senses multiple hands as conductive objects in 1:1 ratio to the surface area; the maximum number of objects is determined by the surface area and objects' sizes. To align players' hands as play agents with swarm agents in simulation space, we bounded the simulation pixel region to the dimensions of the capacitive panel, and scale the projected swarm image to fit the capacitive play surface area. The projected image frame is calibrated with the capacitive surface by projecting markers in each corner of the frame, then touching the capacitive surface at each marker point, and registering the touch points. Swarms reaching the edge of the capacitive surface are reflected from an invisible barrier and maintained within the playable area.

Hand position data is determined at the center of each area where a hand is detected, and transmitted to the corresponding position in the swarm simulation. Each hand position is represented in the simulation as a "super agent". A super agent is directly controlled by a player's hand, and is not influenced by the other kinetic rules. Swarm agents do not recognize super agents differently; they respond to super agents as they do to all other agents, by proximity-based kinetic rules. "Player control" is in this way an emergent property of a simulation where a control agent moves independently of the kinetic rules of swarm agents. Acting as super agents, players' hands manipulate swarm shapes such as deformation and extrusion, separation and combination of multiple groups of agents. Performers engage a swarm's emergent behavior but cannot directly manipulate agents' positions or swarm formations independent of agents' social relations. Figure 2 shows swarms gathered to the hands of four players

Figure 2: Three players around the playable swarm surface. A small robot with LEDs also plays.

Sayama's original code was modified to isolate the simulation code from the frame loop of the swarm animation, and from the control flow of the graphical user interface. Then the isolated simulation code was embedded in an architecture for organizing multi-agent play sequences. Embedding the simulation included the addition of boundary conditions and calibration points mentioned above. The simulation was assigned an independent frame rate, required as the graphics rate cannot run fast enough to support parallel audio synthesis. The new software architecture simplified the routing of hand position data to the simulation, and enabled the specification of the play sequences described in Section 1.1.

3. Methodology: Swarm feature extraction applied to sound models

The integration of the evolutionary interface requires a methodology to extract and use the swarm state information to enrich play experience for human players. Players in Wayfaring Swarms are intimately aware of swarm dynamics through graphics display and also through continuous auditory feedback. To provide an auditory feedback sound synthesis is applied to sonify the swarm state information. One of the criteria for choosing feature extraction techniques for sound representation was to complement the visual representation of swarm dynamics rather than duplicating it. Control strategies for sound models are adapted to use data of features extracted from emergent behaviors in swarm simulations. To test these adaptations, mappings are made between a set of emergent swarm states and a set of synthesis parameter states. The design decision associates the selected states of a sound model to selected states of a swarm. Thereafter other patterns that emerge in the swarm will generate corresponding sound patterns. Data selection is based on salient feature analysis. The process of establishing initial correspondences may be thought of as “tuning” the interface. Tuning in this sense is calibrating the relationship between swarm dynamics and sound dynamics. As an example, positional data of swarm clusters are used to localize positions of sound sources. The following discusses the procedure for swarm feature recognition and extraction in preparation of control structure to apply to sound models.

The use of swarm patterns as sound control data presents a significant challenge because in the code there are no numerical representations of the patterns that can be readily applied to sound models. The swarm simulation does not internally represent emergent patterns in classes of control parameters or in feature data variables. Emergent behavior from complex systems has been referred to as the result of *unspecific control parameters* [16]. As system parameter values change the resulting patterns vary, but variation and pattern emergence are not classifiable using systematic, linear representations. Patterns recognized by human observation are not represented in the simulation itself. Instead we extract data from visible features of swarms, and apply the data to sound models to enrich the playability.

3.1 Recognizing Clusters

Swarm denotes the total agents in a simulation. *Cluster* refers to a visibly coherent aggregate of agents. The relevance of cluster formation is that agents in a cluster are responding to mutual proximity, whereas agents in separate clusters are mutually unaware unless the clusters are in close proximity. Clusters are a primary feature to recognize and measure: they are emergent and temporary. Their spontaneous subdivisions and formations provide a highly configurable and playable dynamic. Players tend to focus attention on clusters and how to merge them or separate them, as well as moving them across regions in the interface.

