Investigating autopoiesis in site-responsive sonic art

By Lauren Hayes

Abstract

This paper discusses the ongoing research project *Sounding Out Spaces* which explores technologically-mediated sonic responses to site through human, material, and environmental considerations. Informed by theories of self-organisation and reflexivity, the project attempts to build a methodology for developing portable sound-systems using microcontroller technologies in which sonic entities emerge over time through mutually affecting relationships with the environments in which they are situated. I assess this work with reference to Hayles' discussion of second-order cybernetics and its implications for conceptualising musical systems as sets of relationships between living things, machines, and the environment. I expound these ideas through two case studies of the latest iteration of the tools—hardware and software systems—developed for this work: firstly, a large-scale installation which was presented in the Sonoran Desert of Arizona, United States. The second case study took place as a series of experiments at the Ars Bioarctica residency in the sub-arctic tundra at the Kilpisjärvi Biological Station, University of Helsinki, Finland.

Keywords - Sonic interaction design, sonic art, ecosystems, emergence, autopoiesis

1. Introduction

Sounding Out Spaces is a project which approaches artwork creation as a process in which sonic activity is brought forth through the organisation and movement of things within a medium. These things might include sensing technologies, microcomputers, humans, and other organisms (see Figure 1). Air is the routine medium, but experiments with water and ice have also been undertaken. The project eschews traditional human-computer interaction (HCI) paradigms that are pervasively drawn from in digital musical instrument (DMI) design. In this model, a performer will typically use a variety of input gestures that are sensed by a controller or tracking mechanism, in order to affect parameters within digital signal processing (DSP), resulting in changes in sonic output. Rather, *Sounding Out Spaces* decentralises—but does not forget—the human, drawing on the application of second-order cybernetics in order to produce sonic structures that continuously evolve over time. Specifically, it explores the notion of structurally determined—or autopoietic (Maturana and Varela, 1973/1980)—systems. These are systems in which behaviour can be triggered by changes in environmental factors, but only the structure of the system itself is responsible for how these external perturbations are dealt with temporally.

Figure 1
A Bela microcomputer, wires, and sensors entangled in arctic birch and other flora during *Sounding Out Spaces: Ars Bioarctica,* Finland.

2. Motivations

Since 2014, I have been engaging in a new set of practices that I describe as site-responsive sonic art (Hayes, 2017). This involves developing technologically-mediated sonic responses to site through human, material, and environmental considerations. Concerning the human, this work has been a departure, or rather, a reframing of much of my prior musical research which involves the design of, and performance with hybrid analogue/digital live electronic instruments. Typically, these performances take place within concert venues where audiences stand, or are seated, facing a stage. Over the last decade, I have become increasingly dissatisfied with the near-ubiquitous commitment to preserving the listener-as-spectator model (Small, 1998) in the presentation of live electronic music, and yet increasingly comfortable performing in more unusual spaces and configurations. *Sounding Out Spaces* looks to theoretical movements within the arts to disrupt the notion of audience-as-passive-observer or consumer. For example, its criticisms notwithstanding, Nicolas Bourriaud's (2002) vision of relational aesthetics makes a pointed objection to the individual, private consumption of art. As Claire Bishop notes, it "sets up situations in which viewers are not just addressed as a collective, social entity, but are actually given the wherewithal to create a community, however temporary or utopian this may be" (Bishop, 2004, p54).

This work has been motivated in part by a desire to generate large-scale musical structures which evolve in response to external perturbations in the environment, at the levels of both the sonic material and form. The two case studies that will be discussed in what follows both yield unpredictable sonic results, despite the causal relationships that occur between successive events. Both works are durational and constantly evolving, employing dynamic behaviours rather than pseudorandom computational processes. Being extremely sensitive to initial conditions, this type of chaotic behaviour is deterministic, yet can still be highly unpredictable. The goal is to develop work that is responsive to a particular set of local environmental conditions. This differs from durational works in which events change according to a linear time-based schedule, such as an event score, or a probability matrix.

