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Sound feedback control model for live electronic performance in the *Ecos Study*

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Resumo: Através do Estudo Ecos investigamos possibilidades de estruturação musical com base em teorias de emergência, encontrando um território fértil para experimentações dentro do paradigma dos Ecossistemas Audíveis de Agostino Di Scipio. A inclusão do ambiente acústico como um componente ativo do sistema musical nos levou a repensar as técnicas clássicas de síntese e modelagem sonora, alguns modelos tradicionais de performance eletroacústica, e a criticar o próprio papel de interações em uma perspectiva qualitativa. Um modelo de controle de feedback positivo foi desenvolvido com o objetivo de compreender o comportamento e a estrutura do ecossistema que suporta a implementação de um Instrumento Espacial, um elemento central implementado através de patch MAX/MSP e que oferece uma fundamentação lógica para organizar alto-falantes e microfones no espaço acústico. Apresentamos o debate teórico subjacente e apresentamos o mecanismo de controle de feedback como a base a partir da qual o Instrumento Espacial é desenvolvido.

Palavras-chave: Ecologia Acústica, Teorias de Emergência, Ecossistemas Audíveis, Eletrônica Ao Vivo, Controle de Feedback.

Abstract: Through the Ecos Study we investigate possibilities for musical structuring based on theories of emergence, finding a fertile territory for experimentations within Agostino Di Scipio's paradigm of Audible Ecosystems. The inclusion of the acoustic environment as an active component of the musical system led us to rethink classical techniques of sound synthesis and modelling, some traditional models of electroacoustic performance, and to criticize the very role of interactions in a qualitative perspective. A positive feedback control model has been developed aiming at understanding the behaviour and the structure of the ecosystem supporting the implementation of the Spatial Instrument, a core element implemented through MAX/MSP patch and that offers a logical rationale for organizing speakers and microphones in the acoustic space. We introduce the underlying theoretical debate and present the feedback control mechanism as the basis from which the Spatial Instrument is developed.

Keywords: Acoustic Ecology, Emergence Theories, Audible Ecosystem, Live Electronics, Feedback Control.

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Ecos Study is a theoretical and experimental research that investigates strategies of musical structuring based on theories of emergence[1], taking as experimental territory the audible ecosystem paradigm, presented by Agostino Di Scipio (DI SCIPIO, 2003). As a preliminary result we present the development of an acoustic-digital feedback-loop[2] control device that has enabled us to experiment with the audible ecosystem and observe its behavior. The device is an instrumental part of a bigger system, called Spatial Instrument, that composes the *Ecos Study* operational field along with a theoretical framework for performance support and modeling, and including four experimental studies as well. Faced with the complexity of this object, in this paper, we will focus on the feedback control device as the basis for the Spatial Instrument development.

1. The research field

Dealing with the complexity of the audible ecosystem, the notion of control must be understood on two levels. First, the positive feedback-loop stabilization itself, so that we can deal with the feedback loop without having the system collapsed. Second, the feedback loop usage as an embedded interface spread across the physical and virtual domains, which allows for indirect actions that influence the system's components interactions. In this case, the performance in low-level components provokes changes in the high-level structures behavior of which the emergent sound structures are part.

We believe that the audible ecosystem paradigm is a prominent territory for emergent structures exploration in musical performance for some reasons. First, it is complex enough to exhibit significant emergent structures and, at same time, simple enough to be observed, manipulated and studied. Second, different from complex systems modeling approaches that are inspired in some living systems or limited to some aspect of a nature, the audible ecosystem constitutes a constructed nature itself. According to Di Scipio, "we construct a nature; we do not replicate or model a segment of extant nature" (DI SCIPIO, 2011). Third, due its sounding nature and physical dependency, the audible ecosystem leads us to new listening experiences and explorations of musical gestures. And

[1] A kindly introduction about the emergence thinking can be found in JOHNSON, 2003.
[2] Throughout the text, the term acoustic-digital feedback will also appear as feedback-loop, feedback or positive feedback. In all cases, the term will be referring to positive feedback which, in our research, is always in loop.

fourth, the openness to the acoustic environment creates a challenging context for instrument modeling, proposing new perspectives for sound synthesis and live electronics performance.

2. Theoretical support

Our interest in Di Scipio's Audible Ecosystems work is not trivial. The way the author included the acoustic environment into the musical system brought up questions about live electronics performance and how we deal with electronic instruments nowadays. First, breaking with the notion of musical instrument as in the classical paradigm of interactive systems in electroacoustic music (GREEN, 2014; DI SCIPIO, 2017), which in a broad sense, the human performer controls the musical development through pre-selected parameters, which can be dynamic or not (ROWE, 1999); with the notion of extended or expanded instrument (GAMPER & OLIVEROS, 1998), as well with the common sound spatialization archetypes (BAALMAN, 2010). In the ecosystemic perspective, there is no direct control, but actions that influence the system's behavior. Emergent sound is the result and cause of component interactions rather than the direct actions of a specific component - like a human performer or an algorithm, for instance[3]. According to Di Scipio, the ecosystems "cannot be isolated from the external world, and cannot achieve their own autonomous function except in close conjunction with a source of information - or energy. To isolate them from the medium is to kill them" (DI SCIPIO, 2003, p. 271). In this sense, its very nature is hybrid. There is no digital-and-acoustic or instrument-and-electronics. There is no *and* just as there is nothing to be added or expanded or spatialised. The qualities, connections and interactions are their very condition of being and from these relationships the ecosystem emerges.