Clusters are independent of species and recipes: in a smarm composed of multiple species, a cluster may be heterogeneous or homogenous. Membership of agents in clusters changes over time, so clusters are identified and tracked only by persistence. We examine the position of each agent at each time step and compare it to the positions of all other agents. A proximity threshold determines when an agent is a member of a cluster or a non-member roaming between clusters. An agent may only be a member of one cluster at each time step. For all agents in a common cluster we determine the average center position and provide this data for use in sound synthesis control. Shape is not a consideration in identifying a cluster. When two clusters’ agents have sufficiently close proximity they are considered merged, regardless of shape. Clusters are identified by integer; a cluster keeps its number while it persists; when two clusters merge the lower number prevails, and the higher number is returned to the pool for re-use. The maximum number of simultaneous clusters recognized is set by a run time parameter. A cluster must have at least six agents; this limit is set by a run time parameter. We transmit cluster membership size for sound control; we track but do not transmit data of agents’ individual cluster memberships.

3.2 Temporal variation of emergent features

The variation of clusters over time creates challenges in applying cluster data as media control signals. Clusters are created by subdivision of larger clusters, and terminated when a cluster breaks into many pieces or when its agents become members of a larger cluster.

The transitions at the creation or termination of a cluster often require multiple time steps before the stability of the new state can be ascertained. A time window confirmation parameter is used to track the number of consecutive time steps that a new cluster state is maintained. Initial emergence or disappearance of a cluster is flagged as the first frame of the time window. If the state is continuously present over the time window duration, a confirmed cluster state is reported. A duration threshold acts as a smoothing function to prevent rapid-fire series of messages of alternating cluster states. Alternation can occur when two clusters skirt one another and their perimeters temporarily overlap, or when a larger cluster is pulled apart to form new clusters.

Time windowing introduces unwanted latency in the transmission of cluster data to sound control. Latency undermines synchronization between swarm visualization and corresponding sounds. Latency is imposed by the cluster confirmation time window parameter set at run time. At minimum two frames are required to confirm cluster formation; a simulation frame rate of 50 frames per second provides 25 Hz latency multiplied by the number of frames in the confirmation time window. In practice when two clusters merge or when one cluster divides, two data streams must be managed, one appearing or disappearing, and the other persistent but changing in number of members. The varying size and behavior of the persistent cluster, as well as data of a new cluster, will impact corresponding sound. Cluster history is determined by tracking agent membership across consecutive time steps; history preserves coherence of sounds when a cluster divides or when two clusters merge. Cluster history tracking is applied to a cluster data stream in order to terminate when it is absorbed into a larger cluster. Cluster history also provides a reference for smooth transition when a data stream bifurcates upon a cluster's subdivision.

3.3 Measuring emergent shape

A cluster's expressive features are shape and internal distribution of agents. Rings, elongations, "dumbbell" or "twin star" shapes, and internal rotation patterns are often prominent features. These emerging patterns are not represented in the simulation and must be detected as features by measuring the positions and velocities of swarm agents. In distinction to shape recognition, we determined the essential approach responds to displacement or perturbation. We arrived at this approach by observing that clusters do not achieve a wide range of shapes in terms of geometric primitives, and clusters cannot be forced into shapes other than their stable and emergent properties. We determined to tune sounds in a range corresponding from stable or symmetrical clusters to unstable or distorted clusters. This approach was selected rather than tuning sounds for target shapes unrelated to a cluster's inherent properties. We adopted this initial approach from Sayama's decision to avoid the use of fitness evaluation methods (see page 4 and [14]).

As proof of concept our prototype applies simple statistical measures to explore the application of perturbation recognition. Separate statistics are provided as sources of sound control data: 1) measured across the entire swarm, 2) measured by species regardless of cluster, and 3) measured by cluster. We measure average velocity; average distance from the statistical center; average distribution angle in radians; and average planar coordinate positions on the play surface. We also provide a histogram of each measure to show distribution of agents across the full ranges of these dimensions. For example, while most unperturbed clusters are circular in shape, their symmetry is distorted by interactions with players and with other clusters. Distortions of shape are easily visible features and are detected in uneven histogram distributions of agents' positional angle and velocity.

