Locus Diffuse

Rory Hoy

Digital Media MA 2020

York University

Supervisory Committee:

Doug Van Nort

Graham Wakefield

Table of Contents

1. Introduction

Musical play has acted as a vessel for a communal engagement, identity, exploration, and expression throughout history. While the style of play may vary from recital of composed works to free improvisation (and every permutation in between/beyond), emergent group playing dynamics are revealed through the complex interactions between each player (Borgo, 2006). This musical collaboration is a social ritual in which participants are afforded a medium of aural communication beyond the verbal. The individual soundings of each player can be represented as nodes within a network of participants representing interpersonal playing decisions, and the resulting sonic landscape as an emergent form of the established network. This collective action resulting in a cumulative sound object is then both the product of each node's (player's) input, and becomes the material informing each player's following action/reaction. In establishing a form greater than any individual's input, the collective group play dynamic is mediated by the enacted musical intentions of each participant in relation to each other player. *Locus Diffuse* was developed to investigate and facilitate these emergent participatory network structures within collaborative musical play, through an instrument in which users can "play" a space through interaction with its population of simulated agents and each other. Situated at the crossroads of sonic ecosystems, agent based musical systems, multi-user instruments, and networked performance, *Locus Diffuse* draws on a network of practices to produce a system that is used to interrogate the outcome of their resulting collaborative human/machine interplay. Much like the communication of participants within the sonic ritual of music making, the interplay of systematic components from each of these disciplines results in an overall form greater than their disparate parts. Extending from past research (Hoy & Van Nort, 2019) which will be discussed further within related work, *Locus Diffuse* explores the viability of generating a virtual sonic ecosystem through a multi-user instrument, facilitated by the group playing dynamic of human players in collaboration with a simulated collection of agents. Sonic ecosystems refer to interactive systems defined by the generation of a reactive audio environment in which self observing behavior and participant input result in audible dynamic feedback (Di Scipio, 2003). These works explore the relationships and outcomes established between human, machine, and ambient environment.

Locus Diffuse was initially planned for a full scale room implementation within the DisPerSion Lab at York university, however due to social distancing restrictions caused by the global COVID-19 pandemic, the project was required to pivot to a distributed virtual performance space. Shifting to this virtual space, players and spectators access a live audio/visual stream as a collective hub for generated activity, while controlling their input within an additional browser window or separate device. During this time of relative isolation, the project's aesthetic themes of connection and collaboration are heightened through this additional networking component, facilitating the communal play of all participants. Various changes to the project due to this pivot will be discussed throughout each section.

The behavior of the system's population of agents is modelled on networking structures found within the biological form of slime mold, harnessing natural processes of emergent form and community to mirror the collaborative generative network-like structure found within musical performance. This is achieved by affording sonification to the action of a virtualized organism that is intrinsically mute. A slime mold (specifically Physarum polycephalum) is a polynucleated unicellular organism constructed of a tubular network that allows transport of chemical signals, nutrients, and cellular mass through a pulsating flow of protoplasm (Vogel et al., 2016). As these organisms have been demonstrated to have repeatable emergent behaviors of aversion and attraction to environmental stimuli, they are well suited as a frame for mapping various interaction responses resulting in compelling ecosystemic behavior. Most notably their structure takes the form of thin physical networks between food sources in nature, and through implementing approximations this behavior *Locus Diffuse* generates flowing and reactive networks of autonomous agents moving between player positions. Player positions act as food deposits for the simulated agents, and movement results in variations of the environmental structure sensed by the collective simulated slime mold. This relative player position structure defines the layout of the network which the agents establish, and is reflected within the system's sonification. Due to the physical speed and appearance of slime mold, it could be misinterpreted as a static lifeform more akin to vegetation or fungi where all behavior is enacted at a (relatively) localized level, yet due to its deceptively efficient spatial searching and foraging behavior, incredibly complex and emergent forms result from physically simple actions. The slime mold lacks a central brain or neurons for processing and relies completely reflexively upon external stimuli directing it towards probable locations for food (an extended biological outline will be discussed in 2.1), resulting in stigmergy: self-organization produced by environmental traces and indirect communication between agents. This emergent structure and reactive behavior can be paralleled within the participants of the social ritual of "musicking" (Small, 1998) in which each player has a sensory experience of the whole while also contributing to it.

Locus Diffuse has explicit areas of inquiry it was created to investigate, located at the intersection of each of the disciplines it draws from, and related to how these disciplines also interact with each other. Related works will be presented within section 2 to trace the lineage of creation and scholarly thought through each of these disparate fields and point towards the goals of their amalgamation within *Locus Diffuse*. Design intentions and decisions will be explored within section 3, outlining the creative process and computational inspirations to lead to the formulation of the system. Derived from play session observations and participant responses presented in section 4, the paper will answer questions about the agent based sonic ecosystem/multi-user instrument and the established network's capability to function as an expressive musical system within section 5. These questions deal with the perception of players while playing the instrument/environment, the ways in which the sonic ecosystem fosters participant musical relationships, the projects classification as instrument in and of itself, and the role the simulated agents play within each of these areas of consideration

2. Related Works / Literature Review

Each of the disparate research areas addressed and employed within the development of *Locus Diffuse* point to a key aesthetic goal throughout various implementations of their themes and structures: Emergence. While "emergence" is a wide reaching term for a procedural creation or an unveiling of some kind (McCormack & Dorin, 2001), it will be demonstrated that each of these disciplines consciously involve the interplay of their own disparate components of various human/machine relationships, resulting in a whole. The rich explorative space of each of these processes results in behavioral, aural, and performative emergence culminating in dynamic and exciting artistic applications which in turn also facilitate communal musical play.

2.1 Harnessing Biology - Artistic & Computational Implementations

Natural Computing studies the applicability of natural phenomena within ecological systems and biological structure upon techniques for employment in a multitude of computational tasks (G.Rozenberg, 2012). Mimicry, approximation, and inspiration from structures found within natural systems (such as the human brain) have played a large part in the establishment of research branches that have resulted in the arrival of techniques like Deep Learning as the contemporary figurehead for the potential of intuitive and surprising computational output (Arel et al., 2010) and biologically inspired algorithms able to mutate to fit tasks through evolution

(Olariu & Zomaya, 2005). The advent of this research into mapping approximations/parallels of natural phenomena into computer simulations/computational techniques dates back to John von Neumann's Cellular Automata, which explored emergent structure through simple behaviors attributed to cells assigned the value 0 or 1 within a lattice. The relation of position between neighbouring cells would then result in a state change according to the rule that simulation was following. Incredibly complex behaviors have been shown to result from various rules, including exhibiting universality (Cook, 2004).

Slime mold, specifically Physarum polycephalum as subject of inquiry, exhibits extraordinary behavior for an organism which contains no explicit sensory organs (the surface of the unicellular body is capable of tactile, chemical, and photoreceptive sensing). Most famously, Tero et al. (2010) depicts the slime mold's ability to mimic the efficient layout of the Tokyo subway system, depicting the foraging and optimization ability of the slime mold as its most impressive quality. The body consists of a single cell, yet it can produce vast quantities of space searching tubules (pseudopodia). Each of these searching tubules are flexible and can change thickness to allow for a greater flow of cytoplasm. This cytoplasmic streaming is the force for all movement conducted by the slime mold (chemotaxis), relying on undulating propagations in the tubular structure to direct growth in a positive direction towards food/positive stimulus or away from negative stimulus (Durham & Ridgway, 1976). Upon searching an immediate area, the slime mold is able to then retract extraneous probing pseudopodia, reinforcing a minimal path between all available food sources within even complex spatial layouts such as mazes (Toth & Nagagaki, 2000). This feature of the slime mold's biology is quite exciting for physical route optimization and is the basis for computational incorporations of its behavior, which will now be presented.

Experimental applications of slime mold computational implementations have resulted in creating logical gates, computing Voronoi diagrams, solving resource heavy computation, achieving primitive memory, and solving other topography related problems (Adamatzky, 2010). The predominating resources for the simulation and research of slime molds is that of scientific analysis and experimentation into the mathematical formulation for their physical attributes. The mechanics in which movement, sporification, and nutrient transfer occur are also widely covered within both physical and simulation contexts. Adamatzky (2010) points to the computational applications of slime mold behavior as exciting within the field of “unconventional computing”, designs that implement behavior from the natural world as attempts to develop non-standard algorithms and computing architectures. Harnessing the behavior of slime mold and its ability to create and optimize network paths in both physical and simulated contexts is additionally exciting for artistic applications, due to its generative outcomes which can be manipulated through planned stimuli, or tracked for data which can then be applied to creative media.

Recent artistic applications of slime mold have been flourishing in tandem with computational implementations. Harnessing the electrical activity of an established physical slime mold network across a series of food nodes, Miranda et al. (2011) constructed a sound synthesis project which allowed for long term recordings of voltage at 8 various slime mold feeding locations. This data was then used within a granular synthesis engine to generate sonic events in chunks of 150ms, consisting of 8 partials relating to the electrical activity at each electrode. Granular synthesis is a technique to generate sounds from very small samples of source audio. Given a small enough delay between firing, these samples are perceived by the ear as continuous audio, often firing many hundreds of times a second. Iannis Xenakis (1971) first outlined the musical technique following the theoretical presentation of “quanta” in Gabor (1947), with the first real time implementation from Barry Truax in 1986, two years prior to the paper outlining the technique (1988). Each generated partial is the result of a voltage normalization mapped between 20Hz and 4kHz, with varied runs of the work mapping both frequency and amplitude or solely frequency to recorded voltage readings. As these readings were done over 1 week, synthesis has to occur off-line following completion of the recording. A real-time synthesis solution was established within a simulated computational approximation of Physarum polycephalum, where population density calculated at virtual electrodes estimates a realistic correlation to physical electrical potential readings. Miranda et al. (2011) present their use of physical slime mold as a “biological computing substrate”, noting its resource efficiency and cost-effectiveness vs other novel computational devices. This project was a key artistic and technological inspiration for the work done for *Locus Diffuse*, acting as a divergence point in which to extend the intention of the system to account for collaborative play, expressive musical gesture, and the incorporation of the self within the biologically simulated networked environment. Miranda et al. (2011) depict a clear technological and artistic application of the behavior of slime mold, mapping the organism’s networking behavior to musical output through both physically recorded stimuli and computer based simulation. In line with the inspiration of Adamatzky (2010) to work with unconventional computing methods, Miranda et al. (2011) place the incorporation of slime mold and its behavior as a novel computing paradigm worthy of exploration. While their main focus of the paper is indeed upon the physical living slime mold, the inclusion of a simulated organism shows the benefit of such a virtualization. Allowing for on-line audio generation and playback, virtual implementations of slime mold allow for the manipulation of its biological processes to favor artistic generation through variable environmental and behavioral parameters.

Past personal work with the simulation of slime mold has been within the realm of visual art. *Physarum: Biologically Informed Algorithmic Structures* mapped the trajectories of simulated slime mold-like agents, displaying residual and lasting trails left behind by swarming agents. Agents from *Physarum* were extended from a base implementation of *Boids* (Reynolds 1987),

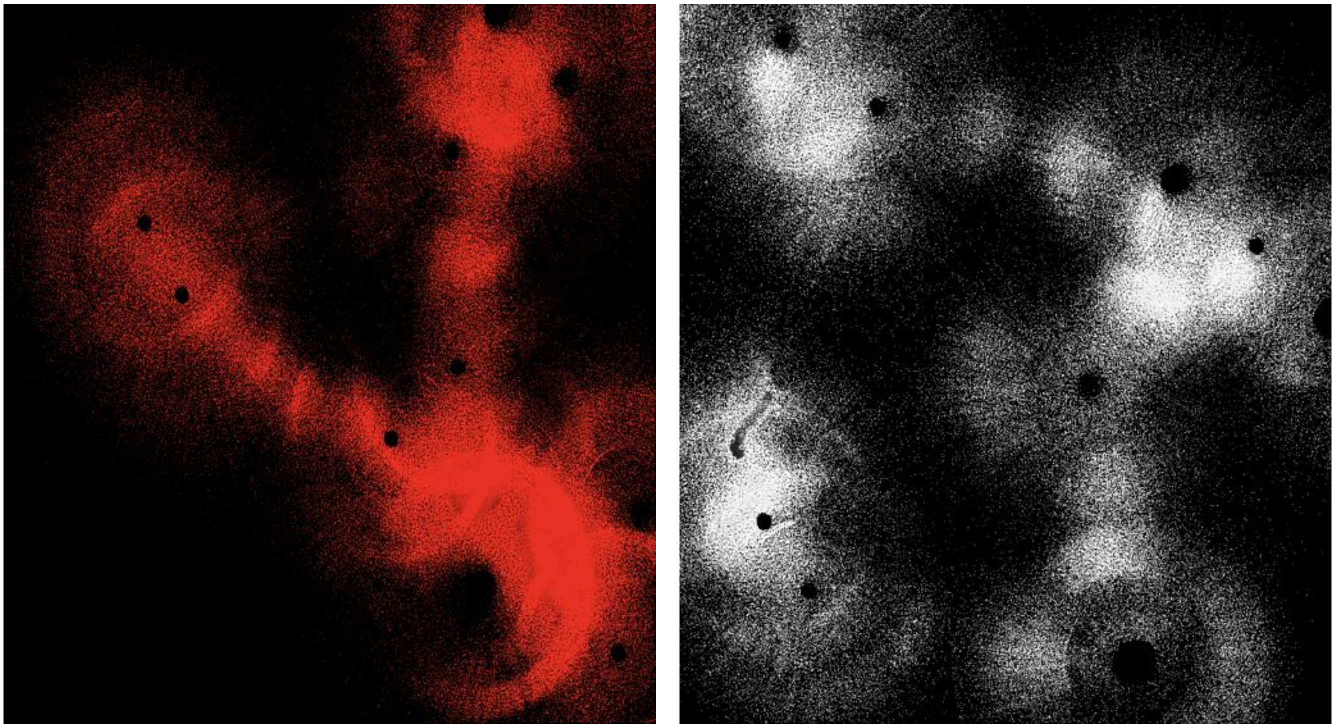


Fig. 1&2 - Two final generated images created through agent trail recording (~10 minute runtime) from “Physarum: Biologically Informed Algorithmic Structures”

autonomous agents which can traverse through a simulated world according to attributed behavior. Where *Boids* have various interactions relating to neighbour behaviour (collision, separation, cohesion), the simulated agents within *Locus Diffuse* rely completely upon trail deposits they release when sensing food (player positions) or another agent’s trail. The goal of this work was to observe the behavior of a simulated organism, and attempt to draw conclusions or identify hidden complexities within cell movement from temporally stacked traces of its movement. After a predetermined run time, generative images were produced from the networks formed between randomized static dispersed chemoattractants within the simulated space.The cellular simulation within *Physarum* was informed by the research of Vogel et al.