3 Background: Cybernetics and Musical Systems

3.1 Homeostasis

N. Katherine Hayles elucidates how the field of cybernetics has evolved in three discernible stages through a chronological analysis (Hayles, 2008). Her work specifically critiques the separation of information from any material basis by examining several moments in the history of cybernetic development where moves towards such disembodiment were contested by key researchers. A discussion of the first two stages and their employment within musical contexts can be helpful in demonstrating the power—and limitations—of cybernetics as a creative model. The third wave in Hayles' chronology—which is largely concerned with artificial life—is beyond the scope of this work.

Cybernetics was formally introduced by Norbert Wiener with the publication of his book on the science of control and communication in living beings and machines (Wiener, 1948). Wiener's key contribution was to marry the study of information flow with control theory. He suggested that the same methods could be applied to animals, machines, and perhaps even societies alike. The first wave of cybernetics, spanning approximately two decades from the mid-1940s onwards, focused on the notion of homeostasis, whereby a system is able to maintain stability given changing external conditions. In this view, organisms exists as closed-loop systems, constantly checking and updating their state: for example, when in a cold environment, a mammal maintains homeostasis by generating heat. In most cases, preserving homeostasis depends on negative feedback loops: responses that act to negate environmental stimuli.

This principle informed the design of early circuit-based electronic instruments by composers such as Bebe and Louis Barron, and Herbert Brün (Dunbar-Hester, 2010). Often, these assembled circuits would generate sound until they eventually burned out, demonstrating a coupling between musical form and material. By the 1960s, Brün had moved on to designing cybernetic computer systems for composition. His goal was to integrate noticeably human—or intelligent—characteristics within the machine. This was done by imbuing just enough compositional rules from which to generate changes of state that could be accepted as musically coherent. Yet in this case, moving from sounding circuitry to 'intelligent' programs, we find one of the first epistemic shifts that Hayles aims to complicate: namely, the conceptualisation of information as something distinct from the materials or substrates which carry it (Hayles, 2008). For Hayles, "abstract pattern can never fully capture the embodied actuality, unless it is as prolix and noisy as the body itself" (Hayles, 2008, p22).

Could such disembodied information processes, however, modelled from the biological domain into the compositional realm, be creatively fertile? In her early work on cybernetic musical systems, Alice Eldridge describes several possible implementations of homeostasis as a compositional device. In one example, it is applied as a way to create meaningful relationships between pitches, where harmonies are generated via homeostatic feedback mechanisms (Eldridge, 2002). Her work draws on biologically-inspired models, believing that “their intrinsic properties can create musically meaningful relations" (Eldridge, 2002, p2). Eldridge’s aim to generate music that is deemed sophisticated enough to deserve human attention echoes that of Brün. But she notes that the majority of prior research in this area has produced only short musical examples. It has not fully explored other potential avenues, such as the generation of larger structures and multiple time-scales. Working with homeostatic models within the digital domain, Eldridge has been able to explore interesting couplings between the evolution of harmonic content and structural form.

3.2 Autopoiesis

It is the second cybernetic wave that has arguably been the most fruitful for musicians (Dunbar-Hester, 2010). Here the focus shifts from homeostasis to autopoiesis, without completely leaving the former behind. Hayles describes this transition, which occurred during the period from 1960-1985, as a move towards reflexivity (Hayles, 2008). Crucially, where homeostasis typically involved systems that could be observed by agents external to them, the circularity of second-order cybernetics acknowledged the observer as an intrinsic part of the system. Heinz von Foerster, who notably collaborated with Brün, fleshed out these developments in his wryly named “Observing Systems” (von Foerster, 1984). The potential social and political ramifications of this were vast, given the implications for scientific objectivity. The theory of autopoiesis problematised the abstract, disembodied notion of information found in first-wave cybernetics by “insisting that information without a body does not exist other than as an inference drawn by an observer” (Hayles, 2008, p149).