Figure 3 provides a sequence showing a separation of one cluster into two. The cluster is heterogeneous having two species forming a ring pattern. Figure 3a shows a player's hands bringing about the separation, which requires 8 to 12 seconds to complete. Figure 3b-3d shows the sequence of separation and the corresponding statistics and histogram data, displayed in a companion diagnostic tool, with multiple histograms overlaid by color. The red bars indicate average velocity; green indicates angle of distribution around the center; blue indicates distance from the center; and yellow and pink are average horizontal and vertical position respectively. From Figure 3b to 3d the cluster separation is reflected in the histogram of average velocity (red) and distribution angle (green). Not easily visible in Figure 3d, the distance-from-center histogram (blue) indicates the separation of species in the ring structure. In Figures 3b and 3c the visualization includes a small circle at the center of the ring formation. This circle is a diagnostic of the cluster center as determined by the feature detection system. In Figure 3d two circles denote two clusters are detected.

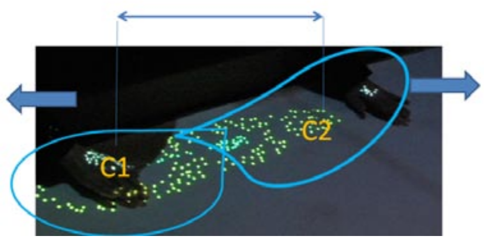

Figure 3a: Separating one cluster into two.

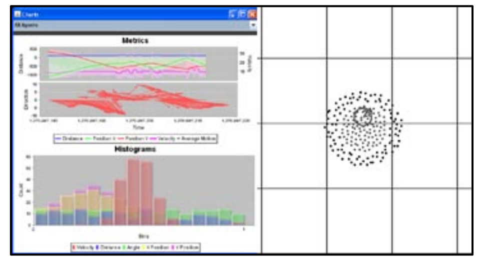

Figure 3b: Histogram of stable cluster.

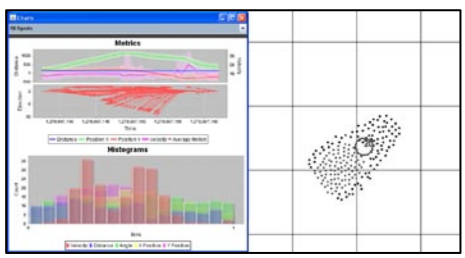

Figure 3c: Data divides with cluster deformation.

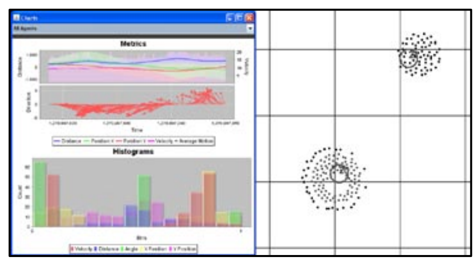

Figure 3d: Data and clusters separated

4. Methodology: Play Scenario with Sound Model

Wayfaring Swarms extends swarms' social behavior as a paradigm for playability and players' interactions with musical play agents. The abstract representation of sounds by swarm graphics is reminiscent of abstract musical notation, not in level of detail as to specify pitch or duration as standard musical notation, but rather in the capacity to represent diverse sounds and transformations. Initial conditions are asserted by tuning swarm recipes to states of sound generators. Swarms' relationships to sounds are relative to the initial tunings and the corresponding ranges of transformations. Ranges of sound transformations are designed to correspond to player's actions inducing emerging properties of swarms.

4.1 Sound Model: Synthesis Methods

Sound sources are synthesized using wavetable lookup, physical modeling [17], and formant-modeling techniques [18]. Sound control parameters are derived not directly from graphics, rather from non-visual data of the agents' states and tendencies. These states are reflected in the graphics and in parallel in the sounds, resulting in multi-modal emergent behavior. Sound authoring is applied to control sounds using the VSS sound server [19].