(2016) and technical implementation of Jones (2010), who outline the mechanics in which Physarum polycephalum is able to perform behaviours such as network connectivity optimization. Additional findings within Vogel et al. (2016) point to interesting physical and behavioral properties upon which participant interaction could yield compelling results for dynamic musical systems. Their research indicates that at a distance, two plasmodia would choose a source at random, potentially choosing the same source as the other mold, yet both organisms would always choose the same food source if placed next to each other. They present this as a potential result of the plasmodia having a communicative ability in order to plan and cooperate if so desired. Vogel et al. (2016) additionally reflect on the work of Reid et al. (2012) who found that temporal interactions between plasmodia occur in areas where feeding has already taken place by another plasmodium; strong avoidance behavior was observed in areas with previously eaten nourishment. This behavior also introduces the possibility for compelling simulation behavior, as past action within the environment would lead to an aversion area which could be considered during spatial composition of a reactive audio ecosystem.

2.2 Sonic Ecosystems as an Interactive Design Framework

The classification of a Sonic Ecosystem arises from questioning where, when, and how interaction occurs within a reactive environment (Di Scipio, 2003). To restate their definition from section 1; Sonic ecosystems refer to interactive systems defined by the generation of a reactive audio environment in which self observing behavior and participant input result in audible dynamic feedback. These works explore the relationships and outcomes established between human, machine, and ambient environment. A pertinent investigation within the field is questioning the role of the human participation within an established work. Some writers within the field dispute this necessity, opting for an experience purely mediated by an established system, while others find room for human interaction, allowing the autonomy of human participants within a space to deepen these potential interactions. Augustino Di Scipio challenged the common label of "interactivity" within musical systems through his *Audible Eco-Systemic Interface project* (*AESI*), where a machine/ambience interrelationship is understood to function as "interaction", rather than the typical cyclical relationship of human input resulting in machine output. Di Scipio notes that the majority of interactive systems employ a linear communication flow in which a participant's action is the singular cause of output. *AESI* moves away from this linear flow through its self-observing design, resulting in the ability of the system to understand and define its own internal state without outside interaction. This directly decentralizes the importance of human agency within the space, giving sole authority and control to the generated sonic ecosystem. Di Scipio describes this ability of system self observation as "a shift from creating wanted sounds via interactive means, towards creating wanted interactions having audible traces"; and claims that it is through these traces that compelling sonification can occur. *AESI* emits an initial sound that is captured by two or more microphones in the room. Relevant features are extracted from this capture, which are then used to drive audio signal processing parameters. Measurements on differences between microphone signals are used as additional control values, and the internal state of the *AESI* is set through functions defined by this ecosystemic concept. The four functions achieving this are compensation (active counterbalance of amplitude with the ambient environment), following (ramped value chasing given a delay time), redundancy (supporting a predominant sound feature), and concurrency (supporting a contrasting or competing predominant feature).

Past personal work (Hoy & Van Nort 2019) focused upon augmenting the Tuning Meditation from the practice of Deep Listening, through the implementation of a sonic ecosystem. Grounded in mindfulness and pure attention to sound, Deep Listening is described as "a practice that is intended to heighten and expand consciousness of sound in as many dimensions of awareness and attentional dynamics as humanly possible" by its developer Pauline Oliveros (Oliveros, 2005). The Tuning Meditation asks participants to engage in a cyclical breathing vocalization in which they match a tone that another participant in the group is making, and then provide a new tone that hasn't been made on their next breath. The project, "dispersion.eLabOrate" facilitated the generation of a sonic ecosystem in the context of the Tuning Meditation, and placed the system as an agent along with the human participants to examine the role of its presence in the piece. The project involved a pilot user study in which participants sequentially performed the tuning meditation 5 times, moving through each of the system's states, altering its responsive behaviors. Following the meditations, participants completed a survey answering questions about perceived behavior of fellow participants vs the system's output, timbral differentiation between the two, and confidence of recollection for each run. From written and oral responses it was found that participants tended to acclimate to the presence of the machine as another participant within the tuning meditation, using its output as tones to follow and noting the response of the system to their tones. For example, one written response stated that "the electronics held (the) same importance as other performers", pointing to how the agency of the system is clearly participatory while also facilitating the generation of the sonic ecosystem. Where dispersion.eLabOrate placed the machine as a participatory agent in the ecosystem through 9 points of interaction (the ceiling microphone array) and its resulting audio, *Locus Diffuse* distributes this presence further through a collective of hundreds of simulated agents culminating on a singular participatory entity interacting with player input. Branching from dispersion.eLabOrate's process driven by human listening/vocalizing networks of interaction, the sonic ecosystem of *Locus Diffuse* is facilitated by the intersection of this human participatory input and the virtual network of activity to result in a space which can be performed as a multi-user instrument.

Self-observation and its outcomes of equilibrium and adjustment are explored critically by Haworth (2014), who questions if the ecosystemic model should be updated in “alignment with current thought on ecosystems, which deemphasizes stability and regulation in favour of imbalance, change and disorder”. Haworth’s statement can be understood as a push for our conception of ecosystems to have room for movement away from a ‘steady state’ paradigm, where a system will always return to a form of equilibrium due to inbuilt feedback networks. Identifying two distinct ‘strands’ of (sonic) ecosystemic thought, Haworth notes Di Scipio and Simon Waters as presenting two views on the topic. Haworth positions Di Scipio as “conducting a cybernetic experiment in an ‘unknowable’ system”, contesting the linear communication flow he sees as basic in regards to affording interaction. Di Scipio’s form is a cyclical closed system in which traditional control structures of linear systems in interactive audio works are dismantled in favor of a self-regulated ambient sensing - representing “a formal ontology in highly technologized music”. Meanwhile, Waters moves away from tendencies to instrumentalise technology, instead highlighting the role of human attention upon relations formed between each of the components within a generated ecology. Waters posits, “The notion of Performance Ecosystem enfolds all three concepts (performer, instrument, environment) and allows room for the undecideabilities of the virtual domain” (Waters, 2007), depicting this interrelated nature of ecosystemic components as primary over their intersection with the “virtual domain”.

The existence of these differing viewpoints depicts the various approaches possible within the realm of sonic ecosystems but does not present one path as absolute. Where the removal of human input within the system can result in dynamic and evolving output, so too can a system that revolves around the interplay of human/machine/ambience. The original in person formulation of *Locus Diffuse* was planned to play off of the self-observing vocal response feedback within the human/machine/ambience design of dispersion.eLabOrate. In this networked version of the instrument, the self-observing behavior of the system is conducted at the agent level. Each agent is only aware of its own state (vs a sense of other agent's current states) and acts according to its sensory input from the environment. Environmental changes and subsequent sonification are a result of the interplay between players and the system's agents. This responsive agent action results in the overall formation of the network structure and sonic environment which is aligned with the cyclical performer, instrument, environment paradigm of Waters (2007), but by actively instrumentalizing technology for human input and expressing in concert within the machine.

2.3 Agent Based Musical Systems Facilitating Sonic Ecosystems

An early work of sonic ecosystems incorporating simulated agents is Eden, discussed in McCormack (2009). The work was an artificial life evolutionary sonic ecosystem in which agents lived in a virtual environment and received food by the presence of viewers in the space. Eden's audio output is driven by the behavior of these simulated agents within their structured environment and is focused on the reactive behavior of agents in relation to each other. Their singing behaviours call to other agents and generate the continuous soundscape that permeates the work. Residing within the same ecosystemic design paradigm/classification outlined through Waters (2007) in which the interplay between machine, human, and ambience results in the encompassing ecosystem, key similarities are found between design considerations of Eden and *Locus Diffuse*. McCormack (2009) outlines two problems that the design of Eden intended to answer: "how we can create a virtual AL [artificial life] world that evolves toward some subjective criteria of the audience experiencing it, without the audience needing to explicitly perform fitness selection and, second, how the relationship between real and virtual spaces can be realised in a way that integrates those spaces phenomenologically". While there is not an implementation of agent evolution within *Locus Diffuse*, the goal of establishing some aspect of autonomous emergent behavior in regards to human participants parallels this design consideration from Eden, placing key interest on the art object as a whole and the reciprocal experiencing and acting of ecosystem participants. The second design problem of establishing coherent play between physical and virtual spaces resonates with the original in-person conception of *Locus Diffuse*, where player position in physical space aligns with virtual input and agent reaction.

Bown et al. (2011) examine various models for creative output from multi-agent and ecological systems, proposing five elements which constitute their proposed set of “minimal ecosystemic specifications” of a creative domain. These proposed elements include space, materials, features, actions, and processes. Space: a topologically constrained dimension in which location and relative location can be defined, allowing for a set of neighbourhood proximity relations to be defined. Materials: Make-up of the environment, quantifiable (eg. pixels, audio samples, midi values). Features: Analysis of space and materials (the art object) for agents to perceive the environment. Actions: Agent modifications on environmental materials. Processes: Natural events within the simulated environment (eg. energy transfer, chemical diffusion). These five elements can be seen within each of the past examined agent based projects here and further discussion in section 3 will note how these elements come into play within *Locus Diffuse*.

2.4 Multi-User Instruments

Developed to explore close relationships between players and resulting play techniques, multi-user instruments allow many participants to perform through a singular instrument. Where acoustic instruments may be suited for the interaction of many due to size which can accommodate multiple people, physical interactions are thus confined to physicality, limiting the amount of interaction possible simply through the physical space taken up by other participants.

This paradigm has expanded through the proliferation of digital instruments. Designing for a multi-user instrument context requires explicit consideration of the intricacies and collaborative experiential content which the instrument/system needs to convey. Jordà (2005) outlines key aspects of multi-user instruments that facilitate shared collective control within a musical system. These properties include number of users, user roles, player interdependencies/hierarchies, and the flexibility of each of these components. The ability for a multi-user instrument to accept a set or unbounded number of players will limit or form the basis for what is achievable in terms of interaction and determine a framework for the potential dynasicsm of player roles. Following this, how do these roles function together within a communal playing environment? Jordà (2005) questions the definition of a multi-user instrument through the interactions it affords. Were a system to allow multiple players yet afford no interdependencies between its players, its classification as a multi-user instrument may be debatable. Jordà (2005) continues by proposing interaction paradigms in the realm of acoustic instruments, referring to many hands piano playing in which various roles are delegated. If all participants were to play purely on the keys it can be seen that there would be an unimportant amount of interdependency between players, beyond the inability to play a singular key at the same time. Were the roles of the piano to be delegated to one player who is playing the keys and another manipulating the strings, complexity arises in the ability to directly engage in interplay between the generated sounds of each player through physical manipulation. This would move each player into a “nonessential” role, as either can produce sound independently. Jordà (2005) states that the more interplay and flexibility is introduced within a system, the greater the complexity of the final expression.

Contemporary implementations of multi-user instruments challenge traditional interaction paradigms through incorporating novel mixes of control interfaces and sensory technology.

Erdem et al. (2019) outlines the design considerations for a dance controlled multi-user instrument entitled *Vrengt*. Musical collaboration is achieved through composed segments focusing on varied interaction mappings in which the dancer and musician work in tandem to generate and shape the sonified output together with the machine's data processing and sound capabilities. Their mapping of EMG (electromyograph) and breath data from the dancer emphasizes the applicability of sonic control through manipulating physical space. Data resulting from the dancer is used to drive synthesis which is then also acted upon by the accompanying musician. This modulation of dance generated audio by the musician is akin to the dispersed roles of the many hands piano described previously. Where the dancer is in control of the "keys" of the audio generation, they are in collaboration with the musician playing the "strings" who is modulating their input and is capable of autonomous audio generation. Neither participant can occupy the same interaction "space" as the other due to their distributed roles, but both are acting upon the greater sonic output of the instrument. Where both roles can be seen as "nonessential" (Jordà, 2005), complexity arises in their interdependencies. Audio generation influences the actions of the dancer and cyclically informs the generation of new audio through interpretive reaction. The authors speak to this mapping as resulting in "shared control", portraying intimacy between each of the systems established relationships (dancer/musician then duo/machine). Where the original ideation for *Locus Diffuse* aligns itself more closely with this embodied room scale interaction paradigm, the networked composition version of the project abstracts this interaction to a browser based control surface, and affords the same interaction schema in regards to player position affect and simulated agent reaction.

Rotondo et al. (2012) echo the findings and claims of Jordà (2005), where the result of incorporating dynamic interplay between varied roles of players is intriguing and expressive system output. This contrasts systems with uncoupled/lacking interdependencies resulting in final output which is essentially the general sum of all individual player contributions. Their paper describes two instances of creating multi-user instruments with varying interaction paradigms. The first, *Feedbørk*, relies on interdependencies drawn between two performers within an asymmetric control distribution. The first player manipulates a touch screen to generate audio, while the second controls the orientation of another device directed towards the first. The devices display their live video feed from front facing cameras, capturing a recursive and infinite view of each other device. The resulting changes in video feedback due to altering a recursive video stream are then mapped to additional audio features. Players reported an enhanced sense of cooperation over past traditional collaborative musical experiences due to the physical closeness required and from "the intermodal nature of its performance, which necessitates close attention to be paid both visually and aurally". The second piece, *Barrel*, establishes a 9 player multi-user instrument in which one singular player conducts the actions of the 8 other players which follow a symmetric mapping scheme. Tracked through two 3-D position sensors each, a player can control the pitch, loudness, and duration of produced notes, following instruction by the 9th player conductor. Rotondo et al. (2019) posit that while the majority of players are playing within the confines of the position tracking interaction which includes no interdependencies with fellow "arm" players, the conductor's instruction (which can be directed to the whole group, sub-groups, or individuals) results in a complex system through the interpretation of enacted gestures by fellow players.