During the decade following 1972, the notion of reflexivity was fully expanded into the theory of autopoiesis by biologist Humberto Maturana, with his then student Francisco Varela (Maturana & Varela, 1973/1980). In closed-loop homeostatic systems, changes in state are determined by variances in the environment. Autopoietic systems, being initially concerned with the cellular level, but later expanded to deal with the entire nervous system, determine their activity on internal, rather than external (environmental) factors. Changes in the external world cause perturbations, yet the organism always acts upon its own internally-determined rules. Another key aspect of autopoiesis is the notion of structural coupling, which arises “whenever there is a history of recurrent interactions leading to the structural congruence between two (or more) systems” (Maturana & Varela, 1987, p75). While energetic exchange can occur, information does not cross the boundary from the environment into the organism, or vice-versa. Distinguishing itself from the first wave, this approach favours “change over constancy, evolution over equilibrium, complexity over predictability” (Hayles, 1994, p446). Furthermore, in addition to being able to regulate their own states (self-organisation), autopoietic systems or organisms also have the capacity to reproduce the very organisation that makes them (self-making). Maturana’s early experiments with amphibian perception suggested, quite radically, that reality is constructed by what can be perceived by the organism, rather than simply being registered through observation. Organisms bring forth their environments “through ‘the domain of interactions’ made possible by [their] autopoietic organization” (Hayles, 2008, p137).

From a musical perspective, Christina Dunbar-Hester argues that it is a composer's tendency to be "concerned with self-making and the interplay of agency between composer, audience, machine, and the musical piece or performance itself" (Dunbar-Hester, 2010, p116) that accounts for this being the most applied wave of cybernetics for musicians. This is evidenced in research which imagines subsets of these relationships as performance ecosystems (Waters, 2007; Green, 2008). Furthermore, composers Agostino Di Scipio (2003) and Dario Sanfilippo (2013) describe their work using language that explicitly references autopoietic theory. Di Scipio discusses the role of noise as the ambience—or medium—of his *Audible Eco-Systemic Interface* project. He insists that:

> "self-referential attributes—like 'self-observing' or 'self-organising'—are meaningless unless we also account for the relationship to the ambience, and to the noise that the ambience provides a system with. Noise is a necessary element, crucial for a coherent, but flexible and dynamical behaviour to emerge" (Di Scipio 2003, p272).

Working with adaptive dynamical systems, the goal is to create audible ecosystems that unfold over time with coherent characteristics which are determined by their internal structures. All this necessarily occurs in strict coupling with the performance space and audience present (Di Scipio, 2003).

3.3 Creative Challenges and Implications

> "Human music is infused with cultural conventions and traditions that create expectation on the part of the listener and imbue the music with certain forms of 'deep' structure" (Eldridge, 2002, p1).

Herein lies one of the main historical challenges of employing machine intelligence within musical systems for human listeners. While training a system using machine learning techniques on a corpus of sonic material has led to convincing musical creations in various genres, the task of developing wholly new music and musical structures, Eldridge argues, is more problematic (Eldridge, 2002). Her solution is to employ system dynamics to develop higher-level structural forms. Rather than simply regulating themselves in accordance with their own internal states, parts of the system auto-regulate based on the state of the entire global system. This bottom-up approach, she proposes, can lead to complex and engaging musical forms through the organisational mechanisms of the algorithms involved. Other techniques employed in this vein include incorporating self-regulating damping factors within a modular network of homeostatic elements in order to avoid rapid stabilisation within the system. This allows for complexity to arise while still "preserving the essential characteristic properties of homeostasis" (Eldridge, 2002, p8).

According to George Lewis, it is specifically the interactions that can be had with intelligent computer systems that reveal clues about the characteristics of the cultural communities in which they were produced (Lewis, 2000). Nowhere has this been made clearer than in the endemic issues of bias that have been raised within the AI industry. While Eldridge sought biologically-inspired solutions, Lewis, in discussing his *Voyager* musical improvisation system, describes the experience of developing and performing with it as "a kind of computer music-making embodying African-American cultural practice" (Lewis, 2000, p33). One example of this is the tendency towards the production of dense passages of sonic events within small temporal intervals, distinguishing his work from “much institutionally produced trans-European computer music” (Lewis, 2000, p37). *Voyager* further differs from other work in the field of human-computer improvisation systems in that while it can accommodate human input, it is semi-autonomous, and does not depend on a musician’s activity in order to produce musical output (Lewis, 2000). The hierarchy between human and machine is removed in terms of the gesture-and-response models that are often typical of such systems.