Secondly, following the performance ecosystem concept, coined by Simon Waters (WATERS, 2007), the inclusion of the acoustic environment breaks with the notion of portability of the musical

[3] For example, one might think that the feedback control digital device is responsible for the existence of the ecosystem. In fact, it is an essential part of it. But not only. The digital control does not work without direct contact with the acoustic environment and its acoustic modes, fluctuations and interferences. The same goes with the analogue part: the microphones, cables, preamplifiers and speakers. In this sense, there is no linear cause and effect action, but a complex interdependence among several components. These relationships become more critical when we consider a human performer as part of the ecosystem, because the whole system needs to be excited to do something. Therefore, the human performer must play with the system's responses, teasing, but also listening and understanding what its sensitivities are. In other words, turning a knob or applying signal processing is not enough. This is a resonance relationship.

work in which the space of performance does not, or should not, exert influence over it. Instead, the performance happens in-between a network of interdependent spaces – intimate, personal, social and public spaces – that are connected through feedback-loop where the sound is a form of touch (ibidem, 2009, p. 152). In this sense, the acoustic and aggregated bodies conditions are critical (ibidem, 2007, p.5). The very conditions, surfaces and possibilities, both physical and virtual, can be considered as relational spaces, and so, as narrative spaces (BOURRIAUD, 2009).

Although the relational idea runs through many contemporary musical poetics based on emergence theories (SOLOMOS, 2013; VAGGIONE, 2008), in the audible ecosystem paradigm it acquires particular issues, showing that a generic view on relationships is not sufficient. A deeper insight into the *interaction qualities* that involve the system's components is required: most of them do not choose to interact. We are faced to Di Scipio's appointment to the shift from *interactive composing* to *composing interactions* (DI SCIPIO, 2003, p. 270), but questioning what kinds of interactions? In what conditions do they happen? How does the interactive structure work in the audible ecosystem?

There are analytical and technical issues surrounding the implementation of the Ecos model that cannot be thought of separately. Although this is far beyond the scope of this paper, it is worth highlighting the deepness of the structural thinking in the ecosystemic perspective. We cannot consider only the instabilities of the emergent construction, searching for "what is moving inside what we are listening to?" (MERIC & SOLOMOS, 2014, p. 16), because the events in the acoustic domain are only a part of the relational structure. They are results and parts of an operational field that lies in and between other domains[4]. This hybrid relational structure is converted into multiple chains of operators that modulate the sound structures, which in turn are converted to the operator that modulates the relational structure. There is a cyclic causality that never remains the same (MORIN, 2005, p. 87). In this sense, we also cannot consider the audible ecosystem as a *process* in which the structure is closed and the organisation is open (DI SCIPIO, 2003, p. 276), because the very conversion of operator into structure and vice-versa shows that it is totally open: it is becoming itself. Its structure cannot be reduced to the digital algorithm nor to the physical space of the room

[4] The operational paradigm is related to Simondon's Individualization theory. In his words, "what makes a being itself, different from all others, is neither its matter nor its form, but is the operation by which its matter takes form in a system of internal resonance" (SIMONDON, 2020).

or the microphone and speakers' timbre; *the audible ecosystem's structure happens before and through the interactions.* By changing the quality of the interaction, one can change the behaviour of the system, but keeping the essential characteristics.

Faced with this complexity, we found in Jochen Fromm's taxonomy of emergences (FROMM, 2005) a strong theoretical support to think about the primary structure of the Ecos model. Fromm proposes a feedback type-based taxonomy that also opens up for a categorization in terms of causal correlations (PESSOA JR., 2006). Even with such a generalization of a highly complex phenomenon, it draws attention to the modelling of possible topologies of relational chains, that we are calling feedback topologies. For instance, by changing the feedback topology we change the spectra content (THOMASI & FARIA, 2021).

So, in the Ecos Study, Fromm's taxonomy works like an organology of the audible ecosystem, helping us to predict what kind of emergent structures a certain configuration can generate and what kinds it cannot. It helps us to select and establish structural points that enable us to act and perform with the ecosystem, both in the acoustic and digital environment. It is crucial, first, because we need to act in a micro-level field that exists before the interactions; and second, because it helps us highlight the natural dynamic conditions of emergent properties in order to explore them artistically and musically, rather than just going through it with the same old digital processes of sound synthesis and modeling.

3. Methodological approach

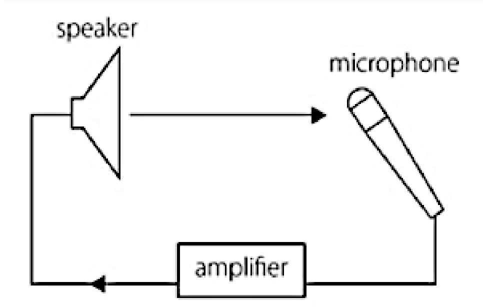
As mentioned before, Ecos Study is divided into three interconnected parts: the implementation of the mechanism for feedback control and performance, called Spatial Instrument; a theoretical framework that supports the structural thinking of modeling and musical performance; and four musical experiments, called *Ecos n.1-4,* for evaluations in musical and artistic situations, in which the first two are focused on mapping the capabilities of the Spatial Instrument in the acoustic and digital domains, respectively. *Ecos n.1,* for feedback acoustic environments, aims to investigate creative possibilities related to the spatial organization of sound sources and coupled acoustic environments (THOMASI, 2018). This experiment has been essential to define which spaces seem to be more significant for the performance in the acoustic environment, here called acoustic niches, as well as the modes of interaction with them. *Ecos n.2,* for sound feedback and digital processes, aims to investigate idiosyncratic processes in the digital domain and how to deal with the attractor components, seeking a balance between arbitrary processes and natural responses. The latter two, Ecos n.3 and n.4, are related to exploring performance models beyond the architype of live electronics solo, for instance, including acoustic instruments, body performances and audiovisual installations.

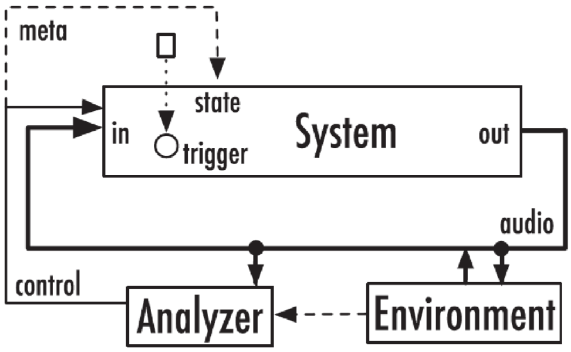
At the same time the feedback control device gives us technical and compositional constraints, the *Ecos n.1-4* experiments give us parameters to expand these constraints, criticizing which controls or tools are, in fact, interesting for our musical purposes. Thus, the experiments intend to cover different perspectives on the use of the audible ecosystem aiming at the live performance and creative possibilities, in a broad sense. The results presented in this paper came from *Ecos n.1* and *Ecos n.2* experiments.