2.5 Networked Music

Networked musical performance has a rich history within the avant-garde and experimental music contexts and refers directly to structures formed between groups of players within the social ritual of sounding together (Weinberg, 2003). Recently in terms of the history of musical creation, these networks have also been explored within the realm of telematics, employing the internet as a facilitator of such musical collaboration (Oliveros et al., 2009). While *Locus Diffuse* was not initially devised as an internet networked piece, it is fortunate that such technology is available and widespread to allow such a pivot to take place. Incorporating a telematic aspect into the play of *Locus Diffuse* required abstracting interaction from planned in-person body tracking to an accessible online interface, actively considering the aesthetic, performative, and experiential changes that would occur as a result.

Weinberg (2003) presents the concept of an Interconnected Musical Network (IMN), live performance collectives in which player interdependencies result in dynamic social relationships and reactive playing. Weinberg states a successful musician network would promote "interpersonal connections by encouraging participants to respond and react to these evolving musical behaviors in a social manner of mutual influence and response", pointing to the performance of music as a social ritual. Additionally, exploring a biological metaphor of the established network, Weinberg (2003) states:

> "Such a process - driven environment, which responds to input from individuals in a reciprocal loop, can be likened to a musical 'ecosystem.' In this metaphor, the network serves as a habitat that supports its inhabitants (players) through a topology of interconnections and mutual responses which can, when successful, lead to new breeds of musical life forms. Such IMN ecosystems differ from other closed process based musical networks in the significant role they provide to the real -time input from a society of live performers."

This directly parallels the key ecosystemic theme of *Locus Diffuse* and points back towards the culmination and amalgam of these disparate practices as viable emergent art making forms which can foster a connected musical collaborative space. Following the discussion of multi-user instruments, it can be seen that the goal of such musical systems is to engage players in communal creation. It can then be positioned that all “true” multi-user instruments which establish varied roles and interdependencies between players as described within Jordà (2005) should result in an IMN between players. These instruments may vary through the range of novice to expert IMN system classifications, however their goals intrinsically place them as facilitators of such networks. It should be noted that while all multi-user instruments should indeed result in some form of an IMN, it is clear that these networked relations can also be established between an arbitrary instrumentation grouping not necessarily incorporating multi-user instruments.

To restate, IMNs do not specifically refer to internet based musical performance, but to parameter-sharing networks and methods of play that could engage the general public in musical experiences, connecting others through the social attributes of music. Tracing these aesthetic hopes through the history of music and into modern applications of such networked structure, Weinberg highlights key figures in internet musical experimentation in the League of Automatic Music Composers and The Hub. As a member of The Hub, Gresham-Lancaster (1998) discusses the translation of locally networked music to the larger context of the internet stating “In my opinion, there is a tangible difference in that the use of the Internet must be met with new methods and aesthetics”. This statement followed a disappointing outcome from remote tests in which the interdependence of their work was challenged from cascading crashes or freezes if something went awry remotely. It is apparent that translating local interaction to a remotely accessible shared space requires clear consideration through musical interface and interaction design.

Allison (2013) outlines a design paradigm for collaborative performance interfaces using the mobile browser, also considering distributed performance systems which employ such interfaces. Distributing control through the web inherently allows the location of performance to be decentralized. However, this spatial decentralization is not a guarantee of a given displacement scale of course, as players could interact with the system from within the same space or across the world given the established network infrastructure. This paradigm also does not necessarily point towards a multi-user instrument context, however this is one possible application of such a design. Allison outlines various network topologies which can be employed within a telematic network musical control context. An Autonomous Collaborative Performance System would entail self-contained installations of an instrument upon each participant's device, encapsulating a UI, input/output mapping, and sound production engine. Allison presents this architecture as suitable for laptop orchestra, and mobile music contexts in which audio benefits from spatial variance due to player location. Contrasting this, a Centralized Audio Production Distributed Interface system would consist of a central update server tasked with receiving messages from and refreshing remote interface information. This information would then be used to generate audio on a centralized audio production machine, removing the need for potentially hefty installs or processing on remote devices and allowing the barrier for entry to be quite low. This paradigm is employed within *Locus Diffuse* to allow remote play from anywhere with a stable internet connection.

3. Artistic Intention & System Overview

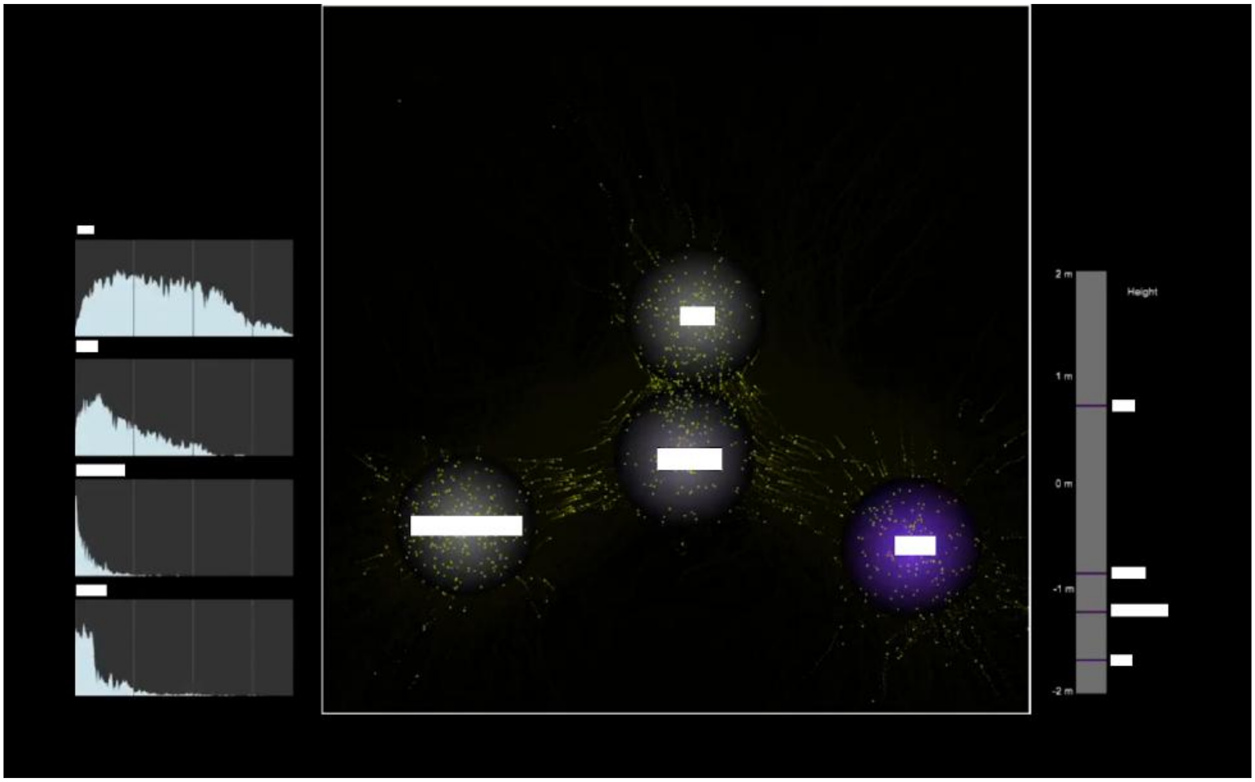


Fig. 3 - Stream view of the system in its default agent behavior state (player names censored)

At the forefront of the design intentions for *Locus Diffuse* is the sonification of networked connectivity; establishing nodes within a virtual environment to explore the viability of generating a compelling multi-user instrument resulting in a sonic ecosystem. While this project was not intended to be established as a networked piece in terms of the incorporation of internet connectivity, its transition to this form has emphasized key thematic inspirations for its development. Where the original network of physical players within the lab space was aimed at exploring the embodied nature of physically orienting oneself as a member of an audio generating network, the realized form of the project abstracts this embodied position to distributed telematic control. The network structure is pervasive in all forms of communication which allows hierarchies of connection to be established, distance can be measured, and causal chains to be followed and understood. *Locus Diffuse* introduces a simulated being that is physically changed by the movement of players, acting as the arbiter in which communication can occur, permeating the environment as a traversable living medium. The main sonification of the system is only achieved when interacting with this mediating "other", and this other only can exist/function through the symbiotic relationship of players to it and each other. *Locus Diffuse* gives a voice to the naturally alien/unheard, and allows it to speak for all participants in a collective play in conversation with their input. Control is not centralized to one participant, nor surrendered to the simulated organism. This control facilitates the musical composition of space, focusing on sculpting a form for which the simulated organism populates spatially and aurally. Given the uncanny timely nature of its development, *Locus Diffuse* promotes proximity and play within space in a time where social distancing needs to be enforced. These remote nodes (telematic players) tapping into this virtual space move the local connections made to a macro scale, and allows the project to link disparate players throughout the world to a shared collaborative and living audio space.

The ecosystem is controlled by the autonomous behavior of a simulated slime mold, a singular organism consisting of hundreds of cytoplasm concentration agents which disperse through the virtual environment to link each player. Where scholars like Di Scipio attempt to distance the interaction models of their work away from the human centric or even human participatory, *Locus Diffuse* enacts a symbiotic relationship between the simulated slime mold and active playing of the environment by incorporating their action as the key to generate varied sonic experiences. The simulation is contained within Max MSP, composed of a JS script directing agent control and control data for grain sonification, JWeb in Max for visual feedback in an HTML page, and audio synthesis control patches additionally held within Max. Online interaction is conducted through MIRA Web and live audio & video hosted on the steaming service Mixer. The following sections will highlight key system components while delving into the aesthetic and artistic decisions driving each of the technological implementations. While the resulting generated audio is the key artistic output of the system, it is important to first foreground the simulated biological function, player interactions, and development progression from which the final sounding results.

3.1 Simulated Agents

Locus Diffuse's simulated slime mold is inspired and informed through the biological behavior of the Physarum polycephalum, but does not represent a purely scientific model of the organism. Through various approximations and artistic liberties for the (subjective) betterment of aesthetic outcomes, the project presents a simulation which successfully follows behaviors found in the physical organism and applies them to a dynamic multi-user instrument sonic ecosystem resulting from the generation of optimized network paths between each player. Player positions are represented as radial gradients within the simulation. All autonomous agent behavior is implemented within JavaScript, using the glMatrix vec 2 module for calculating necessary forces on each agent and checking environmental stimuli. Agents follow a few key rules that allow them to reproduce the search paths of slime molds, resulting in connections between environmental nodes. As discussed in 2.1, these rules are aligned with and are presented within Jones (2010), extended in *Physarum: Biologically Informed Algorithmic Structures,* then adapted for a musical context.

Agents spawn in the very centre of the simulated environment and are given a random starting vector. The seed number of agents (500) results in a fairly evenly dispersed ring outwards from the centre. Each agent has a centre mass which is equipped with two extraneous sensors positioned at an angular offset and set distance ahead of the agent's direction of travel.

Sampling of the environment is conducted through these sensors in order to determine upcoming actions for each agent,allowing them to turn and face food once it senses a deposit close to itself. Jones (2010) suggests a symbiotic relationship is necessary between a data map (storing current agent positions, sensor locations, and any potential pre-patterning stimuli) and trail map (diffusing food sources and agent trails) for proper systematic reaction of cells and environment. This is achieved as separate HTML canvases to allow for relevant visual display of the simulation state, and hidden visual layers which can be sampled for gradients of trail vs empty environment data that can also be toggled to reveal or hide agent trails. Agents sense the world through their current position, and through sensors located at 45 degrees left and right from their current direction. As the simulated world is quite large (1000 x 1000 pixels) in relation to the size of the cellular bodies (2 pixels), it is necessary for each cell to have sensors that have a far reach (350 pixels), allowing them to “smell” food sources and trails from a reliable distance. This simulated world exists as the feature of “space” from Bown (2011), a topologically constrained dimension in which location and relative location can be defined, allowing for a set of neighbourhood proximity relations to be defined. The pixels of the space constitute its “materials”. Agent sensor distance can be tweaked to result in varied density of agent clusters, where a lower sense distance will cause stickier behavior between agents due to trails being deposited closer to food sources or sensed trails, or loose groups of agents which have the tendency to wander more due to their ability to sense trails and energy at a greater distance. As mentioned in Jones (2010), this large distance would normally be considered remote sensing separate from the body of a simulated cell, however this distance also acts as the “overlapping actin-myosin mesh of the plasmodium gel system”, allowing the cells to understand their position relative to each other and to nutrient sources. Jones continues, adding that the offset sensor design can result in a strong local coupling of agents in which the input of one agent could be directly a result of nearby cellular action (residual trails from recent sensing). Optimization of the agent network is achieved through a decaying chemoattractant trail deposited and sensed by each agent. Trails are deposited when an agent senses food, or senses another agent's trail. This results in cascading trails and paths towards food deposits, following the flow of the cytoplasmic streaming. Trail deposits constitute "actions" as presented within Bown (2011). As these trail deposits diminish over time an established network is strengthened when searching agents return from an unsuccessful search, or active cytoplasmic agents travel to-and-fro along the stream, continually depositing additional trails. These new trails reinforce the strong main arteries established between nodes. Additionally, as trails decay over time new reinforced trails are kept as the most active routes - constituting "processes" from Bown (2011). Agents are continually sensing the environment for input (fluctuations in averaged RGB content of either the food or trail canvases). Sensors check for light values upon the food and trail canvases, average the data collected, and then determine the direction the cell should face. The cells keep a running memory of the last strongest "smell" they've sampled and choose what to do based on the current reading. For example, if the cell senses its current highest reading on its left sensor, and that value is higher than the last sample's highest value, the cell will turn to face that left sample position. If that new left sample were to be less than the last highest sampled "smell", the cell would continue on its current course.