Early in the development of cybernetic theory, Wiener quickly recognised the significant latent dangers in its potential applications of control on humanity, and the positive or indeed destructive effects this could have. While his anxieties were widely publicised, it is worth remembering that his “science of communication and control was explicitly considered in terms of American racial politics, in terms of mastery and slavery" (Chude-Sokei, 2015, p83). Several decades later, public fear continues to exist around a range of related issues, including the automation of labour. Yet Hayles, with a cautionary optimism, emphasises that “[j]ust as the posthuman need not be antihuman, so it also need not be apocalyptic” (Hayles, 2008, p288). The potential for cybernetically-informed socially empowered art practices can be seen in, for example, the growth of networked music ensembles, as well as the workshop format as a mode of participative and collective creativity (see [Koutsomichalis, 2018] for further examples). Lewis provides a decentralised approach to collaborative music making, where control and decision making is distributed between both performers and machines. Moreover, through his de-instrumentalisation of the technology involved, he suggests that by (musically) improvising with our machines, we can be taught “how to live in a world marked by agency, indeterminacy, analysis of conditions, and the parent ineffability of choice” (Lewis, 2018, p128).

4 *Sounding Out Spaces*

Sounding Out Spaces is an ongoing body of research that involves context-based performances and installations which consider technologically-mediated sonic responses to various sites. The project involves machine listening techniques for the recording, analysis, processing, and the amplification of sound present in the environment. Additional sensing hardware, including anemometers, photocells, and soil sensors are also used to detect environmental activity. What emerges is derived from the acoustical and environmental dynamics of the specific location, along with the unique characteristics of the microphones, loudspeakers, and DSP techniques that are utilised. While many of the most recent iterations of this series have taken place outdoors, the project does not align with the practices of soundscape composition, where sound is collected through recording devices, isolated from its context, processed or arranged in a studio, and later played back as a fixed media piece in a different space. Nor does it claim to be derived from the established discipline of acoustic ecology, which often enforces binaries between the man-made and the natural, or desirable and undesirable sound (Thompson, 2017).

As Marie Thompson (2017) makes plain in her Spinozist ethics of noise and silence, synthetic sound, for example, cannot be inherently ‘bad’ as judged from a human-centred perspective. Its impact on a living organism can only be determined in each specific context whereby an affective relationship is established that unfolds between sound and perceiver. Synthetic sound can disrupt sleep, but it is also used within tinnitus masking devices to actually promote rest and wellbeing. The site-responsive sonic art practices that will be discussed in this section do not bias towards the 'natural', but rather explore relational possibilities between autopoietic entities which may comprise humans, other organisms, and also machines, which maintain and reproduce their structural organisation through their operational characteristics.

4.1 *Garden Ecologies*

Sounding Out Spaces is series of works which offers direct engagement with sites, in which participants may become part of the work itself by way of their movement through an environment (Hayes, 2017). They may experience it in multiple ways and from various perspectives. In 2017, along with artist and researcher Julian Stein, I developed a modular system of sound and sensor processing devices using portable microcomputers (Moro, 2016b), which were distributed through a large public garden (see Figure 2). Working with audio feedback through systems of microphones and loudspeakers, we employed self-organisational strategies within the software, which was embedded on the microcomputers. Using simple mechanisms for self-adaptation and calibration, we were able to regulate acoustic and sensor input leading to responsive sonic output (see [Hayes & Stein, 2018] for full technical details).

Figure 2
Participants experiencing *Sounding Out Spaces: Garden Ecologies* in Tempe, Arizona, 2017.

Both first and second-order cybernetic ideas were employed in this project. Comprising four distinct zones within a community garden, this large-scale work used various homeostatic models throughout the installation. For example, a microphone, loudspeakers, and microcomputer were placed inside a stack of large discarded tractor tyres. The inherent resonances of the tyres were used as physical filters. The amplitude of what was captured through the microphone was multi-mapped within the code, in order to regulate both time-based changes in the sonic output—how quickly an oscillator would cycle—as well as the frequency of a digital filter. This produced homogeneous sonic material with continuously changing rhythmic characteristics, which was nevertheless coupled to the material tyres in which it was embedded (see Video Example 1).

Video Example 1
Self-organisation of sonic material using feedback within a tractor tyre.