4. Feedback system overview

The system core is based on the positive feedback of a signal that passes through the acoustic, analog and digital environment, creating a loop. A classic example is the microphony or Larsen effect (AUGOYARD & TORGUE, 2005, p. 65). The positive feedback tends to infinity being restricted only by the physical capacity of the equipment. In general, feedback system models for musical performance come coupled with a type of analyzer that will be regulating or changing the system's internal state so as not to let it saturate, as we can see in the Figure 1. In the case of the Larsen effect, the sound frequency heard is the first level of emergent sound structures. The system itself does not contain the frequency and it does not have a sound generator that produces this frequency. Rather, the frequency is produced from the physical conditions and limitations exhibited by the system.

FIGURE 1 – On the left, the feedback loop in the Larsen model that produces simple microphonies (AUGOYARD & TORGUE, 2005). On the right, a generic model of feedback system for musical purposes (SANFILIPPO & VALLE, 2013). The looped signal has constant information exchange with the environment and the analyzer dispositive that regulates the system's internal state.

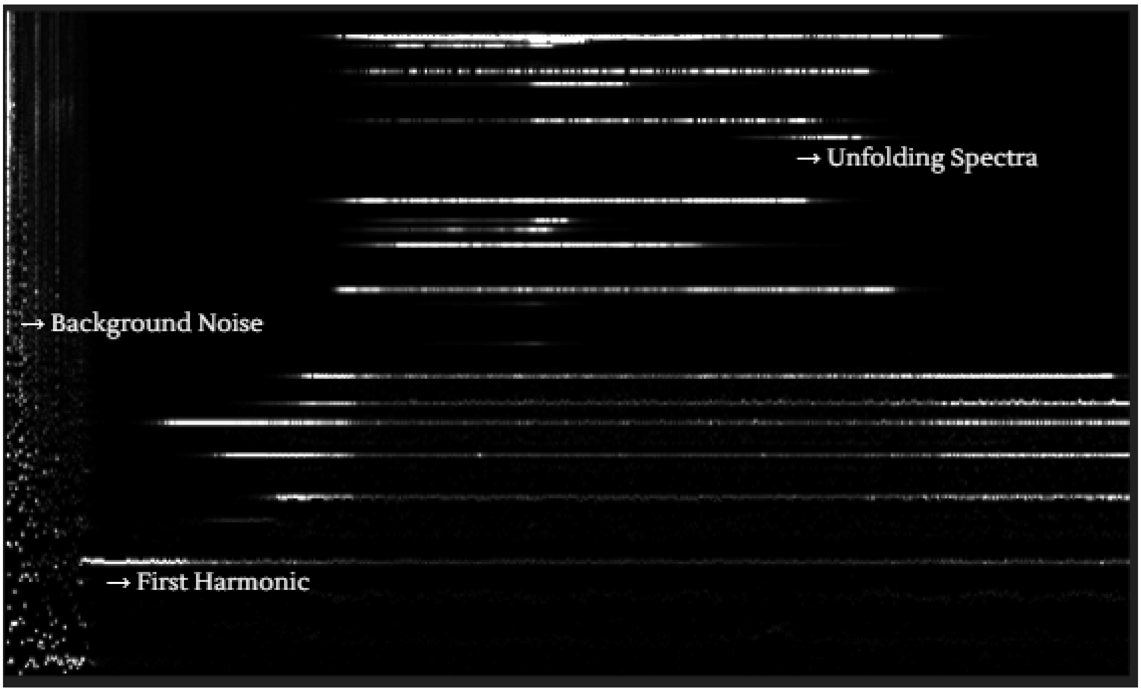




Source: SANFILIPPO & VALLE (2013, p. 18)

Figure 2 shows the moment when the resonant frequency starts to take shape in the Ecos model. On the left side, we have only background noise, like disordered particles. As the loop forms, in each of its turns, some qualities of the acoustic and digital environments and of the equipment come to the fore and stand out from the others, thus, shaping the first harmonic. That is a sound structure that appears as part of an *organization phenomenon*. In other words, the feedback loop is an attractor component, in which part of the initial qualities of the whole system are revealed through the resonant frequency. As Mitchell observed, it is "called an attractor, since, loosely speaking, any initial condition will eventually be attracted to it" (MITCHELL, 2009, p. 30). When the first frequency is controlled, it gives room for a second frequency to appear, then the second is controlled and a third appears, and so on. So you have the emergence of a spectrum that unfolds from the first harmonic and whose content depends on acoustic, analogue and digital qualities.

FIGURE 2 – Peak frequency sonogram showing the spectral formations as the feedback loop energy increases. On the left, the metastable state where small changes are critical. Next, the first harmonic formation followed by the unfolding spectra.



Source: The author

5. A feedback control for musical purposes

During the development and implementation of the Ecos feedback control model we tried to avoid two common traps in the recent computer music. First, to create an evolutionary or self-regulatory system that is not able to legitimate itself in the aesthetical experience sense *per se.* And second, to create a bundle of digital sound processes lacking musical structuring support. In this regard, we set five guidelines for modelling the feedback control engine and the Spatial Instrument as a whole. The first three take into account the signal control and the equipment involved, helping to make choices for the implementation of the feedback control itself. While the last two are more related to performance issues and relationships with musical structuring, therefore, to the modelling of the Spatial Instrument.