Each agent mimics the cytoplasmic streaming behavior of a slime mold, and represents a theoretical main concentration node of this cytoplasm. A biological slime mold does not have these nodes; they are used within this simulation to approximate the flow and trajectory of such cytoplasmic streaming and searching behavior. The main function of this cytoplasm within the biological slime mold is to facilitate movement for the through controlled pulses following chemotaxis (movement corresponding to a gradient of increasing or decreasing concentration of a particular substance resulting in attraction or aversion), as well as carry nutrients throughout its body. Agents representing concentrations of cytoplasm within the simulated slime mold body are able to traverse beyond the “edge” of the emergent slime body, seemingly alone in their search. These represent the searching tubules dispersed by the slime mold (pseudopodia), which probe the surrounding environment for nutrients. When a network is established between nodes and attempts to optimize, these biological pseudopodia retract and divert their cytoplasm along main arteries.

Like the biological drive of the slime mold, the simulated agents are in search of energy to keep moving and find more food. Energy is a value held by each agent and player attractant node which directly maps to qualities of each granular sonification (will be discussed in 3.3). In relation to agent function, energy results in increased motor response for faster movement and the ability to react to stimulus more abruptly (faster rotational movement towards trail or attractant). Reaching and engulfing a player will result in an energy gain for the agent, mimicking the retrieval of energy in food sources for the biological slime mold. Mimicking the secretion of enzymes which dissolve the slime mold’s food, and allow for the ingestion of nutrients within the physical world, simulated agents actively gain energy while upon a player (dissolving food), while passively losing energy during wandering and travelling between nodes. While a physical slime mold evenly disperses its energy through its body, or focuses on certain areas for the propagation of pseudopodia, *Locus Diffuse* keeps individual energy values for each of the agents. Following this, each agent can then produce a unique sonification in relation to the amount of energy it contains. Storing these localized energy values and not distributing them throughout the body allows for unique pitched grain voicing for each simulated agent, and also visually represents the agents success at finding food as an individual searching tubule of the slime mold.

Simulation of the slime mold allows for manipulation of time, allowing for on-line sonification of its action. Where biological slime mold crawls at an extremely slow maximum speed of ~5mm/hour (Latty & Beekman, 2011), the simulation can act as fast as desired - thus speed is chosen in relation to current energy to ensure regular granular excitations in the sonification, and appropriately reactive following of sensed energy deposits. Upon expelling too much energy, the agents become lethargic and slow to react to any stimuli other than eating (eg. if a player moves to a concentration of low energy agents they will immediately start feeding the malnourished agents). When agents reach almost 0 energy, they then go into a semi-hibernation like state, where movement is extremely slow. If these agents are surrounding a player who has also expelled all of their energy, the agents will be in stasis, stuck in orbit around the current player. This mimics the slime mold's extremely resilient nature, in which dehydration, lack of food, and cold temperatures can all result in the slime mold to be “stuck” in position. Visually this manifests as a white, chalk like appearance within the biological structure. If an agent’s energy is reduced to zero, it will no longer be visible, move, or cause audio synthesis. This places the agent in a death/hibernation state which can be reawakened if another agent within close proximity reaches a high threshold of energy. The maximum population of agents within the simulation is 1000, and revived/birthed agents are from the pool of currently dead/hibernating agents. Where agents do not typically share energy, this birth/reincarnation of agents is triggered by the health of the slime mold represented by individual energy values. The physical slime mold can be “revived” from this state if again rehydrated, or if it senses food within its proximity. Within *Locus Diffuse* this re-energization is expedited to result in active sonification of perceivably increasing energy values. Another interesting physical phenomena within the real world that is emulated within the simulation is the ability for the slime mold to split into separate versions of itself. If part of a slime mold becomes separated, it will attempt to rejoin the other section by searching the immediate area (Vogel et al. 2016). This new section can continue to live autonomously from the original, able to forage and further explore its environment. Within *Locus Diffuse*, splinter groups of slime mold may occur between local networks of cytoplasm agents. If separated too far from surrounding player attractants, “lost” cells will continue to live autonomously and again can rejoin a group by chance while foraging or by sensing a trail/energy source.

3.2 Interaction Mapping / Mapping Interaction

The topological structure of the established network resulting from the traversal of agents across the simulated space is the outcome of deliberate spatial decisions made by each player in collaboration with the current distributed nature of the simulated slime mold. This interaction paradigm differs from a variety of traditional musical interactions from both classical instrument playing, and electro-acoustic instruments. Traditional acoustic instrumentation tends to have a relatively concise one-to-one action mapping between player action and sound output of the instrument. This can be demonstrated in the piano - striking the middle C with consistent pressure between key hits will produce the same note; however it is true at some degree that measurably exact reproduction of any repeatable tone would be unlikely no matter how consistent the playing may feel. Extending this to the violin, there are infinitely many degrees of pressure, tilt, and finger position combinations which result in a unique sound. While physically improbable, theoretically perfectly reproducing this combination of instrument excitations will result in the same sound. There are a myriad of factors which result in a varied final timbre heard by the ear including minute fluctuations in playing, and environmental factors affecting the air transmitting the sound and physical properties of the instrument (Harris, 1966). Past these details it is theoretically true that the same piano key, saxophone fingering & air pressure, violin bow pressure & fingering, etc. will result in a perceivably identical timbre. Many electronic systems challenge this direct mapping. Dynamic mapping can be achieved through electronic instruments which could not necessarily exist within acoustic instruments, while still having the possibility of one-to-one mappings, or combinations of both. This mapping layer is key in establishing the very feel and essence of the instrument (Hunt et al., 2003), as interaction may be cross-coupled, convoluted, or as simple as desired. *Locus Diffuse* plays off of this aesthetic inversion of instrumental mapping in creating an instrumentalized performance ecosystem; allowing the instrument to map to the player. “Mapping to the player” could be interpreted in many ways within the electronic instrument practice, following the potential for an instrument to perform analysis on player input and alter internal mappings as a response to specific action or given parameters. This mapping of players refers to agents physically congregating to the virtual locations of players, and these locations then map the generated audio to the appropriate virtually spatialized locations. As the cytoplasm concentration agents permeate the simulated room, they must come in contact with a player’s position to result in sound. It was important to provide the player with an audible queue to denote that they are moving (speed mapped to high frequency tones), but their moving does not guarantee the sounding of the primary voice assigned to each of them. This symbiotic process of providing energy for the slime mold, and hearing the resulting sonification of energy being gained (firing an audio grain when eating) creates an interesting power structure within the sonic ecosystem, as its form and output are reliant on each player and the simulated agents. Intention resulting in deliberate sonification while playing with *Locus Diffuse* is mediated by the actions of others within the space and the action of the system agents, rather than affording the player freedom to sound independently beyond the sonification of their movement.

In designing a multi-user instrument it was paramount that one player should not have the power to dominate the sonic landscape without the enacted consent of the other players, again mediated by the simulated agents. Participating within the shared audio space is enacting the social ritual of musical play, thus the roles and capabilities of players along with the function of environmental agents were established to rely on all players. Initial concepts and tests of the system would allow an uncapped number of players into the system, barring physical space restrictions or technical limitations. This was reduced to focus on 4 players to account for clear and discernable sonifications for each player, reduce computational complexity, and to ensure perceivable interconnected behavior between players and the simulated agents as a result of spatial positioning choices. Where Vrengt (Erdem et al., 2019), Feedbørk, and Barrel (Rotondo et al., 2019) disperse interaction roles and interdependencies solely among human players, *Locus Diffuse* assigns these role asymmetries between the human participants and the system as an active agent within the simulated environment. This paradigm extends from the incorporation of the machine as a player within an ecosystemic context during dispersion.eLabOrate (Hoy & Van Nort, 2019), foregrounding the human/machine relationship as viable and expressive within a sonic ecosystem. Returning to analogy and mapping of interaction within multi-user instruments from Jordà (2005), it can be seen that the system's reliance on player presence to produce sound places the player as an essential role within the system. Reciprocally, the player is limited in their sound production without the presence of the environmental agents. This symbiotic relationship deems the roles of both player and system to "essential" to some degree. Where Jordà (2005) may claim this is not the ideal interplay scenario for a "desirable and inspiring situation" within musical creation through multi-user systems, I claim that the symbiotic essentiality of players establishes a sonic ecosystem in which the interplay of machine and human gives rise to a dynamic collaborative play environment with emergent sonic qualities. Waters (2007) posits, "The notion of Performance Ecosystem enfolds all three concepts (performer, instrument, environment) and allows room for the undecideabilities of the virtual domain”. These ‘undecideabilities’ are where complexity and exploration can happen within the social ritual of play within a sonic ecosystem; where ephemeral states and communal attention within the social ritual of musical play arrive at a space greater than the sum of its parts.

3.3 Sonification

The aural aesthetic goals for the project come from attempting to emulate a pervasive environmental texture defined spatially by the positions of each player. A unique voicing emanating from each participant was key to ensure a personally recognizable timbre for each player, and to also add depth to the sonic landscape. Initial tests and development prior to agent energy implementation centred around the manipulation of identical source content for the granular sonification of cytoplasm streaming agent nutrient absorption (eating), resulting in subtle fluctuations in terms of timbre but overall this resulted in dull and relatively static movement of sound within the lab based version of the project. Housed within the DisPerSion Lab’s extensive 28 speaker system, this subtle movement was still timbrally compelling, however this is likely due to the incredible aural capability of such a speaker system rather than a necessarily well crafted sonic output of the musical system. Moving to this networked version of the project clearly revealed that this limited sonic palette would not convincingly result in a dynamic mutable texture which would accurately represent the player's actions appropriately. Extending this palette to encompass 4 separate frequency ranges and timbres allows each player to act as a distinguishable, yet cohesive member of the collective sonic texture. Public play sessions were done in two waves (Explored further in sections 4 & 5). Chosen audio sources were edited between waves for refinement of sonification aesthetics, and to determine changes in play due to these varied timbres. Source material for Wave 1 players was inherently textural in nature, incorporating slime, synth drones, running water, and a filtered conversation as audio material. Sources for Wave 2 tests were chosen to result in crisp and salient sonification - timbrally in line with clicking, dripping, droning, and swarming noises.

Mapping of player interaction to sound went through many forms during the development of *Locus Diffuse*, with various interactions resulting from distance between players, player speed, and energy of both players or simulated agents. Sonification is primarily triggered through the consumption of energy by a simulated cytoplasm streaming agent, enacting the potential generation of a single grain from a granular synthesizer per tick of energy gained. Within *Locus Diffuse*, trigger messages correlate to an instance of eating at a particular player location, caused by an agent which has taken energy from the player's representational chemoattractant. As a default, there is a 1 in 500 chance of a grain triggering upon an agent gaining energy from a player occurring every tick of the simulation. This sounding potential is randomized to avoid continuous audio output from a single agent consuming energy, while also mimicking variance in time needed to break down and process energy from food sources. These messages include the energy value of the agent which triggered the sonificiation, and the player which is currently acting as their host/source of energy. Messages are sent from the logic JS running in a JWeb object out to Max, where they are then routed to one of four granular synthesis engines, each corresponding to a different player. Each of these granular synthesis patches contains the Petra buffercloud object (Müller, 2016), which allows for easy setup of granular contents and accurate single-grain firing. Incoming trigger events are checked for current energy value and maps this value to a pitch multiplier of the source material. Granular buffer content is pre-set to aesthetically pleasing potential grain start/stop locations within the source material, and establishes a range for grain length. As energy values range from 0 - 100, values are scaled to an appropriate pitch range multiplier between 0.5(±0.2) and 1.7(±0.2). Granular synthesis output is then sent to the corresponding player source position within dispersion.Spat.Spat, the DisPerSion Lab's extension to IRCAM's Spat Max Library (Jot & Warusfel, 1995). Apart from the generated granular output of the system, the only other sonification occurs from player movement itself. Variances in x and y spatial movement result in beating high frequency tones from two sinusoidal oscillators with varied ranges per player, additionally spatialized to player position. Tracking rate of change in both axes, higher values are mapped to higher frequencies and lower volume, while slow movement will result in lower (still quite high) frequencies and more pronounced volume. Aesthetically and informationally this gives a sense of direct action to the players and signals a shift in the generated structure of the agent network due to player position changing.

Spatialization and virtual room simulation is key to the immersive quality of *Locus Diffuse*. IRCAM's spat allows for the generation of a virtual room through which all input sound can be processed. After defining input sources and positions of real-world speakers within the patch, sources and input audio can be moved dynamically while being reflected in real-time within the simulated audio landscape. Player verticality is only represented spatially within the sonification of the system, and has no result on the behavior of agent movement. Vertical movement conceptually maps to localized agent behavior at a given player's position being stretched up and down within the audio space but still allowing interactions with other players at their respective planar heights. Another way to conceive of the system is a sonic material being pulled in the vertical direction of the player. As these vertical changes do not have bearing on the 2D simulation of slime mold agents, each player's sonic activity (pre-spatialization) and simulated position to one another is not affected. Were the simulation also conducted in 3D, travel time between players would increase given vertical displacement. In the current 2D simulation form, connections between player nodes can be thought of as projected down upon the surface of the virtual environment, while their spatialized placement may be above or below this location.

The DisPerSion Lab extension of Spat 5 allows for the dynamic changing of room perceptual qualities through established states, effectively interpolating between simulated room structural parameters. The use of this room interpolation is not currently implemented within *Locus Diffuse* as a dynamic play parameter but may become a reactive feature for various play states. Updating source position to match player position is necessary to ensure continuity between the visual location where sound is triggered within the logic JavaScript and JWeb display with the sonic reality being formed within the spat engine. Spat receives appropriately scaled data from the Max control interface in order to determine the location each source should be placed. Orientation remains centre facing towards the simulated spat listener, which acts as a reference for all audio positioning to occur around. Reproduction of perceptibly similar audio response to the DisPerSion Lab is achieved through a variety of impulse responses taken at various points throughout the room, and extraction of perceptually-relevant room quality parameters through spat.rat, a patch available through the Spat 4 package. Incorporating spat as the virtual audio environment system gives depth to the generated audio that amplifies the effects of positioning within the space, through horizontal and vertical placement. Spat's output can support n-many channels, however for this networked version a binaural panning method is used to allow for proper audio representation over the dedicated stream. This ensures the work is accessible to those without expansive listening configurations and reduces network load of multi-channel audio.