In the main section of the installation, a collection of microcomputers, sensors, and microphones were distributed throughout several raised beds, creating a complex network of activity which broadcast sound across eighteen small loudspeakers. Audio picked up by the microphones was analysed, and further processed based on extracted time-domain features. For example, in the areas where audio feedback was a created, amplitude was measured over windows of thirty-two samples, which was responsive enough to control an adaptive bandpass filter. Recorded audio was stored in chunks, or buffers of different lengths, which would continuously update with new material; the recorded or processed sound was then amplified through the loudspeakers. The audio that became entangled in the system included the sounds of crickets, birds, and the movement of plants, and humans. This would vary according to the time of day and region of the installation. In this way, sound was produced, transformed, destroyed, and reproduced through the interactions of components—organic, machine, and environmental—within the system.

Ambient sound feeds the system recursively, and through the processes of analysis and transformation, it maintains the structures needed to allow sonic activity to be generated. Through this mechanism, the goal of an emergent, responsive, and durational unfolding of sonic events is achieved (see Video Example 2 for a short excerpt of the transformation of audio through part of the system). The autopoietic nature of the system is evident in its ability to (sonically) produce, sustain, and renew itself. In the most complex part of the installation, microcomputers analysed and processed ambient sound: no other sound sources—such as pre-recorded audio samples—were used here.

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The control data derived from this analysis, along with other environmental sensor data, was used to maintain sonic output, by affecting, for example, the times of delay lines, or the playback speed of buffers. This, in turn, introduced more sound back into the environment, which repeatedly renewed the process. Ambient sound would continue to be heard if the electronic and digital components of the system ceased to function. Critically, no sound would be produced if the system was situated within a completely silent room.

Video Example 2
Listening to feedback generated within a bed of sunflowers.

4.2 Ars Bioarctica
The Ars Bioarctica residency program, organised by the Finnish Bioart Society, is hosted at the Kilpisjärvi Biological Station, University of Helsinki, Finland. I was invited to spend two weeks in the Finnish subarctic tundra in residence, along with visual artist and photographer, Tobias Feltus. Kilpisjärvi is a sparsely populated village in Lapland, which boasts both the Saana fell (see Figure 3) as well as the tripoint at which Finland, Norway, and Sweden meet. Due to its geographical location, the atmospheric conditions contribute significantly to the acoustic domain of Kilpisjärvi, both as weather—wind and rain—as well as the flow of rivers, snow melt, glacial drift, and so on. Other noticeable sounds come from reindeer, insects, mosquitoes, birds, and other wildlife.

Numerous artists working with sound have taken residence at the research centre as part of the art-science programme. Notably, many of these residents have commented on the importance of site and environment in their work there. For example, Arizona-based sound artist Richard Lerman has made several visits to the location, combining field recordings, DIY aeolian instruments, and the sounds of ice cracking over time (Lerman, 2015). Antye Greie, a musician and producer professionally known as AGF, has

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explored the possibilities for incorporating listening and recording practices, along with real-time digital composition during her residency in 2011. Her work there explored how to "plant sound poetry permanently into forms of nature" (Greie, 2011).

Figure 3
View from near the top of Saana, Kilpisjärvi, Finland.

Thomas Grill's work involves collecting field recordings which are analysed offsite. His iterative process later feeds the selected sonic material back into the system at the original location (Grill, 2014). Grill stresses the multisensory aspects of this technique, commenting on the situated and embodied processes at play here, and calling for a non-representational approach in his project:

> "It is an attempt to feature concrete and synthetically derived sound and associated performative elements where it is alive and in proper context, not in a home cinema, not in a concert venue, not in a white cube gallery, or other acoustically neutral and anonymous sites, but at a concrete place, and put it right among all the related and corresponding sounds and other sensuous impressions that make up a truly holistic experience, including vision, touch and scent" (Grill, 2014, p2).

While Grill notes the objections to the preferential value placed on certain categories of sounds in some domains of acoustic ecology (Grill, 2014), it is unclear from his writing whether he agrees with these objections or not. The key creative goal for Grill's work is to create an enhanced listening experience for audiences as a result of the small audible changes that he manifests through the use of technologies. For Grill, "the loudspeakers serve for framing the scenery in space and time within a quasi-boundless nature, spanning an invisible stage for the augmented soundscape" (Grill, 2014, p7).