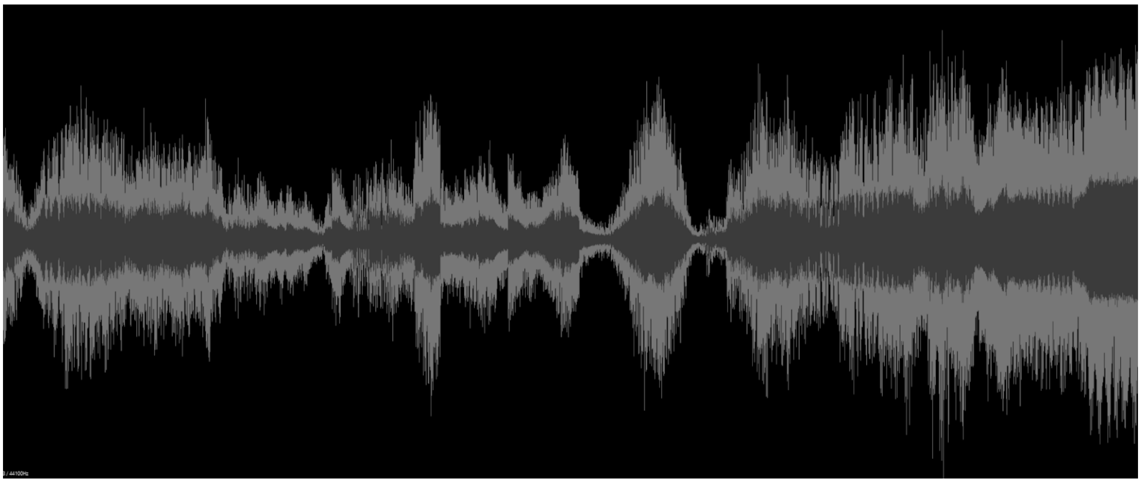
A) Preserve the sensitivity to acoustic fluctuations. We believe this is one of the most important audible ecosystem characteristics and it is the core of the whole system *behavior profile*, because it directly affects the organic relationship between digital and acoustic domains. In this sense, we get a highly sensitive system capable of working within a considerable dynamic range (Figure 3), without audio compression or saturation (Figure 4).

B) Preserve the role of sound feedback and its relation with sounding structures. Since the feedback loop is the basis of the ecosystem and the Larsen effect is the first emergent sound structure, we consider this as the primary relationship to be studied, as we believe it contains the core of the ecosystem structure. As we can see in Figure 2, we are not only preserving the feedback loop, but exploring the spectra that unfolds when the positive feedback is controlled (THOMASI & FARIA, 2021).

C) Carefulness with equipment, audio quality and the usability in performance situations. Preserving the integrity of the audio equipment, microphone and speaker, and avoiding undesirable artifacts like D.C. offset, very common in positive feedback situations, is an essential technical providence. Fortunately, our model is capable of ensuring that the feedback signal does not reach the maximum level by controlling the signal-to-noise ratio, rather than using audio compression (Figure 4). This feature also allows us to quickly set up the microphones and speakers in different room spaces and control the overall loudness, which improves the usability in musical performance. Acoustic niches explorations are also improved, since one can deal directly with the microphone during the performance.

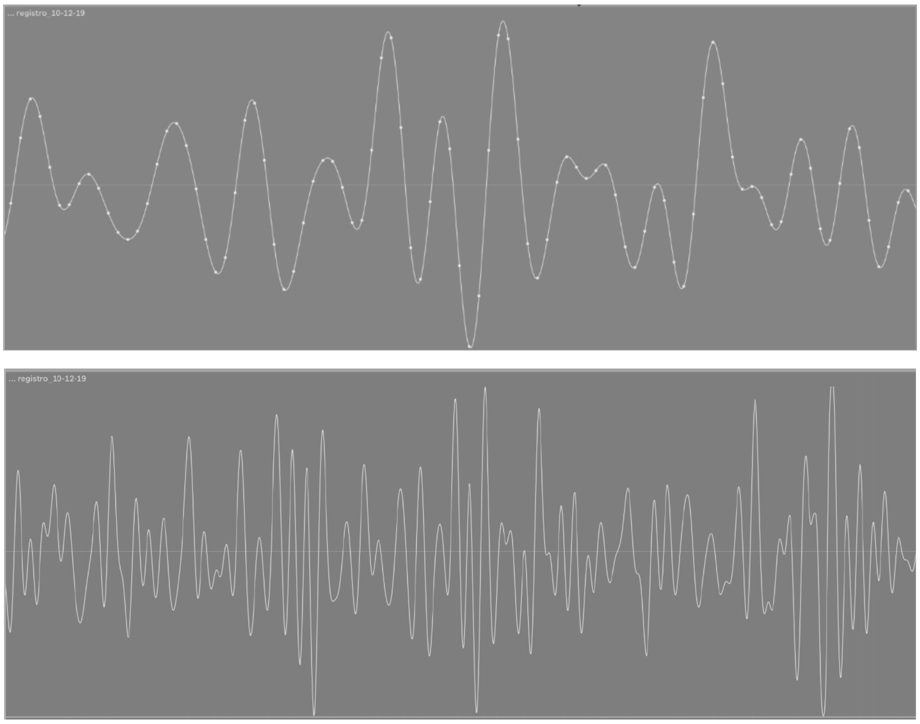
D) Assess the weight of arbitrary processes in the formation of emergent sound structures to allow for structural jumps. An essential care taken in modelling this system was not to overlay the ecosystem's natural behavior with classical techniques of sound modeling, such as envelope generators, filter banks and wavetable synthesis, for instance. In the first moment, this was a challenging consideration. But after Ecos n.1 and n.2 experiments a new conception of control and performance came to foreground. In this sense, classical techniques work quite differently in the audible ecosystem, because the processes, when inserted into the loop, become iterative. For instance, modulations by resonant filters and periodic oscillations become attractor points, and they can provoke the emergence of new frequencies. In the same way, inserting a subtractive synthesis or ring modulation technique serially in the loop - considering the feedback loop as a common sound generator - makes the system insensitive. In this sense, an insensitive system is unable to make structural jumps.

FIGURE 3 – Waveform showing different amplitude levels of the sound feedback signal. The center part of the waveform shows the density and the continuity of the feedback loop signal even in lower amplitudes.



Source: The author

FIGURE 4 – As we can see in the waveform, even in higher amplitudes the feedback signal does not exhibit saturation, compression or digital conversion offset. Above, a zooming to the sample rate, and below a hundred milliseconds clip.