3.4 Networked Interaction & Visualization

"I find Internet time delay rather interesting and I think of it as a kind of unique acoustic of this media. . . . Rather than to play existing music on this new time basis, what is interesting to me is trying to find a musical language that works on this time axis. . . ." - Atau Tanaka

(Interview with Föllmer, 2001 as cited in Barbosa, 2003)

Wide accessibility was a key consideration for the networked aspects of *Locus Diffuse*. As the project was not initially meant to be a telematic work, pivoting to accommodate different devices and network connections was an essential goal in order to allow a diverse participation and audience population. Control of player movement occurs in the browser through a provided URL, allowing access to a Max Mira interface from beyond the local network the patch is being run on. This is achieved by pointing a web domain name at the public IP address of the host computer, using the service no-ip, with port forwarding to ensure Mira receives the external input. The interface contains a panel for each player consisting of identical controls, including a centre black square mira.multitouch object for position input, and a right hand slider for vertical movement. Mira frames are capable of mouse or touch response, so the interface may be also used on a touch enabled device. Testing with advanced visual feedback within the Mira interface resulted in consistent crashes when the central computer was accessed by many players. This seemed to be caused by an excessive amount of requests while updating the Mira panels on each player's interface. This advanced visual feedback depicted the positions of other players within the touch interface, allowing players to understand their relative position to each other simply though the one interface, but this would also cause strange visual bugs. Due to the limited max objects Mira is able to interact with and display, a visual stream of agents within the Mira interface was also not possible. Without this visual feedback, all active visual attention needs to be directed towards the audio and simulation stream hosted on Mixer. The Mixer stream displays a main simulation pane of each player node position, player names within each node, and the simulated slime mold agents constructing the network between each node. To the left of this main pane is a series of spectroscopes where players can view a representation of

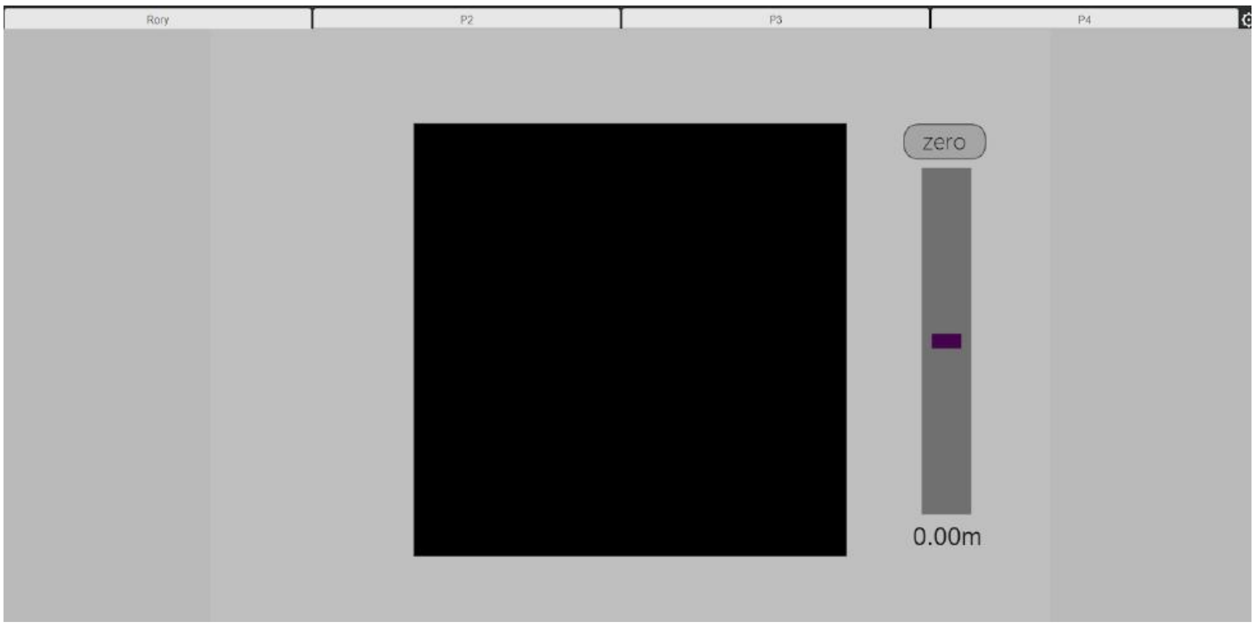


Fig.4 The player web interface

their current sonic output. Lastly, to the right of the main pane is a group of stacked sliders which depict the vertical position of each player. This approach of visualizing all networking for both players and audience members situates the stream as a centralized hub for the experience of the instrument and established sonic ecosystem. Centralizing the display of emergent activity and abstracting graphical user elements to a separate interface reduces visual clutter for participants and audience, while also providing all necessary visual feedback in a place both groups can see. This approach can be seen to follow a modified version of the “Aestheticized GUI” paradigm put forth by McKinney (2012), who addresses strategies for networked multi-user instrument visualization. Designing for aesthetics directed specifically at the audience to remove superfluous information or unsightly components, an aestheticized graphical user interface is an abstraction of a separate interface specifically for the players. Since *Locus Diffuse* incorporates a primary visual interface for both the players and spectators while encapsulating the interactive elements to an additional interface, it should be apparent that the visual aesthetic experience is presented as equally important for both parties. Further exploration and analysis of this visual component of the work will be discussed in section 5.

The Mixer streaming platform allows for sub-second delays from the source to viewer through its FTL technology (Mixer, n.d.), allowing it to be practical for applications such as collaborative musical play within a collective social ritual context. While this delay would be too great for traditional composed music (unless explicitly composed for), a contemplative and improvisational piece such as *Locus Diffuse* can incorporate it as part of the very nature of the instrument. Echoing the section's opening quote, it is clear that flexible musical language needs to be employed within works that are at the whim of network delay. This delay becomes a defining feature or mediating texture of the instrument’s interaction, amplifying or playing out gestures over time. Initial networked tests employed Zoom as the platform for audio and visual streaming, however the results of audio and video quality degradation from latency and compression were beyond the limits of maintaining aesthetic coherence with the emergent reality of the sonic ecosystem. Moving from Zoom additionally decreased the barrier of entry for participation within a performance session, avoiding the use of a separate application outside of the browser. A potentially prohibitive aspect of the project’s networked implementation is the need for a fast internet connection. While that is not an issue for the most part within major cities or communication routes, weaker connections would suffer a range of noticeable to crippling delay (10-20 seconds) from the Mixer stream. Mixer’s “low latency mode” may become automatically diabled given a low enough bandwidth, which resulted in players needing to adapt to delayed streams.

4. Survey & Player Responses

Play sessions were held in two waves as open calls on set dates, and public exhibitions following the weekly electro-acoustic improvisation series DisPerSion Relation X, held on Zoom. The first wave of play sessions was focused on a default behavior state of the simulated slime mold, while the second wave presented players with four varied states that the agent behavior moved through. Sonification changes also occurred between the first and second test waves, refining timbral content and movement tones. Sessions lasted roughly 25 minutes (with some going for up to an hour), allowing each player ample time to explore the sonic ecosystem and the results of their spatial interactions with other players and the simulated agents. Sessions held as open calls rarely used verbal communication for extra context beyond an initial briefing in text, while some utilized voice chat in Discord for answering questions players may have had. Sessions following DisPerSion Relation X utilized Zoom for live verbal discussion of project goals, progress, aesthetics, and potential troubleshooting if technical challenges arose. Prior to play sessions, all participants were given information on the experience they were going to be taking part in. This information is as follows:

> “The system is a multi-player instrument populated by a simulated slime mold which will attempt to reach all players and optimize networks between them. The simulation is a top down view, with the listening position located at the centre, facing the top. When an agent is upon you, it may take a “bite” where it attempts to draw energy from you. If successful this will trigger an audio grain to fire in your personal voice. Each player's voice is unique. The pitch and loudness of this voice is tied to the agent energy. Personal player energy can be regained through proximity to other players. Agents with no energy die, and new agents can be born or old agents revived if alive agent energy is high enough. You’ll be playing with 4 varied states that alter the behavior and

simulated qualities of the simulated agents - try to be conscious of how each feels, noting key differences and how your playing differs."

Following participation in play sessions, players were asked to complete an anonymous form provided at a different URL, questioning their experience with playing the system. As Wave 2 was centered around four different behavior states, the response form was updated to accommodate this change. These questions were aimed at attempting to get a sense of their perception of the system in terms of relations with other players and the resulting sonification. Worded generally, the goal was to coax out detailed descriptions of player experiences of the instrument and avoid priming the players with leading questions while encouraging them to think about certain areas of their experience. The **questions for Wave 1 (W1)** were presented as follows:

1. What was your sense of playing in this virtual environment?
2. What was your sense of connection to the others in the virtual space? (Other players or agents)
3. How did you perceive your own "voice" while playing? (Location, timbre, relation to environment and others)
4. How would you describe your ability (or lack of) to perform expressive musical action?

Investigating the changes that may occur to player behavior through varying the system's response to their presence, Wave 2 (W2) introduced states which altered agent trail decay, sensory distance, death threshold, birth odds, and agent energy decay. Players were not primed on the behavior of each of these states. The transition between each state was announced to prompt the players that they will be interacting with new agent behavior. States progressed sequentially through 1-4, but in free play after experiencing each, players could request to revisit certain states. The experienced **states** were:

1. **Solitary**: Fast trail decay, low sensory distance, default death threshold, low birth odds, and default agent energy decay

2. **Needy**: Slow trail decay, low sensory distance, lower death threshold, high birth odds, and very fast agent energy decay
3. **Lively**: Fast trail decay, high sensory distance, default death threshold, high birth odds, and slow agent energy decay
4. **Starving**: Slow trail decay, high sensory distance, lower death threshold, low birth odds, and very fast agent energy decay

These states were established to provide a gradient of agent behaviors while retaining similarities with each other, with the intention of having players map observed characteristics of each into their responses. The names provided before the description of each state were given by the author through personal interpretation of their behavior and were not told to players. States will be referred to by these names followed by the state number (eg. Solitary (S1)). Reframing the questions to direct player responses towards each of these four states, **W2 response questions** were as follows:

1. How would you describe the behaviours of each state? (changes in response, characteristics, etc)
2. For each state: What was your sense of playing within the environment?
3. For each state: What was your sense of connection to others in the virtual space? (Other players or agents)
4. For each state: How did you perceive your own "voice" while playing? (Location, timbre, relation to environment, movement, and others)
5. For each state: How would you describe your ability (or lack of) to perform expressive musical action?

Answer lengths were not prompted to be short or long, allowing players to provide as much detail as they wished. 10 player responses were recorded for both W1 and W2 (not all players completed a response), and key reflections will be represented here.

4.1 Wave 1 Player Responses

4.1.1 W1 Q1: Sense of Playing in the Virtual Environment

A central theme throughout the responses of both waves is a recognition of biological mimicry and emergent form. W1 question 1 feedback centered around a sense of flow or an organic quality, conjuring audio and visual metaphors of streams, swarms, and natural rhythms. One participant noted “I definitely had the sensation of being immersed in a medium – fluid. The dynamics of the particles, of course, were responsible for evoking this sensation, but so were the sounds and the way that they transformed”, noting key aesthetic drives of the work. Qualities about the playing relationship with others and the overall sonic generation were brought forward by another participant within their response to W1 question 1, stating “When standing still it was more of a passive experience, however being able to move around really increased the sense of playing, and made it feel like my movement was a part of a larger whole”. This sense of emergence also applied to the general form of experiencing the instrument, with a player noting “It was a unique experience which first felt technological or scientific and then artistic”.

4.1.2 W1 Q2: Sense of Connection to Others

Various degrees of connectedness were reported, where some felt there was little connection due to the lack of dialogue between players, while others pointed to connection mainly with the simulated slime mold or the meditative qualities of the communal movement. One participant hinted at the sense of a potential goal in playing, stating “There was a feeling of mild, unhurried magnetism shared through the particles with the other participants. It felt both cooperative and competitive”. Another resonated with the visuals and established network, writing “There was a certain appeal to doing things like building "bridges" between myself and other users, and seeing the cells speed up and slow down made it feel like we were almost taking care of the cells in a way."

4.1.3 W1 Q3: Perception of Own "Voice" while Playing

Many players reported difficulty in pinpointing their specific voice as it was perceptually lost within the greater emergent sonic ecosystem. A player noted "My 'voice' felt removed from my input..., [the voice] felt more controlled by the other factors in the ecosystem. While I wasn't able to identify my own "voice" I still got a sense of how I played a role in the relational soundscape". Another participant recounted their voice simply as "Location", noting an active search of the sonic space for their timbre.

4.1.4 W1 Q4: Ability to Perform Expressive Musical Action

Players again related their interaction and resulting sounding as part of the communal whole. Players pointed to feeling limited in terms of explicitly expressing musical gestures within the play sessions. One participant wrote, "I couldn't have been able to effectively perform given the multiple uncontrollable variables at play. I think the discordance in itself is expressive but ultimately no individual player is in complete control", placing their perceived lack of expressive control as a product of the encompassing communal sound of simulated agent sonification. This was recounted in another player's response, stating "This experience felt more like multiple users becoming one whole".