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The goal with *Sounding Out Spaces: Ars Bioarctica* was to evaluate the tools that had been used in the Sonoran Desert of Arizona in a radically different setting. We were hoping to determine whether an aesthetically interesting, or at least cohesive sonic experience could be elicited using the same hardware, software, and processes of familiarisation with the new environment that had been previously employed. Could the results reflect the unique and wholly distinct acoustic, environmental and geological characteristics that this northerly region of Finland provided? Over the two week timeframe, we focused on two specific locations for this work. The first was at a small lake that had formed near the top of Saana, into which a shelf of residual ice continued to slowly melt. The second location was in and around the Kitsiputous waterfall on the Malla Strict Nature Reserve (see Figure 4), a highly protected area which also contains the three-country cairn at which the international borders of Sweden, Norway and Finland meet.

Figure 4
Musicking with the Kitsiputous waterfall, Malla Strict Nature Reserve, Finland.

In addition to standard microphones, a selection of hydrophones were used, including

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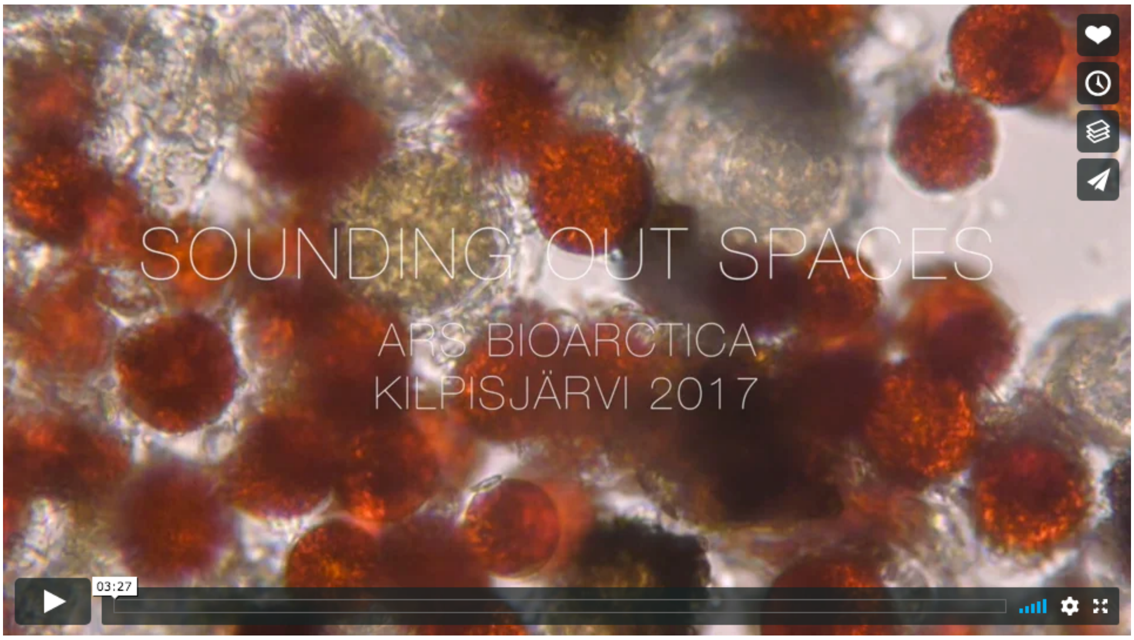
piezo-electric and electret condenser types. These allowed for slow processes—such as the dripping of melting ice—as well as the faster movements of flowing water picked up by a hydrophone in a pool to become part of the hybrid sonic ecosystem. Furthermore, as the loudspeakers used were also waterproof, this permitted feedback loops to be created underwater. In combination with the hydrophones, we were able to change the medium through which sound would propagate, and potentially be heard (see Video Example 3, c. 52" for an example of this). It is important to note here that following Bennett Hogg's discussion of his *Landscape Quartet* project (Hogg, 2013), the audio-visual documentation that accompanies *Sounding Out Spaces* does not constitute the work itself, and is not presented as a chronological representation of what transpired. Instead, it is a simply collection of decoupled audio and visual recordings of events that took place during the realisation of the installation or performance.