Source: The author

E) Establish structural musical thinking correlations. The fast response of the Ecos feedback feedback control model in achieving and maintaining the system at the critical point – metastable region where the system is highly sensitive (VIEIRA, 2003) – affords the generation of a complex, dynamic and relatively controllable spectral material and a quick adaptation to different acoustic environments. From this behaviour, it has been possible to establish a theoretical framework for dealing with emergent sound structures in performance situations. At the moment, a theoretical discussion on the operationalization of the audible ecosystem is in progress.

6. The digital domain

We developed a sound feedback digital control dispositive, built in MAX/MSP[5] patch (THOMASI, 2021), that are based on an adaptive and self-regulating bank of filters – we are calling by adaptive multiband gain control (Figure 5). In this sense, each filter and its correlated components are considered as an agent that follows simple rules and interacts with the other agents and the environment (WILENSKY & RAND, 2015). In short, as the input signal increases, the respective spectral band is proportionally filtered. But as the natural desire of these filters is to remain at rest, and the input signal tends to increase indefinitely, taking the filter out of the resting state, an equilibrium relationship arises between the filter gain level and the input signal.

FIGURE 5 – Four different moments of the adaptive multiband gain control. The filters can adapt and self-regulate in independent spectral bands simultaneously.

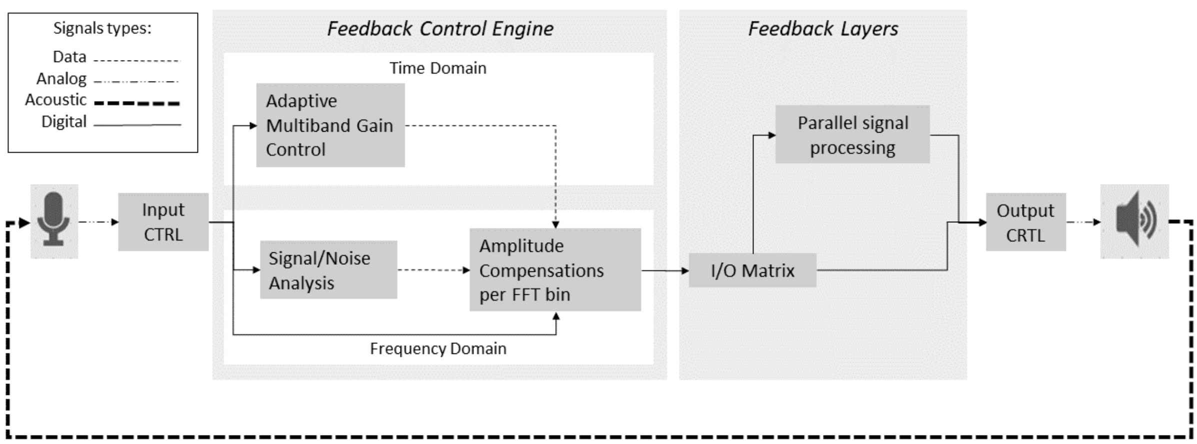
Source: The author

[5] www.cycling74.com

The MAX/MSP patch contains two parts: the feedback control engine and the feedback layers (Figure 6). The former is responsible for ensuring the positive feedback will not saturate the system. The latter is responsible for creating more complex sound structures. The feedback control engine is a coupled time and frequency domains system, in which the resonant frequency stabilizer is based on spectral filtering techniques (SETTEL & LIPPE, 1994), and the adaptive multiband gain control is based on amplitude response control techniques (DUDAS & LIPPE, 2006; DI SCIPIO, 2006). Acting together, they are able to control the feedback signal through its signal-to-noise ratio by shaping the filter banks in different spectral bands simultaneously, as shown in figure 5 – it is like a weird version of a classic vocoder!

The feedback layer controls are composed by a Matrix, that allows the human performer to act in the feedback topology though the MAX patch – rather changing the microphone positions, for instance –, and by parallel signal processes implemented for a live electronic performance situation. We will discuss some of them in the following sections.

FIGURE 6 – The illustration shows the schematic of the feedback control engine in which the data signals regulate the digital signal in the frequency domain, stabilizing the positive feedback loop. On the right is the Matrix which is responsible for the input and output signal paths, and the parallel processes such as delay and filter lines which generate the feedback layers and which are mixed with the original feedback loop in the acoustic environment.



Source: The author

7. The acoustic domain

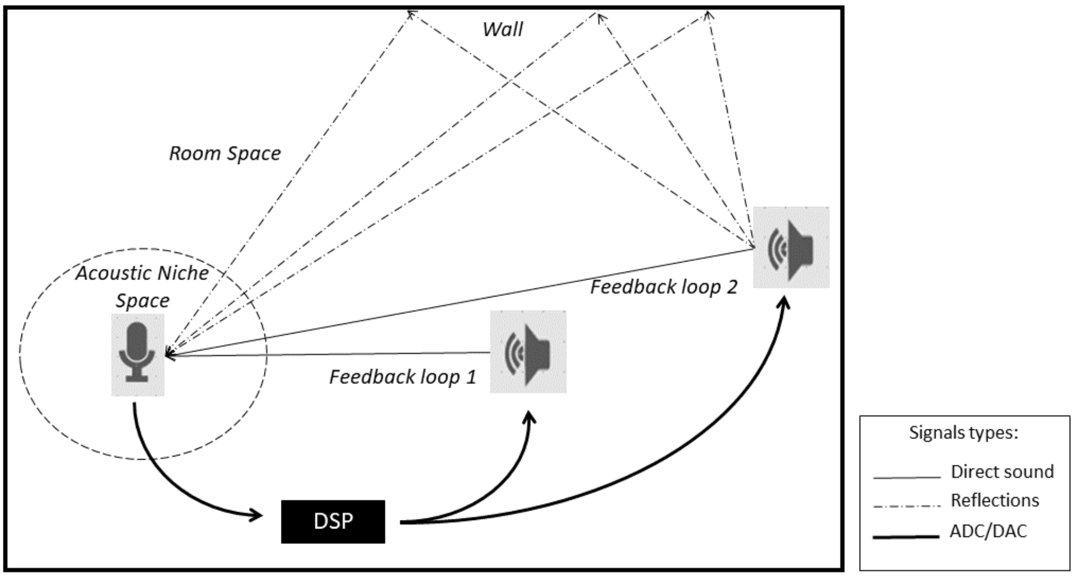
In practice, the openness to the acoustic environment is what transforms this system into an ecosystem: different natures, organisms and communities, with their physical and chemical environments, sharing the same place through continuous flows of matter and energy in an interactive open system[6]. In this case, the acoustic environment acts as an openness for continuous non-linear iterations (DI SCIPIO, 2003, p. 273). So, even with the simplest sound material, like a sinusoidal sound, becomes richer and more interesting, musically speaking; the almost trivial signal processes like simple delay lines and gain controls become capable of changing the whole system behavior. None of the component features are neutral anymore. The microphones positioning, frequency response, the speakers' characteristics, the DSP engine configuration, the reverberation time of the room, the size of physical surfaces and their location in space, how many people are in the room and what they are doing, among many others, can provoke significant changes in the emergent sound spectra. This is why the continuous iteration makes the system very sensitive to the initial conditions: small changes lead to big results, as in Edward Lorenz's Butterfly Effect.