4.2 Wave 2 Player Responses

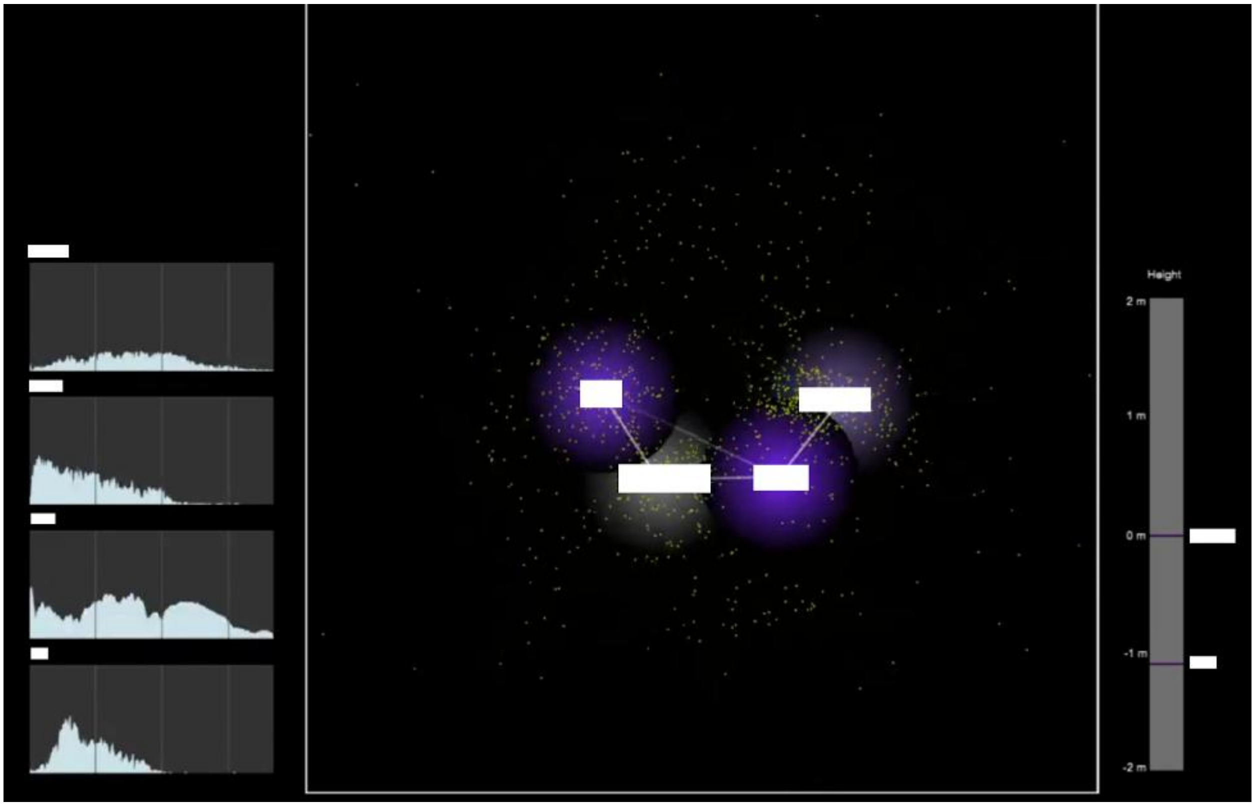
W2 responses are for the most part aligned with the observations and reflections of W1, but are in conversation with established states previously listed. As the responses for each state are of key interest, player feedback will be reported here in terms of summaries of state reactions rather than individual question responses. While some players tried to quantify the experienced agent behaviors in terms of the specific system changes that were occurring, others attributed characteristics, moods, and intention to the states. Responses for each state tended towards reporting an organic feel akin to the nature metaphors of W1, noting the way the cells moved as pockets of action. Overall, a clear grouping of Solitary (S1) & Lively (S3), then Needy (S2) & Starving (S4) were reported as feeling similar. Overall, players reported interest in learning the new behaviors as they happen, with one participant stating “It felt as if I was solving a puzzle in each environment, as I was always trying to figure out what attracted other cells to come close to me”.

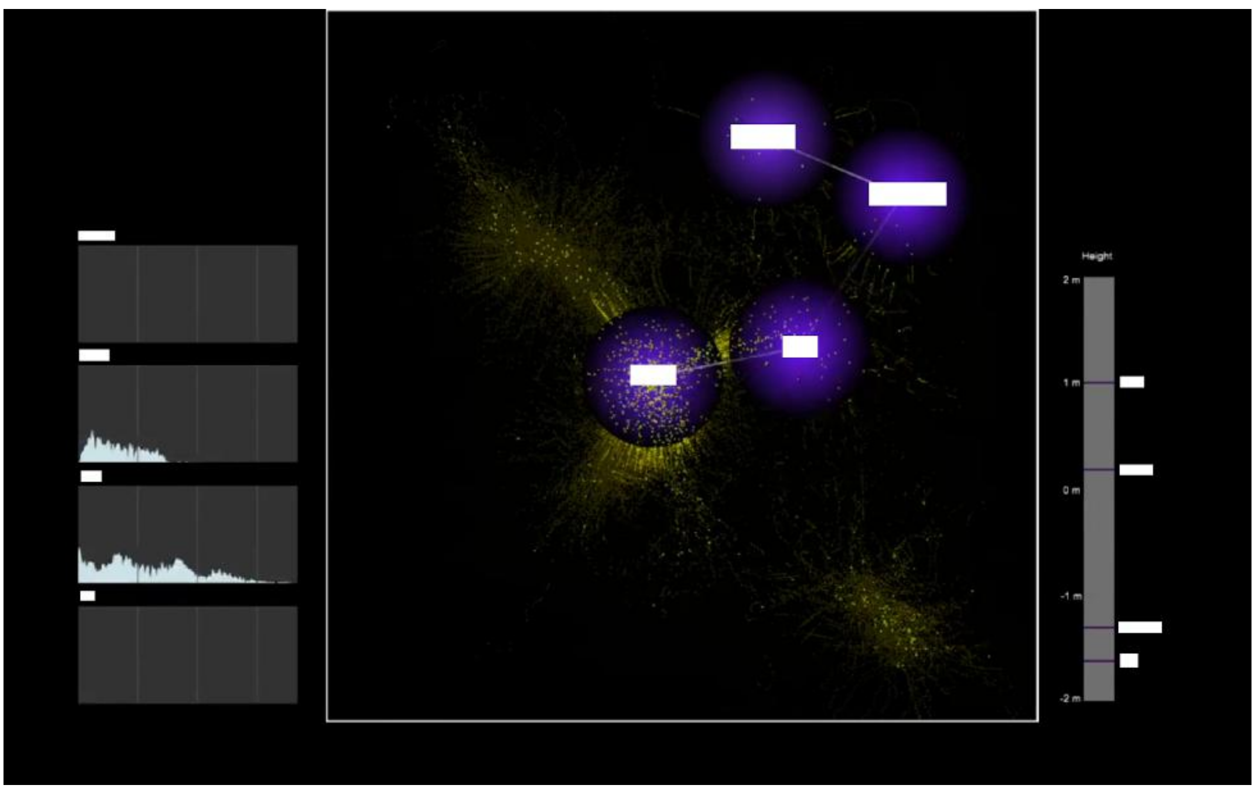
4.2.1 W2 Solitary (S1) & Lively (S3) Responses

Most players pointed towards Solitary (S1) as dispersed but reactive in its behavior, and Lively (S3) as feeling similarly dispersed but chaotic in its movement - difficult to deduce its intention. An overall sense of the whole space being playable was reported for these states, with varied interpretations for their exact behavior. Both of these were reported as moving through a texture or substance, notably a “mass/cloud”. This chaotic nature reported from Lively (S3) is also paralleled with players noting that it was sonically more active than the others. One participant wrote, “The cells seemed to rapidly charge when the subjects were together, and the sound became busier”, pointing towards varied behavior of agents in regards to player proximity.

4.2.2 W2 Needy (S2) & Starving (S4) Responses

Responses in regards to states 2 & 4 tended to centre around the physiology and life cycle of the agents rather than comments of the self within the environment. Key responses for these states are in terms of their relative fragility. Where states 1 & 3 were able to function more independently without player interception, states 2 & 4 are especially volatile due to their high agent energy decay coupled with lower threshold for death due to low energy. One player noted that these states “rewarded stillness”, noting that one's interaction felt more impactful to the sonification through waiting and allowing the agents to move towards and through them. It was also clear that participants realized the volatility of the agents can be countered through their spatial co-operation, providing multiple sources of energy close to the agents while also generating energy for themselves.


Height
2 m
1 m
0 m
-1 m
-2 m


Height
2 m
1 m
0 m
-1 m
-2 m

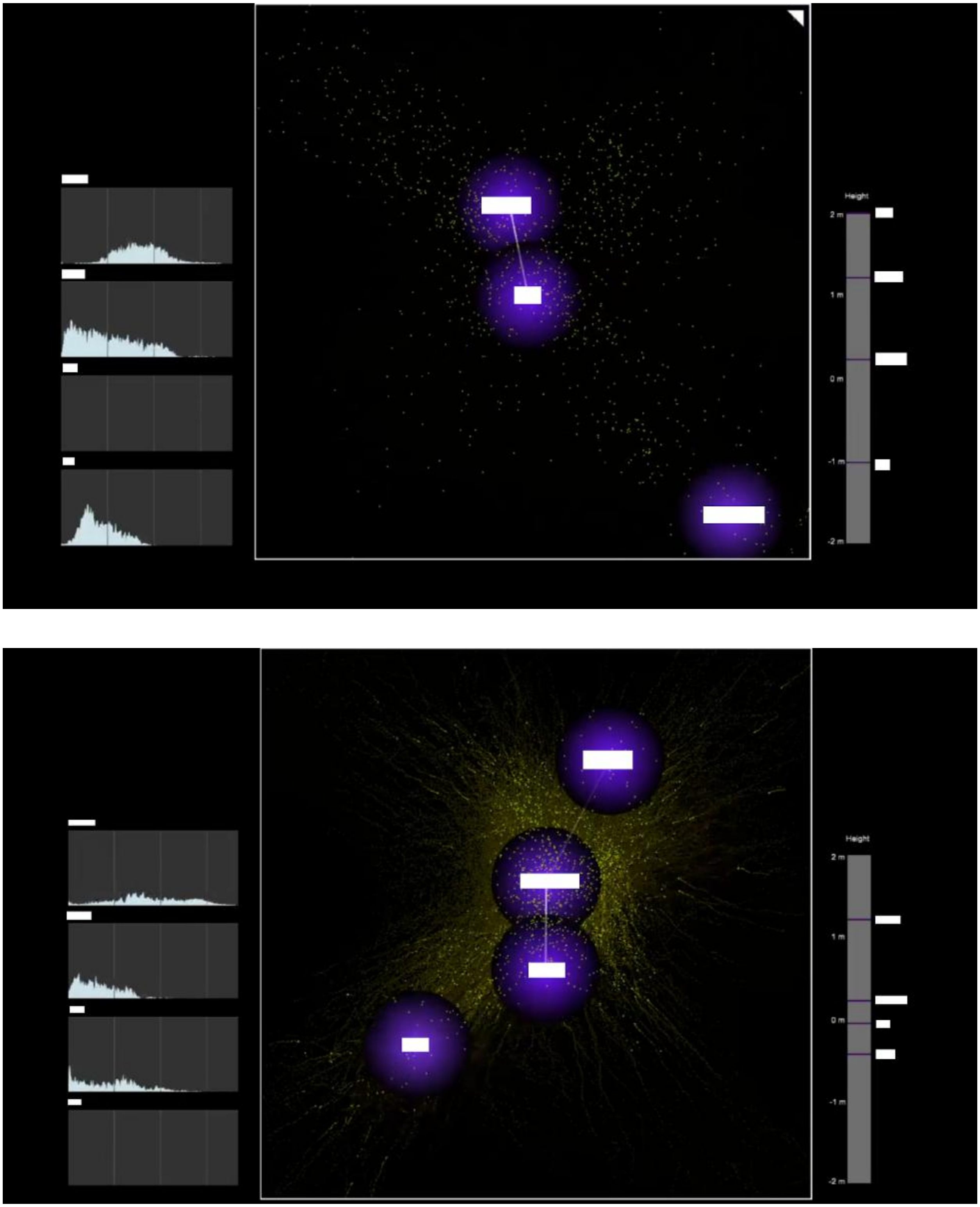


Fig. 5/6/7/8 - States 1,2,3,4 Respectively (player names censored)

5. Analysis & Outcomes

Locus Diffuse had many technical, aesthetic, and research-oriented goals in mind throughout the various components of its development process. To reiterate these goals before discussion of the project's outcomes, the project brought key aspects from the disparate fields of sonic ecosystems, agent based musical systems, multi-user instruments, and networked performance to produce a work that allows players and spectators to participate in the communal social ritual of musical collaboration along with a simulated organism. Investigating the viability of an agent based multi-user instrument to establish a sonic ecosystem, players engaged in a human group/machine symbiotic relationship to establish a virtual network with the simulated slime mold populating the space. Individual player interaction and the responsive agent stigmergy resulted in the collective sonification of the virtual space. Collaborative play of the system does not assume any prior experience with musical systems, networked music, multi-user instruments, or any aspect of the play experience, allowing play to be accessible and accommodating.

Through play sessions, observation, and development, key outcomes came to the forefront as salient features of the system resulting from each of *Locus Diffuse*'s research goals and aesthetic decisions. Player responses tended to characterize the system behavior at the state level, and established narrative drive to the behavior of the agents. Players noted that expressive musical action is limited as the collective is prioritized over the individual. Players report a sense of game-like play in which they would establish personal goals in relation to collaboration with others, or they noted that a more discrete playing goal would be beneficial within sessions. Play session observations and responses point to common play techniques for interacting with the simulated agents. These responses will be addressed in relation to:

1. **Natural metaphor**: Players reported varied biological analogies for system behavior.
2. **Aural vs visual understanding of the system**: Player reports had a tendency to bias the visual aspects of the simulation in order to differentiate similarities between states, but would jump between visual and aural behaviors of the states to result in characterizations.
3. **Sense of self within the collective and the resulting sonic ecosystem:** Player responses pointed towards the understanding of themselves within the shared space and resulting network structure, with some focused more on their interaction with the system agents rather than other players.
4. **Explicit agent state characterization and emergent narrative:** Player responses gave identities to each of the agent behavior states, and noted caring and nurturing feelings towards the more vulnerable agents.
5. **A game-like understanding of the system:** Some players reported anticipating or wanting game-like goals of the system.
6. **Instrumental playing techniques:** Salient playing techniques were observed through play sessions as a result of system design choices.