Sound localization and spatialization are added downstream. Sound sources are distributed to a multi-channel speaker array that surrounds the play area. Swarm clusters' positions are used to determine sound sources' localized positions in a simulated acoustic environment. The simulated auditory field is larger than the physical play area, with proportional dimensions. Clusters in the center of the play area generate sounds located directly above the play surface. Clusters at the periphery of the play area generate sounds heard at simulated distances behind the players. This acoustic model encompasses players within the spatial field of the play area.

4.2 Sound Model: Designing coherent transformations

Several techniques were developed to enable reliable correspondences of sounds with highly variable behaviors of clusters. (1) Local deformations of clusters were used uniformly to modify formant characteristics of sounds. This technique may be applied to many classes of sounds. It involves modifying the vowel-like qualities of "openness" and "tightness" of a sound. With this technique the effects of a player's hand deforming a cluster are immediately reflected in the local tone quality of a sound, without disrupting the composed pitch and rhythmic structure of the sound. (2) Data related to changes of cluster size and velocity is assigned equally to pitch-related and rhythm-related sound properties. This technique is preferable to trivial associations involving isolated audio or musical parameters that co-vary linearly with cluster data. (3) Sound sources are not associated one-to-one with clusters. The number and timing of cluster instances is highly dependent upon local performance actions. Creating a sound source for each cluster would be capricious from a sound modeling standpoint. Clusters are local variations and are not structurally analogous to the composition of sound sources. Instead the designation of sound sources is determined by the scheduling of swarm species in sections of the play sequence. To reflect the local formation of clusters, data from cluster instantiation and termination is applied through the spatialization of sound sources, which emulates a musical technique known as *antiphony*, the exchange of musical ideas from one sound source location to another.

5. Concluding Narrative: Informal observations of initial results

Preliminary informal observations involved groups of one to five players, including college students, technical staff, and faculty, of both genders with diverse cultural and racial backgrounds. Players freely used one or two hands and played for a 20-minute session. Players' lively social interactions have been noted. Whether shy or disinterested or reluctant to play initially, once they "get the hang of it" players tend to explore diversity of local dynamical patterns. In general players respond to emergent behaviors of swarms. Players verbally refer to agent clusters as individuals, and also refer to single agents as individuals. Utterances attributing personality traits to agents and clusters are regular.

Players exhibit modes of play behaviors that might be roughly grouped in three types: random, exploratory, and ensemble-like modes. The random case is when players either just joined the group or seem lost in the middle of play. When they seem lost, some players tend to step aside and watch others while some players tend to try out random positions on table. The exploratory case is when players tend to investigate clusters by perturbing and diverting while attending to changes in the sounds. In this mode, play behaviors seem to be uncoordinated as players focus on their individual investigation. The ensemble-like case is when players are attending to cluster merges and separations as a goal. In this mode, play behaviors tends to be coordinated to stated tasks regarding sound as feedback. However it is noted that these three modes are not necessarily progressive in a linear way. Players tend to switch mode regardless of their level of experience with the installation. This may be due to the evolving nature of the interface, suggesting a future research direction to investigate the relationship between the measure of the swarm state statistics and the players mode switching. Orientation of neighboring players also has an influence on play mode.

Listening to sounds appears to add a level of social interaction among players beyond the sharing or stealing of clusters. This observation is noted mostly from body language of largely unspoken cues for exchanging or managing clusters, which suggests a future research direction. Some players appear initially reluctant to interact, and this caution may be heightened by unfamiliarity with the sound textures and uncertainty how the sound may change if the swarm is perturbed. Some players do not wish to be responsible for “breaking something” or “making a noisy sound”.

All observations are subject to formal study. The project presents a promising setup for two kinds of controlled formal studies for playability: 1) Investigation of correlation between swarm states and play mode switching and 2) Investigation of differences in play behaviors when the evolutionary interface is presented with graphics alone and with both graphics and sounds.

Acknowledgement. We wish to thank Hiroki Sayama for sharing his code base to develop the playable implementation. Arthur Peters debugged the capacitive surface and data transmissions and coded the playable simulation version and authoring environment. John McCullough constructed the performance platform. Michael Chladil mounted the projection system and aided the overall implementation, and calibration.

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