We find a fruitful way to deal with this complexity in Fromm's Taxonomy of Emergences (FROMM, 2005), which leads us to think about a structural model that precedes these multiple layers of interactions, what we are calling *feedback topologies*. So, instead of controlling each component's behavior, which seems to us to be quite impossible – however, even if it were possible, it would inevitably be artificial, at least –, we just change the chain that connects the components making them interact with one another. Figure 7 shows an illustration of two different possible feedback loops created with two speakers and one microphone. The physical distance between speakers and microphones as well as the acoustic qualities of the niche space create distinct spectra content. If using a cardioid response polarity, changing the microphone position also changes the way the direct sound and reflections reach the sensitive region, which results in a different feedback topology. It also can be done controlling feedback loops through the Matrix, individually or mixing them – see the next section –, opening up an exploration field through the transition space between feedback loop 1 and feedback loop 2, for instance. The characteristics of each loop can be tested and

[6] For a full debate about the terminology, please see RAFFAELLI & FRID, 2010.

pre-configured, so that the essential qualities of the emerging spectra can be predicted later during performance.

FIGURE 7 – An illustration of the feedback loop in the acoustic environment generating possible feedback topologies. It is important to point out that the propagation of the sound wave through the loop is very complex and cannot be thought only as a result from the direct sound and primary reflections hitting the microphone. However, it helps us to think about the organization of the speakers and microphones in the room, adjusting them empirically.



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8. Towards the Spatial Instrument: notes on performance with the Ecos model

As we developed a feedback loop control engine and were able to observe the behaviour of the audible ecosystem, we began to map its structure based on feedback topologies, seeking to establish low-level controls to perform with it. Due to its hybrid nature and its acoustic and spatial dependency, we call the mechanism for performance in the Ecos model by Spatial Instrument. As first developments for performance with audible ecosystems, we establish three basic interdependent categories for low-level control: the gain structure; the feedback topologies, what includes the Matrix; and the feedback layers.

8.1 The gain structure

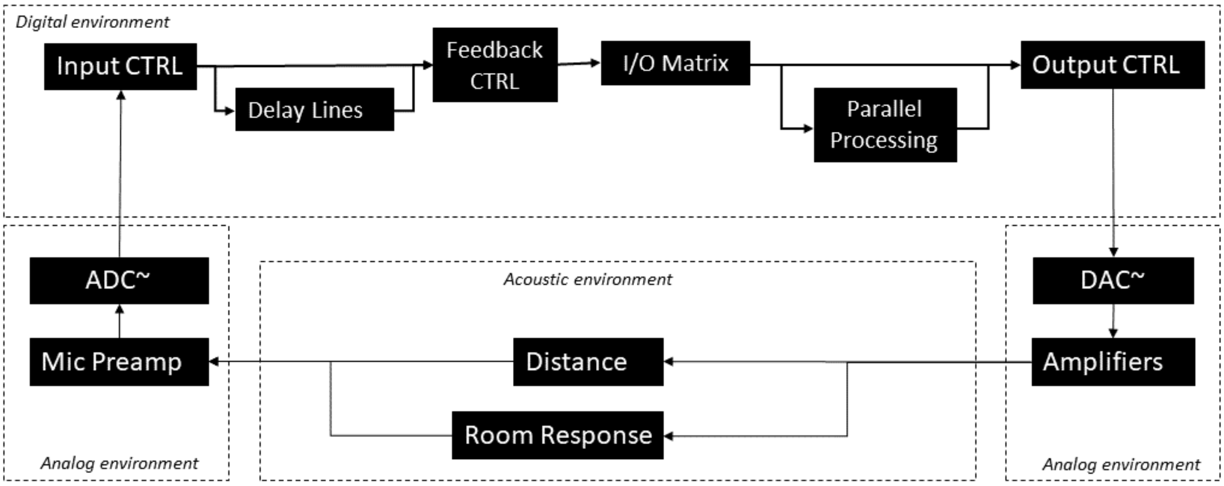
In the feedback loop every point can be an initial point. The way some components modulate the signal is more important than the order of the components. In this sense, the implementation of a gain structure and respective controls was fundamental and also a great challenge. First, because the gain does not have a simple impact in terms of increasing or decreasing the sound volume. Instead, the greater the gain, the greater the energy that circulates through the system, which corresponds to an increase in the harmonic content resulting in spectral expansions and transformations. The second issue is that the gain control is not centered on a single control unit, but distributed across the system. Each signal, each created feedback loop, generates its own gain structure and interacts directly with the other loops that are already circulating.