Video Example 3
Excerpts from site-responsive work undertaken at Saana, Finland.

Working at the second site, the Kitsiputous waterfall, there is a marked difference in sonic result, which can be heard at the start of Video Example 4. Here the rapid and dynamic activity of the fast flowing water, along with the white noise characteristics that are produced by a waterfall have clearly contributed to a much harsher sonic response. In fact, all experiments in Finland resulted in a noisier and distorted sonic domain compared to what transpired in Arizona. The same environmental sensing technologies were employed here as were used in the United States, including light, wind, and soil sensors. These are not used in an attempt to provide a holistic impression or objective measurement of the state of the medium in which the installation is taking place. Rather, these offer additional ways in which environmental perturbations can trigger changes as determined by the autopoietic entities, leading to more complex behaviours. Despite these low-cost sensors functioning largely in a predictable manner based on changes in the amount of sunlight, wind, or soil moisture present, these simple components can still contribute significant differences in results (Goodman, 2018).

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Video Example 4
Excerpts from site-responsive work undertaken in and around the Kitsiputous waterfall, Finland.

5 Discussion

"Människan är del av naturen, inte dess herre" (Valkeapää, 1984).

As part of the residency programme in Kilpisjärvi, we received mentoring from environmental artist and academic, Leena Valkeapää, and talked with her husband Oula, a reindeer herder and Sámi (the indigenous peoples from a region of northern Europe, transversing Finland, Norway, Sweden, and Russia). Their relative Nils-Aslak Valkeapää was one of the most well-known Sámi figures, being an advocate of their culture, as well as an artist, writer, and musician (Hautala-Hirvioja, 2015). In particular he revived the traditional yoik, a form of vocalised expression involving "anything at the yoiker's perception at the given moment, therefore emotions, landscapes, animals, birds and other people are yoiked" (Hämäläinen et al., 2018, p3). Thus yoiking can be described as an act of expression and also creation (Hämäläinen et al., 2018). Valkeapää cautions the categorisation of the yoik as art or music, having little in common with the latter within mainstream European culture (Valkeapää, 1984). He explains that yoiks do not begin and end, and they do not need to be limited by Western cultural ideas about form or structure. For Valkeapää, the nature-culture binary and the hierarchies that it connotes is unhelpful: "Man is part of nature, not its lord" (Valkeapää, 1984). It is interesting to note that both Grill and Greie comment on the parallels to yoiking in their work at Kilpisjärvi (Grill, 2014; Greie, 2011).

While it would be tempting to make similar comparisons with *Sounding Out Spaces: Ars Bioarctica*, we were merely tourists on an artists' residency immersing ourselves in this heritage for a short amount of time. Despite the creative potential of the autopoietic systems described in this paper, they are not intended to replace—or indeed replicate—the rich and unique cultural approaches to music making that are practiced around the world. Speaking of what is afforded by cybernetic systems, Hayles reminds us that:

"these reflexive complexities do not negate the importance of the sedimented history

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incarnated within the body. Interpreted through metaphors resonant with cultural meanings, the body itself is a congealed metaphor, a physical structure whose constraints and possibilities have been formed by an evolutionary history that intelligent machines do not share" (Hayles, 2008, p284).

Nevertheless, the project was navigated and curated through the processes of listening, familiarisation with the site, and the moving around and positioning of various components such as sensors or microphones. This fundamentally embodied process is described by Tim Ingold as "a knowledge born of sensory perception and practical engagement, not of the mind with the material world... but of the skilled practitioner participating in a world of materials" (Ingold, 2007, p13). A Harawayian perspective (Haraway, 2013) can be helpful here in understanding that while feedback systems can be useful creative devices, they do not enable us to discover any kind of 'natural' or 'objective' sonic reality. These musical systems are necessarily constructed by means of culturally informed choices of materials, hardware, and importantly the embodied actions of the artists and other participants involved. This echoes Lewis' point as discussed earlier.