5.1 Natural Metaphor

The recorded responses of participants through both Wave 1 and 2 outline a range of artistic interpretations that can be produced from an explorative work like *Locus Diffuse*, as various natural metaphors from players arose through the audio and visuals. While players were primed that the agent behavior was emulative of slime mold, their natural metaphors for the agent behavior tended towards more common (or at least more encountered) phenomena of the natural world, most likely from having no prior experience with the organism. Those participants who noted various other natural processes such as swarms of bugs, the flowing of rivers, and immersion within a fluid substance notably did so as a reaction to both the aural and visual content of the simulation. These natural analogies line up with source content used for the various player voices within Wave 1 (slime, synth drones, running water). Wave 2 responses for audio content and resulting metaphors were similar but characterized the audio as more perceivably pointalistic, noting the crackle of fire, dripping, and creaking like sounds as components of the sonification. While these sources are used as granular input, they of course keep aspects of their timbre which certainly shape the mental image of the overall sound field. In my understanding of player responses, this points to the potential strength and flexibility of establishing a sonic ecosystem using a granular based multi-user instrument. Variations of the sound source in collaboration with agent behavior could result in an altered sense of the system behavior itself, in which participants map/perceive a personal interpretation of the agent action in relation to dense or sparse aural behavior they've experienced previously.

5.2 Visual vs Aural Understanding of the System

Play sessions from Wave 2 which centred around the experience of four varying agent behaviors were enlightening in relation to the role that the collaborative agent behavior has upon the perception of the system's goals and player responsibility. As the players and simulated agents work symbiotically to establish the resulting sonic ecosystem, the audio and visual cohesion of the system is necessary for players to internalize a complete understanding of the culminating agent behaviors. An interesting trend is shown in some player responses to seemingly favor a visual representation of the system state vs an aural representation, hinging mainly on the trail decay value of a given state. A clear example of this reliance upon the visual is through changing the sensory distance of agents. Where a state with low sensory distance would have equal sounding potential as opposed to a state with high sensory distance given appropriate player interaction, this variance in sensory distance may not be effable beyond a feeling of more chaotic/stable sonic behavior. This can be seen within states 1 and 3 of the W2 testing, which both have short trail decay times but short and long sensory distances respectively. Where Solitary (S1) has a short sensory distance and localized pockets of agent activity, Lively's (S3) large sensory distance results in loose clouds of agents that had trouble deciding which player or trail to orient themselves towards. While this allowed Lively (S3) agent behavior to sense and act towards players at a greater distance than Solitary (S1) agent behavior, these states were regarded as similar. Sonically this was not the case, where state 3 was clearly noted as more chaotic or busy, whereas state 1 was reserved and stable. Visually this was also not necessarily the case apart from the lack of residual trails, given the formations of agents that were observed. These states were seemingly deemed similar in contrast to the visual weight of states 2 & 4. Where Solitary (S1) & Lively (S3) had fast trail decay, Needy (S2) & Starving (S4) resulted in large static patterns of trails deposited by the slime mold agents due to the very slow trail decay. These lasting agent communication trails within the visualization of the environment state resulted in their deeming of similarity, while 2 & 4 had varied sensory distances mirroring 1 & 3 which resulted again in tight and loose agent groupings. This depicts an interesting weighting of visual above sonic in terms of grouping similarity for performers. This certainly could be a flaw in the information presentation and a reliance upon the visual which can be addressed within future iterations of the work.

It is clear through player responses within the second testing wave that the incorporation of fluctuating agent behavior through system states results in a more dynamic play experience, where each participant becomes more conscious about their action and its result between fellow players and the systems population of agents. Players were much more conscious of agent energy levels when these perceivably changed at a much higher rate. In these more volatile or fragile states (Needy (S2) & Starving (S4)), playing techniques required close coordination with others in order to ensure agents would survive and birth new agents. While the aural output of the system is pervasive throughout player responses, it is also apparent that the visual representation of the player positions and established networks between them are critical for the understanding of agent behavior for players and for contextualizing variances of behavior between states. While quite possible to navigate the sonic landscape “blind” by focusing completely upon audio, the visual representation of the system is clearly influential in understanding the network relations established between each player and agent within the social ritual of musical collaboration facilitated by *Locus Diffuse*.

5.3 The Self Within a Collective

Player responses point to a clear sense of a greater whole which their interaction and presence resides within. In some sense this may have come about through a potentially negative experience of feeling “lost” within a sonic environment greater than the self, as some responses noted their trouble finding their own voice within the space but could perceive subtle changes through their input. This experience of loss of self does point towards the establishment of mutual engagement, which is described as the points when “people spark together, lose themselves in their joint action, and arrive together at a point of co-action” (Bryan-Kinns & Hamilton, 2012). This engagement can occur both between the player and the product of the joint activity (the resulting output of the collective network structuring), and/or between the other participants within the activity. As this cohesive connection to other players is reported as somewhat lacking in responses, there is an evident bias towards the engagement with the system’s agents, resulting in the product of the joint activity (the emergent sonic ecosystem). This is to be somewhat expected through the foregrounding of the established network and greater auditory form of the system as of key importance. Drastic sonified changes can only occur through drastic movements of the agent facilitated network. The individual may alter their position and subsequent audio generation (spatialization, timbre through agent energy/personal energy manipulation, flow of agents), but the group playing dynamic is established by the actions of each member of the social ritual, thus the greater form will follow the majority.

Relating the outcomes of *Locus Diffuse* with past work in sonic ecosystems through dispersion.eLabOrate (Hoy & Van Nort, 2019), it becomes more clear where the role of the system lies within facilitating a sonic ecosystem, and how each methodology works best for their respective projects. Where the behavior of the system within *Locus Diffuse* is a central form of the slime mold dispersed across hundreds of autonomous agents, the agent system employed within dispersion.eLabOrate is one central reactive performance agent distributed across 9 modules. Branching from dispersion.eLabOrate's process driven by human listening/vocalizing networks of interaction, the sonic ecosystem of Locus Diffuse is facilitated by the intersection of human participatory input and the virtual network of agent activity to result in a space which can be performed as a multi-user instrument. In section 3.2, I claimed that this symbiotic essentiality of player roles in collaboration with the simulated agents establishes the virtual sonic ecosystem. This is evident through Waters (2007), who states "The notion of Performance Ecosystem enfolds all three concepts (performer, instrument, environment) and allows room for the undecideabilities of the virtual domain". These interdependencies between human, agent, and environment result in a symbiotic environment reliant upon each component.

As the systems differ in terms of goals and reactivity beyond the facilitation of a sonic ecosystem, parallels can be drawn between player responses in terms of projecting biological or sentient-like behavior or narrative upon the agents. Players within dispersion.eLabOrate sessions began to view the output of the system as another participant within the Tuning Meditation, with one player stating, "the electronics held (the) same importance as other performers". This statement was related to both the prevalence of the system output within the performance space, and also the close following of participant vocal input into the system. A similar phenomenon is recounted in player responses within *Locus Diffuse*, where a mental image of a singular being or sound object is established through the auditory and visual complementaries. This can be seen from player statements like one participant who noted “It felt like I was being swarmed by invasive digital bugs when the sound was present all around”. Players would establish play narratives throughout experience, while no narrative is explicitly introduced beyond the priming of the instrument as simulating a slime mold.

5.4 Characterization & Narrative

A sense of narrative is established through various interaction techniques and their resulting sonic and visual output. Some key reports of players through both play session waves noted urgency of wanting to nurture the agents to save them from expelling their energy. This was exemplified within states Needy (S2) & Starving (S4) of Wave 2, where accelerated agent energy decay and earlier death resulted in huddles of player positions protecting a core population of agents. This worry for the well being of their simulated musical companion was made vocal in a few of the play sessions that included a chat channel in Discord for players to discuss their experience and speak while playing. Multiple players stated to their collaborating players that they “can’t let the agents die!”, urgently coordinating with others to ensure their virtual collaborator would survive. Along with the urge to ensure the survival of the simulated slime mold, players attributed direct and/or implied characteristics towards agent and environmental behavior throughout each of the states. Players would alter the target of these characteristics depending on which agent or system values were changed, displaying that these changes were felt on either an agent or environmental level. To recap, trail decay, sensory distance, death threshold, birth odds, and agent energy decay values were altered between states. Environmental related characteristics attributed by players tended to be a product of the visual aspects of the system, noting the “busyness” and “growth” of the slime mold within Needy (S2) & Starving (S4) when trail decay was significantly reduced. In regards to agent behavior characteristics, Solitary (S1) was perceived as “independent”, resulting in localized areas of attraction, with distant agents acting indifferent/ignorant to the presence of energy. Needy (S2) agent behavior was perceived as fragile and communal, reliant on close groups of players and agents to sustain life due to the very fast agent energy decay. This was compounded by high birth odds that resulted in tight birth clusters which would quickly die off if wandering away to look for more food. Lively (S3) was observed as “chaotic” both audibly and visually. Due to the high sensory distance, high birth odds, and low agent energy decay, this state resulted in a high population which dispersed through the environment. This is echoed by another who attributed ‘interest’ as a quality the agents possessed, noting that “agents seem to be highly invested in the actions of players when they are sharing energy, but seem to actively avoid players who are not working together to share energy”. Lastly, Starving (S4) tended to be described environmentally as inhospitable or famine-like. Quick death threshold, low birth odds, and fast agent energy decay required players to focus on maintaining even closer networks of agents or else risk losing the population to energy decay. While these varied states resulted in interesting and spatially compelling changes of behavior for the agents and resulting changes in player interaction, player responses and characterizations point to a potential downside of the current system in relation to its goal as a musical instrument but occur naturally through the incorporation of responsive agents within the system - the tendency to gamify its simulated agent behavior and the interactions players have between each other.

5.5 A Game-like Perception of the System

A gamification of game-like perception of the musical play experience is certainly not intrinsically negative, as structured “rules” of play can lead to interesting compositional or improvisatory expression, and musical composition techniques can draw parallels to game-like behavior (such as call and response). This game-like understanding of the system is troublesome however if interest or musical collaboration is lost due to wishing there was more gamified behavior. Noted within section 4.2, one player reported “It felt as if I was solving a puzzle in each environment, as I was always trying to figure out what attracted other cells to come close to me”. This statement may point to a lack of flow within a play session and following response experience. While players are not given a task within the play sessions other than exploring how the instrument reacts to their input and position relative to others, this attempt to understand the mechanics of each state may have become the main goal for some players, distracting them from the collaborative play itself.

This perception of game-ness in play or an active statement of seeking game-like goals within the collaboration was noted in some play sessions, with comments along the lines of “how can I/we win?”. I theorise that these sentiments arise due to specific components of the system, the interaction paradigm of cooperative networked play, and the lack of clear musical/compositional direction within play sessions. As the system is establishing a sonic ecosystem within a virtual space, the players are placed within an environment which could be understood as a game “world”. Given the range of player familiarity with both networked musical systems and electro-acoustic/noise musical aesthetics ranges from no experience to a high degree of familiarity, there was a diverse background of players who took part and offered responses from play sessions. Those unfamiliar with abstract/non-traditional music regarded the sonification as audio texture resulting from interaction within the simulated agents, but their focus tended to be towards what they can “do” with the agents or “what should they be doing?”, rather than how they can establish musical collaboration with their accompanying players. The networked communal aspect of the work is certainly also evocative of online games through the visible player names, presence of fellow players, and presence of the simulated slime mold which can be interpreted as a non-player character within the world. Kirkpatrick (2007) draws parallels between the breadth of available options in a gamic environment to that of playing an instrument, stating “In multi-player games we are exposed to the diverse conventions of play and the full range of its possibilities. There is a strong sense of virtuosity in play”. This sense of virtuosity relates directly to instrumental language, where repetition of action can lead to familiarity with a musical/game system and a deeper understanding and ability of its function through this familiarity. While some players may have internalized their action as relating to a sense of game-like play, this too would lead to an explorative and emergent form of the established networks through collaboration with other players and the system agents. This desire for a game-like goal may also be interpreted as a product of loose playing instructions within the play sessions. One player verbally noted that having a more directed experience or communal goal for all players could be beneficial. This will be considered in future studies with the instrument, as providing players with explicit play techniques, strategies, timing, or goals could allow for greater communal expression. This iteration of the project incorporated a free/exploratory structure to its play sessions in order to get a sense of the natural and un-guided playing response of participants in relation to others and the simulated agents. Without an explicit goal, interesting play actions were observed to have clear audible and visual response within the environment, which will be discussed next.

5.6 Playing Techniques

Salient playing techniques emerged through spectating, responses, and personal play of the system. *Herding* agents allows a player to coax the direction of the established slime mold network to the desired location, and allows players to create splinter slimes - small disconnected local networks of agents. This can be achieved through slowly pulling through a dense area of agents, allowing them to generate a network to your node, and continuing to pull away to the point where the connection is severed. This method allows for clear and continuous sonification at any location in the simulation (if agents are coaxed along at a viable speed). The opposite effect can be achieved through agent *avoidance*. Avoiding agents and not letting them form networks with a player node will result in no sonification of that player's voice. This can be achieved through moving within unpopulated areas of the simulation, or moving past the simulation edge. As the agents are bounded by the simulation walls, placing oneself outside this boundary, "stepping out" of the space, will allow for a muted voice. *Vertical changes* can result in dynamic spatialization, and interesting perceptual results when passing through other player locations. Reiterating from 3.3, this vertical movement conceptually maps to localized agent behavior at a given player being stretched up and down within the audio space. *Teleporting* is another clear playing technique which allows players to jump to areas of the environment that would not be physically possible through the original in-person formulation of the system. This can be combined within other techniques like herding to direct the flow of agents and leave or join their sensory range to manipulate the established network at will.