As shown in Figure 8, the gain structure has the following path: *in the analog domain*, a) a signal is picked up by the microphone, with the microphone preamplifier being the first gain level; b) the quality of the analog to digital conversion, which directly interferes with the quantity and quality of the captured signal, and likewise, the quality of the digital-analog conversion and; c) the gain of the speakers[7]. *In the digital domain*, a) the input control in the MAX patch; b) the delay lines, in which for each copy a specific gain control is needed; c) the Matrix that manages all signal routing and has a direct impact on all individual gains; d) and the master output control that sends the signal to the digital-analog converter. *In the acoustic environment*, a) the distance between microphones and speakers, since the closer it is, the greater the gain, and vice versa and; b) the room responsiveness, since a dead room will respond with a harmonic content and intensities totally different from a more reverberant room. However, there is no formal rule to establish the gain structure, as it is more related to the qualities that each component exhibits in the ecosystem, varying from place to place and from equipment to equipment. So, the choice of microphone positioning is essential, but is only achieved through trial and error. For instance, since we are searching for interesting acoustic niches, with harmonics, steady frequencies, beatings and natural phasing, placing the microphones in the corners, right to the wall, windows or other reflective or resonant material is very welcome. In this sense, we

[7] Cables and connectors quality also interferes in the signal quality, but is being disregarded here since its levels cannot be controlled.

are in the opposite direction of a common sense in audio engineering, as our general effort is to enhance positive feedback rather than suppress it, as well as most of the acoustic and equipment inconsistencies are, here, elements that enrich the ecosystem's timbristic capacity.

FIGURE 8 – Schematic of gain structure showing the main components impacting the power flow of the feedback loop.



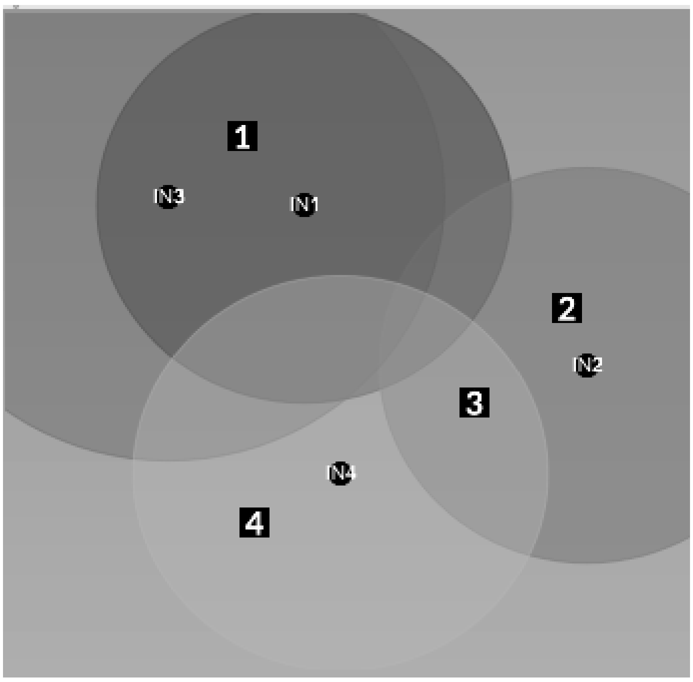
Source: The author

We also have noted along the experiments that the critical state - the moment in which there is energy circulating through the system, but the resonant frequencies have not emerged yet - is very productive for artistic performance, as small variations in gain control allow for significant changes. So, the gain controls in the digital system need to allow fast action and thoroughness at the same time. In other words, the gain structure is responsible for the quality of the signal energy, allowing the human performer to conduct the ecosystem through different states. Performing with the audible ecosystem is like sitting in the park observing the landscape around, but with the difference that you can change its energy flow, change lighting, colors, shapes, and cause distortions.

8.2 The Matrix

Along with the gain structure we implemented a Matrix to manage the signal routes, enabling us to act directly in the feedback topology through the MAX/MSP patch. Figure 9 shows the Matrix interface implemented with the Nodes object. It is a 4 input-4output configuration, where the inputs are represented by the numbers in the circles and the outputs by the numbers in the squares. The circular region around the inputs is related to the gain level: the closer to the center, the higher the gain between the respective inputs and outputs. In the upper part of Figure 9, there is a feedback loop between the output 1 and the inputs 1 and 3. At the bottom, there is a feedback loop between the input 4 and outputs 3 and 4. And on the right, a feedback loop between input 2 and outputs 2 and 3. So three different and independent feedback loop topologies can be accessed by the Matrix, moving the main cursor along the XY pad or mixing them by faders. It's important to note that by mixing the feedback loops one can explore other topologies that may generate new spectral contents or even to provoke a more chaotic behavior. Also, moving along the transition spaces is possible to create phasing effects, harmonic beatings and morphing effects as well. By changing the input and output positions in the Matrix, the whole gain structure and emergent sound structures will also change. If previously set up, the Matrix configuration can be reloaded by presets, which is a powerful tool for performance situations.

FIGURE 9 – Input and Output Matrix interface on the Spatial Instrument MAX/MSP patch. Through this interface, independent and simultaneous feedback topologies can be easily reconfigured.