6 Conclusion

Cybernetics has been used within the creative arts since its inception (see [Reichardt, 1971] for numerous examples). *Sounding Out Spaces* contributes to cybernetics-driven arts practice through its modular and portable approach to the development and organisation of hardware and software components within a network. Working with autopoietic systems makes explicit the role of environment—or medium—in which the work is undertaken. The various implementations of second-order cybernetic ideas lead to new musical aesthetic experiences, while simultaneously offering alternative modes of understanding musical activity—as embodied rather than necessarily formalistic. As autopoietic systems themselves, humans may be present in the specific environment, but are not the prime cause of musical activity. The project generates responsive sonic environments that have the potential to unfold over time in non-random, yet unpredictable and compelling ways. The musical situation that emerges in each iteration of *Sounding Out Spaces* is born out of the unfolding of the environment "in relation to the beings that make a living there" (Ingold, 2007, p14).

Hayles' critique of the reification of information over any material manifestation within first-wave cybernetics is helpful in demonstrating the importance of the site-specificity, and the contextual basis of these works. A piece cannot simply be transplanted to a new location and yield the same sonic results. The technological interventions are intentionally transferrable, yet what emerges is fundamentally coupled to the material substrates provided by a location. Moreover, *Sounding Out Spaces* diverges from soundscape composition and the established practices of acoustic ecology as it is not concerned with with the collection, measurement, and representation, nor the evaluation of acoustic activity. Despite this, it is fundamentally concerned with the relationships between living beings, machines, and environments. It addresses this by primarily acknowledging the circularity of observation that constitutes autopoietic systems. As such, there is no desire to hide human incidental sounds from recorded documentation, nor produce high-fidelity audio representations of events that transpired in a temporary installation.

As the project develops, it could potentially enable participants to understand more about the nature of a specific site through the situated and embodied experience of the sonic response, rather than by measurement and analysis of data. This has not yet been evaluated in a formal manner. Nevertheless, the two case studies described in this paper are presented with the aim of permitting a comparison of using the same technologies in radically different locations. The embedded nature of the works, which incorporate various mediums—air, water, and ice—give rise to different results which could be said to reflect something of the specificities of each site. A key future goal of the project is to develop the software in order to more readily reflect this. Making more use of adaptive calibration strategies will be helpful, where, for example, the overall maximum and minimum decibel level may vary greatly at different locations. Frequency-domain analysis was not fully implemented on the Bela platform using Pure Data software at the time of development of this system (Moro, 2016a). Future iterations will incorporate this as a way to include more spectral sonic properties.

Eventually Maturana and Varela expanded their original notion of autopoiesis to allow for artificial systems to be considered living systems. During the third wave of cybernetics, Varela expanded his research to include the domain of artificial life (Hayles 2008). This move addressed the lack of accounting for dynamic interactions within the autopoietic paradigm with a new model: enaction (Varela et al., 1991). This has been particularly pertinent as a theory of music cognition in its ability to account for the embodied practices of musical expression, and as a way of thinking about gesture and technology (see [Hayes, 2015] for a discussion of this). Yet despite its limitations as a holistic account of musical activity, the idea of informationally-closed autopoietic entities provides a rich model for designing digital musical systems which are generative yet homogeneous, and where agency is decentralised. Furthermore, echoing Lewis' comments regarding what can be learnt about computer systems by improvising with such systems, the approach taken in *Sounding Out Spaces* might offer alternative ways of understanding the behaviour of cybernetic systems expressly through environmentally situated embodied experiences of them.

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Biography

Lauren Hayes is a Scottish musician and sound artist who builds hybrid analogue/digital instruments. She is a 'positively ferocious improvisor' (Cycling '74), her music refusing to sit nicely between free improv, experimental pop, techno, and noise. Over the last decade she has developed an unpredictable performance system that explores the relationships between bodies, sound, and environments. She has created several haptic (touch-based) interfaces and composes music that can be experienced physically as vibration throughout the body. Her research explores embodied music cognition, enactive approaches to digital instrument design, and haptic technologies. She is currently Assistant Professor of Sound Studies within the School of Arts, Media and Engineering at Arizona State University where she leads PARIESA (Practice and Research in Enactive Sonic Art). She is a member of the New BBC Radiophonic Workshop. www.pariesa.com www.laurensarahhayes.com

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