5.7 Closing Analysis

Drawing from these presented reflections, the validity, successes, and shortcomings of the established sonic ecosystem facilitated by an agent based multi-user instrument. Returning to the base formulations of each of these disparate areas, a sense of their key elements can be derived and used to assess their amalgamation within *Locus Diffuse*. Bown et al. (2011) addressed creative domains which are established through an ecosystemic frame. Their paper presents five essential elements which constitute a set of "minimal ecosystemic specifications", including space, materials, features, actions, and processes. These elements were noted as present within the system throughout section 3, meeting the specifications discussed in Bown et al. (2011), and thus achieving a minimum standard or structure to build a creative ecosystemic work. To review, these elements are space (the simulated environment space), materials (the pixels constituting the virtual space), features (agent sensing of ambient environment and stimuli), actions (trails deposited by autonomous agents), and processes (decay and reinforcement of trails over time). However, meeting this minimum does not guarantee a compelling creative output of the system, nor does it assert the system's classification as a *sonic ecosystem,* even if this barrier for ecosystemic-ness is met. As previously addressed within 2.2, the design considerations and interaction paradigm of *Locus Diffuse* as a human/machine collaborative instrument push against the challenge of Di Scipio (2003) to remove the influence of human action upon a generated sonic ecosystem, by actively incorporating human play with environmental agents. Establishing this sonic ecosystem through a multi-user instrument context, the current implementation of self-observing behavior which is key to these ecosystems resides within the cyclical nature of the agent action in response to player input, mediated by the resulting system sonification. While not fitting within his formulation of a machine/ambience focused sonic ecosystem presented within Di Scipio (2003), the goal of "moving from composing wanted sounds, towards composing interactions having audible traces" is achieved through the delegated roles of performer and agent within the system as a product of design considerations from multi-user instruments, and through the resulting audio aesthetics of the generated audio output. These audio traces are an imprint of the established networks between players and agents; audible repercussions and reactions to the culmination of all previous player input and agent decisions.

Complexity of the system arises through the distributed communal interdependencies between each player and the simulated slime mold. While the slime mold can not gain energy and generate audio without the presence of player nodes within the space, players are able to produce sound without the presence of the simulated agents. This movement sonification is secondary to the main sonification of the established feeding networks, but through this independent sonification the role of human players within the system can be seen as “nonessential” in regards to the established interdependencies (Jordà, 2005). The symbiotic nature of the granular audio generation results from cohesive actions between players and the slime mold, placing the slime mold within an “essential” role which cannot make sound individually. Where this instrumental network of interdependencies may not result in the most “extremely intense” interplay between players of the multi-user instrument as dictated by Jordà, the communal network structure of cause and effect between players and environmental agents is strengthened by this close symbiosis and these dependencies. Finally, established from the multi-user instrument facilitated sonic ecosystem, the social ritual of communal musical play is achieved through the resulting Interconnected Musical Network (IMN) (Weinberg, 2003). Expressivity is afforded by the “vocal majority” within the group playing dynamic. Compositional decisions require an enacted group coordination in order to achieve desired spatial output of audio, and to ensure the established agent network remains healthy in order to continue sonification.

6. Future Work & Conclusions

Future iterations and development upon *Locus Diffuse* will extend implemented aspects from each of the disparate research areas the project incorporates. Agent and environmental behavior can be extended to allow for deepened slime mold simulation. The agent behavior is currently dictated by the sensing of players and the deposit of trails. While these trails fade and result in emergent networked structures, advancing the trails to have proper diffusion through the space would result in more realistic behavior of agent movement. This would also be extended to player positions, where their movement would additionally cause diffused trails to be left in their wake. Exploring and adapting physical slime mold-like computing behaviors such as ‘memresitors’ (Gale et al., 2013) could yield exciting and complex sonification possibilities through “smarter” learning agents able to adapt to learn environmental stimuli (both attractants and repellents). In relation to the appearance of the slime mold, visually representing the collective of simulated agents as one cohesive body would give a better sense of the established networks between players. The current implementation of representing key points of cytoplasmic concentration lacks some clarity in understanding the flow of agents which may be remedied through a singular representation of the organism, with visible agents flowing through it. Lastly in terms of addressing agent behavior, incorporating a pulsating movement of cytoplasm (and therefore agent positions) would result in a visually realistic crawl of the slime mold, and additionally may result in interesting sonification potential in terms of rhythmic texture and granular triggering.

Locus Diffuse’s sonic ecosystem currently lacks audio based self-observation in which the agents are able to react dynamically to the resulting sonic landscape. Affording this ability to the agents will allow for deeper expressive states of the system, reactive to their individual output and to external audio influence on the environment ambience through sources such as the incorporated player movement sonification. This would additionally be aided through moving both player and agent roles within the multi-user instrument design on the system to nonessential interdependencies. This could be done by extending the sonification potential of the slime mold to be able to sound independently from human input, but allowing the interplay of these two roles to still yield the key expressive output of the system, akin to the play and modulation of other’s sounds of projects like *Vrengt* (Erdem et al., 2019). The networked form within the sonic ritual of communal music and its output will remain key aesthetically and as a frame for future research.

In a post social distancing time, an in-person room scale version of the system will be held to explore the translation of now networked based musical instrument interaction back into the originally intended space. This in-person staging of the instrument inherently places each participant within a personal and localized listening vantage point. As the current networked version of the piece is relying upon an accessible streaming service to act as the hub for environmental activity, play is limited to a singular central aural vantage point. Extensions to the networked version of the piece will additionally focus on broadening this sense of presence within the environment, allowing for the audio reality of a player's virtual position to align with the sonic ecosystem. Extending survey scope will also allow for deeper conclusions and followable trends through player responses. Incorporating a scale for familiarity with experimental music contexts, multi-user instruments, and sonic ecosystems would result in a better sense of expertise vs naivete in responses. While all levels of experience are valid, context of player background would help justify design decisions in tune with each scale of self reported experience.

Blending aspects of sonic ecosystems, agent based musical systems, multi-user instruments, and networked performance to establish a communal musical play context, *Locus Diffuse* effectively depicts these disparate fields of study as complimentary in their nature to establish emergent behavior through various levels of interaction, sounding, group structure, and process. Agent stigmergy in collaboration with player behavior have been shown to be viable within a multi-user instrument context to establish a sonic ecosystem. Multi-user instruments have also been shown to establish Interconnected Musical Networks which facilitate collaborative musical play. This paper has reported key findings of the established system, justified design choices in relation to affording specific interaction paradigms, outlined systematic implementation of the project's technical components, and presented responses from participants of two public testing waves. Player responses depicted natural metaphors and biological understanding of the system behavior. Visual and aural representations were examined as vital to the understanding of system states, and visuals were shown to overpower the sonic reality in some cases. The emergent form and place of the self within it was considered within the context of sonic ecosystems. Characterizations of agent behavior and resulting narratives of these behaviors were presented. Thoughts on why these narratives and perceptions point towards game-like understandings of the system were explored. Lastly, salient playing techniques for interesting sonic output of the system were presented. Further work will continue to address the network structure as a form to generate compelling communal sonification resulting from the social ritual of music.

References

1. Adamatzky, A. (2010). Physarum Machines: computers from slime mould. World Scientific, Singapore.
2. Allison, J.T., Oh, Y., & Taylor, B. (2013). NEXUS: Collaborative Performance for the Masses, Handling Instrument Interface Distribution through the Web. New Interfaces for Musical Expression, Daejeon.
3. Arel, I., Rose, D. C., & Karnowski, T. P. (2010). Deep Machine Learning - A New Frontier in Artificial Intelligence Research. IEEE Computational Intelligence Magazine, 5(4), 13–18. doi: 10.1109/mci.2010.938364
4. Barbosa, Á. (2003). Displaced Soundscapes: A Survey of Network Systems for Music and Sonic Art Creation. Leonardo Music Journal, 13, 53–59. doi: 10.1162/096112104322750791
5. Borgo, D. (2006). Sync or Swarm: Musical Improvisation and the Complex Dynamics of Group Creativity. Lecture Notes in Computer Science. 4060. 1-24. 10.1007/11780274_1
6. Bown, O., McCormack, J., & Kowaliw, T. (2011). Ecosystemic methods for creative domains: Niche construction and boundary formation. 2011 IEEE Symposium on Artificial Life (ALIFE). doi: 10.1109/alife.2011.5954651
7. Bryan-Kinns, N., & Hamilton, F. (2012). Identifying mutual engagement. Behaviour & Information Technology, 31(2), 101–125. doi: 10.1080/01449290903377103

8. Cook, M. (2004). Universality in Elementary Cellular Automata. Complex Systems, 15, 1–40.
9. Di Scipio, A. (2003). ‘Sound is the interface’: from interactive to ecosystemic signal processing. Organised Sound, vol. 8(3), pp. 269–277, United Kingdom. doi: 10.1017/S1355771803000244
10. Durham, A. C., & Ridgway, E. B. (1976). Control of chemotaxis in Physarum polycephalum. The Journal of Cell Biology, 69(1), 218–223. doi: 10.1083/jcb.69.1.218
11. Erdem, C., Schia, K., & Jensenius, A. (2019). Vrengt: A Shared Body-Machine Instrument for Music-Dance Performance. New Interfaces for Musical Expression, Porto Alegre.
12. Gabor, D. (1947). Acoustical Quanta and the Theory of Hearing. Nature, 159(4044), 591–594. doi: 10.1038/159591a0
13. Gale, E., Matthews, O., De Lacy Costello, B. & Adamatzky, A. (2013). Beyond Markov Chains, Towards Adaptive Memristor Network-based Music Generation. International Journal of Unconventional Computing. 10.
14. Gresham-Lancaster, S. (1998). The Aesthetics and History of the Hub: The Effects of Changing Technology on Network Computer Music. Leonardo Music Journal, 8, 39–44. doi: 10.2307/1513398
15. Haworth, C. (2014). Ecosystem or Technical System? Technologically-Mediated Performance and the Music of The Hub. Electroacoustic Music Studies Network, Berlin.
16. Harris, C. M. (1966). Absorption of Sound in Air versus Humidity and Temperature. The Journal of the Acoustical Society of America, 40(1), 148–159. doi: 10.1121/1.1910031
17. Hoy, R., & Van Nort, D. (2019). An Ecosystemic Approach to Augmenting Sonic Meditation Practices. Computer Music Multidisciplinary Research, Marseille.
18. Hunt, A., Wanderley, M. M., & Paradis, M. (2003). The Importance of Parameter Mapping in Electronic Instrument Design. Journal of New Music Research, 32(4), 429–440. doi: 10.1076/jnmr.32.4.429.18853
19. Jones, J. (2010). Characteristics of Pattern Formation and Evolution in Approximations of Physarum Transport Networks. Artificial Life, 16(2), 127-153.
20. Jordà, S. (2005). Multi-user Instruments: Models, Examples and Promises. New Interfaces for Musical Expression, Vancouver. 23-26.
21. Jot, J. M., & Warusfel, O. (1995). Spat~ : A Spatial Processor for Musicians and Sound Engineers. CIARM 95, Ferrara.
22. Kirkpatrick, G. (2007). Between Art and Gameness: Critical Theory and Computer Game Aesthetics. Thesis Eleven. 89. 74-93. doi: 10.1177/0725513607076134.
23. McCormack, J., & Dorin, A. (2001). Art, emergence, and the computational sublime. Proceedings of The Second International Conference on Generative Systems in the Electronic Arts (pp. 67 - 81). Monash University Publishing.
24. McCormack, J. (2009). The Evolution of Sonic Ecosystems. Artificial Life Models in Software, 393–414. doi: 10.1007/978-1-84882-285-6_13
25. McKinney, C., & McKinney, C. (2012). Visualization of network based multi-user instruments. Live Interfaces: Performance, Art, Music, Leeds.

26. Miranda, E. R., Adamatzky, A., & Jones, J. (2011). Sounds synthesis with slime mould of Physarum Polycephalum. Journal of Bionic Engineering, 8(2), 107–113. doi: 10.1016/s1672-6529(11)60016-4
27. Mixer. (n.d.) FTL (Faster Than Light streaming protocol). Retrieved from https://watchbeam.zendesk.com/hc/en-us/articles/209659623-FTL-Faster-Than-Light-streaming-protocol-
28. Müller, M. W. (2016). petra for max. Retrieved from http://circuitmusiclabs.com/projects/petra-for-max/
29. Nakagaki, T., Yamada, H., & Toth, A. (2000). Intelligence: Maze-Solving by an Amoeboid Organism. Nature. 407. 470-470. doi: 10.1038/35035159.
30. Olariu, S., & Zomaya, A. Y. (2005). Handbook of bioinspired algorithms and applications. CRC Press, London.
31. Oliveros, P. (2005). Deep Listening: A Composer's Sound Practice. iUniverse, Lincoln.
32. Oliveros, P., Weaver, S., Dresser, M., Pitcher, J., Braasch, J., & Chafe, C. (2009). Telematic Music: Six Perspectives. Leonardo Music Journal, 19. doi: 10.1162/lmj.2009.19.95
33. Reid, C. R., Latty, T., Dussutour, A., & Beekman, M. (2012). Slime mold uses an externalized spatial "memory" to navigate in complex environments. Proceedings of the National Academy of Sciences, 109(43), 17490–17494. doi: 10.1073/pnas.1215037109
34. Reynolds, C. W. (1987). Flocks, herds and schools: A distributed behavioral model. Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH 87. doi: 10.1145/37401.37406
35. Rotondo, M., Kruge, N., & Wang, G. (2012). Many-Person Instruments for Computer Music Performance. New Interfaces for Musical Expression, Ann Arbor.
36. Rozenberg, G. (2012). Handbook of natural computing. Springer, Berlin.
37. Small, C. (1998) Musicking: The Meanings of Performing and Listening. Wesleyan University Press, Middletown.
38. Tero, A., Takagi, S., Saigusa, T., Ito, K., Bebber, D., Fricker, M., Yumiki, K., Kobayashi, R., & Nakagaki, T. (2010). Rules for Biologically Inspired Adaptive Network Design. Science, New York. 327. 439-42. doi: 10.1126/science.1177894.
39. Truax, B. (1988). Real-Time Granular Synthesis with a Digital Signal Processor. Computer Music Journal, 12(2), 14–26. doi: 10.2307/3679938
40. Vogel, D., Gautrais, J., Perna, A., Sumpter, D., Deneubourg, J., & Dussutour, A. (2016). Transition from isotropic to digitated growth modulates network formation in Physarum polycephalum. Journal of Physics D: Applied Physics. 50. 014002. doi: 10.1088/1361-6463/50/1/014002.
41. Waters, S. (2007). Performance Ecosystems: Ecological approaches to musical interaction. Electroacoustic Music Studies Network, Leicester.
42. Weinberg, G. (2003). Interconnected Musical Networks - Bringing Expression and Thoughtfulness to Collaborative Group Playing. Massachusetts Institute of Technology, Cambridge.
43. Xenakis, I. (1971). Formalized music: thought and mathematics in composition. Indiana University Press, Bloomington.