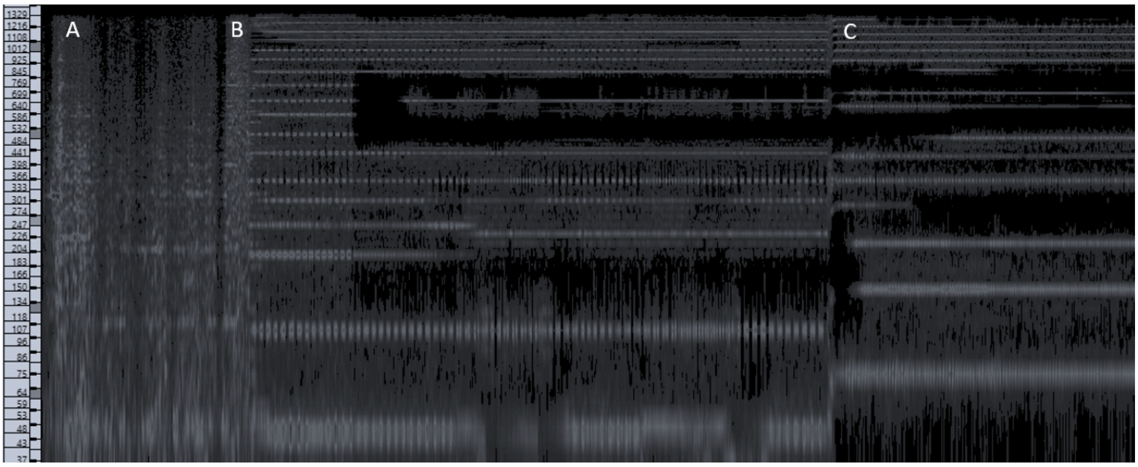
Source: The author

8.3 The feedback layers

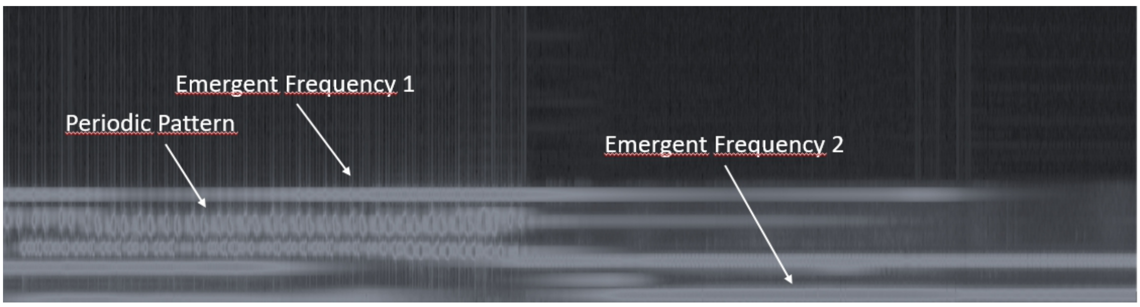
In the audible ecosystem the acoustic environment works like a hub that merges the feedback loops in a more organic way, if compared to mixing in the digital environment, which would isolate the loops from external interference. It enables us to work with parallel processes without the need to mix them in the MAX patch, since all output signals will return already mixed to the input. In this way, the original feedback loop is maintained open with a continuous energy flow, while the processed signals are overlapping. We call this procedure *feedback layers,* and it has shown itself as a prominent tool to generate more complex emergent sound structures and new attractor components, corroborating with the theoretical support on Fromm's taxonomy. In this sense, we have explored some techniques with the parallel processing (Figure 10). *A) Inserting delay lines* to explore other spectral configurations, either by the respective changes in the gain structure, or by the overlapping of voices that generate beats, phasing and filtering; *B) Periodic patterns* that, when used in parallel chain, cause instability in a certain portion of the system's structure resulting in the appearance of new structures. For example, using a periodic oscillator to modulate the frequency of a filter or the phase of a signal in a way that the generated pattern would excite the system so that new structures could emerge. *C) Using digital filters as strong attractors*, using the feedback loop to excite a specific band of the spectrum, instead of using digital filters inserted serially in the loop, which would cause the center frequency to resonate arbitrarily.

FIGURE 10 – Modulations of the original emergent spectrum by creating feedback layers through parallel processing. A) Three different delay line modulations exploring sound pulsations and roughness. First, a random delay time modulation creates a continuous and chaotic behavior. Secondly, a periodic delay time modulation creates periodic oscillations and provokes the appearance of new harmonics. Third, static delay lines modulate the whole spectrum acting like a one-zero low-pass filter (KARPLUS & STRONG, 1983). B) Periodic oscillation of the resonant filter center frequency provokes the emergence of the frequency 1. A static resonant filter provokes the emergence of the frequency 2; C) A resonant filter works as an attractor component, modulating the original frequency to its spectral band.

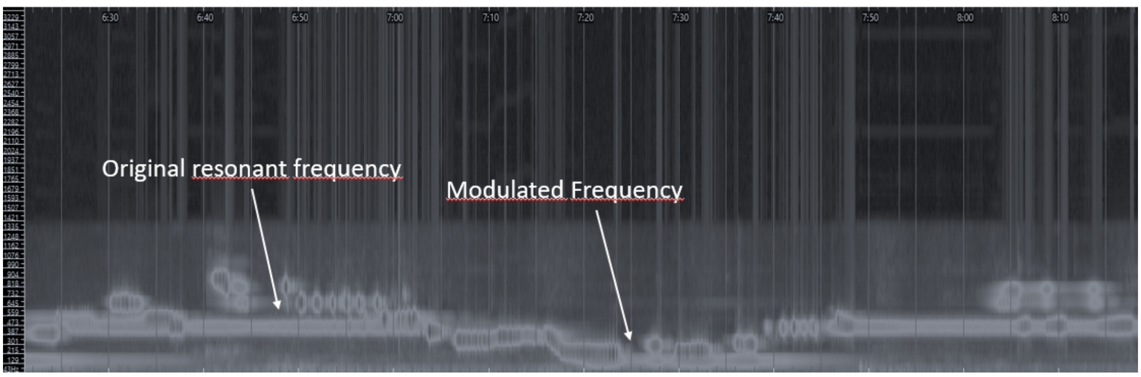
A)



B)



C)



Source: The author

9. Final Considerations and Future Works

The implementation of the proposed acoustic-digital feedback control model allowed new avenues for live electronic performance and has supported the development of the Spatial Instrument. We achieved significant results exploring the feedback topologies and feedback layers as control interfaces to perform with the audible ecosystem. As shown, the Ecos Study has been shedding light to new perspectives about: a) the use of the gain structure, since it has impacts on the generation of the spectral content; b) the multi-channel sound spatialisation, which has exhibited morphological properties; c) filtering techniques, as filters become attractors and reconfigure the system; d) the use of delay lines and phase modulation as means of creating emergent structures *further away* from the initial conditions.

These results have opened a theoretical and experimental field for thinking about musical structuring based on emergence theories, which is under development. In this sense, we have considered the spectral unfolding and sensitivity to acoustic fluctuations, respectively, as the structural and behavioural core of the audible ecosystem, considering the *quality of interactions* as a fundamental guideline. In conclusion, we believe that the wide opening of possibilities for experimentation highlights the paradigm of audible ecosystems as a seed for new perspectives in music creation and performance.

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