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Idiosyncratic Audio Feedback Networks for Music Creation

Adriano Claro Monteiro

Universidade Federal de Goiás | Brazil

Abstract: This article presents practical and artistic contributions to the field of computer music systems based on audio feedback networks. The ideas that oriented the conception of two digital music instruments and examples of their use in the author's music practice are discussed. The article begins with a general conceptualization of feedback systems as well as a brief historical review of its use in experimental music. Later, a more specific contextualization of its application in recent computer music research and artwork is made, and two contributions are presented: the first is a network of cross-modulated sinusoidal oscillators (by frequency modulation), and the second is a network of algorithms for playing and transforming pre-recorded sound samples. In conclusion, examples of the artistic usage of the described systems to the creation of electroacoustic music are discussed.

Keywords: audio feedback systems, generative music, electroacoustic composition, electronic music, digital music instruments.

Resumo: Este artigo apresenta contribuições práticas e artísticas para o campo de sistemas musicais computacionais baseados em redes de retroalimentação de áudio. São discutidas as ideias que orientaram a criação de dois instrumentos musicais digitais e exemplos de sua utilização na prática musical do autor. O artigo inicia com uma conceptualização geral sobre sistemas de retroalimentação, bem como uma breve revisão histórica de seu uso na música experimental. Em seguida, é feita uma contextualização mais específica sobre sua aplicação em pesquisas e trabalhos artísticos na música computacional e duas contribuições são apresentadas: a primeira é uma rede de osciladores sinusoidais em modulação cruzada, e a segunda é uma rede de algoritmos de reprodução e transformação de amostras de áudio pré-gravadas. Ao final, são discutidos exemplos de uso dos sistemas descritos para a criação de música eletroacústica.

Palavras-chave: sistemas de retroalimentação de áudio, música generativa, composição eletroacústica música eletrônica, instrumentos musicais digitais.

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Since the 1960's, audio feedback has been inventively used in experimental approaches in music creation: from the use of the Larsen effect (BONER & BONNER, 1996) by guitar players in bands such as The Beatles and The Jimmy Hendrix Experience, to the creation of analog feedback circuitry in the avant-garde/experimental art-scene, in works by Robert Ashley, John Cage, David Tudor, Gordon Muma and Alvin Lucier (HOLMES, 2008). Alongside these experimental (maybe more empirical and intuitive) approaches, a theoretically motivated use of feedback in the art of the 1960's took place under the influence of cybernetics (WIENER, 1948; ASHBY, 1956) and system theory (BERTALANFFY, 1968) – that were popular at the time, for instance in works by Nicolas Schöffer or Roland Kayn (SANFILIPPO & VALLE, 2013; PATTESON, 2012).

More recently, new approaches in the creation of generative music systems based on feedback networks have been relying on computational methods. An important technical addition provided by computers lies in their capacity to analyze incoming data in order to provide informed algorithmic responses to environmental stimuli (DI SCIPIO, 2003, 2011; ELDRIDGE, 2009; KOLLIAS, 2008; SANFILIPPO, 2018; KIM, WAKEFIELD, NAM, 2016). Some authors of these recent feedback-based works also report influence from cybernetics and system theories and include in their theoretical framework the concept of autopoiesis, introduced in the 1980's by thinkers such as Francisco Varella and Humberto Maturana (MATURANA & VARELA, 1980), claiming an eco-systemic paradigm to define their art works (DI SCIPIO, 2003, 2011, DI SCIPIO & SANFILIPPO, 2019; WATERS, 2007, 2011).

As a contribution to this field of artistic research, this paper presents two original implementations of audio feedback networks that have been used as instruments for music composition and improvisation by the author. The systems differ in their architecture and method of sound generation: the first is based on sound synthesis by Frequency Modulation (FM) (CHOWNING, 1973) in a direct cross-modulation interaction; the second is based on transformation processes of pre-recorded sound samples and adopts a mediated interaction through algorithms for audio analysis.

Before presenting its contributions, the paper starts with a short introduction on general concepts that define or qualify feedback systems, followed by a specific contextualization of its

application in recent computer music research and artwork. At the end, two examples of use of the reported implementations in the author's music compositions are discussed.

1. General conceptualization

A feedback system can be described as one which results, provided by some kind of transformation of the incoming stimulus (data, signal, etc.), are reoriented (fed back) to the system's input after a certain delay. This characteristic is also called *circular causality* and makes the system's causes and effects mutually dependent. As general categories, there are two main types of feedback: positive and negative feedback. In *positive feedback,* the system reinforces the tendency/direction of its input and increases the response towards this direction over successive data iterations, which usually tends to disruption and instability. In *negative feedback,* the system response counterbalances its input tendency, which provides equilibrium and stability to the system's overall behavior (ASHBY, 1956, WIENER, 1948).

Non-linear is a term to qualify the relationship between a system's input and output. Non-linearity means that the system output is not directly proportional to its input. A feedback system is typically non-linear (SANFILLIPO & VALLE, 2013), even though different types of systems can also be described as non-linear.

Another commonly used descriptor for feedback systems is the concept of *self-organization*. This term refers to autonomous systems capable of exhibiting global patterns of organization that emerge from the interactions between their parts in parallel and distributed processes (KOLLIAS, 2011, BEYLS, 1990). *Synergy* is the term used to describe the coupling of the parts of a system under interaction of mutual influence. In a self-organized system, minor changes in the state of any of its constituent components can lead to significant effects on the overall system's response. Then, the system outcome cannot be described as additive, but rather synergistic, which means it is not reducible to the sum of its functional parts (ASHBY, 1956).

Self-organized systems can oscillate between states of stability (also called 'attractors') when exhibiting a static or dynamically balanced behavior, and states of instability when they are continuously shifting between different states.

The outcome of self-organized systems, as well as the type of feedback systems that is discussed here, are usually described as *complex* and *emergent*. Complexity is a concept used to describe intricate and unexpected results obtained from a mass of simple processes. Emergence describes the capacity of the system to provide unpredictable results from its operations. Usually, these two concepts are interrelated as complex systems tend to present emergent behaviors or properties (SANFILIPPO & VALLE, 2013, SANFILIPPO, 2020).

Sanfilippo (2017) points out two other categories to understand feedback systems: time-invariant vs time-variant. According to the author, a time-invariant system "performs the same operations at all times". Its output can be dynamical, as it changes over time, yet its internal state (its operations) is static. A time-variant system allows for changes in its operations over time, which will likely lead to changes in its output.

The term adaptative, also discussed by Sanfilippo, is generally applied to describe systems that change their internal state in function of an input received from its external environment, attempting to achieve balance (usually through combined process of positive and negative feedback), or to accomplish an explicit or implicit goal (MAES, 1994; MITCHELL, 2009). In this sense, an adaptive system is also a type of time-variant system. Hence, there is a more elementary consideration that can be inferred from the adaptative vs non-adaptative classification: a system can be understood as having *internal* or *external feedback* (SANFILLIPO, 2013; SURGES, 2015). Systems with internal feedback have their output directly connected to their input without receiving any external interference in this path, while systems with external feedback provide a communication channel with their environment that allows further transformations in their results before being redirected to the system's input.

2. A deeper look into the field

Although the use of audio feedback in music dates back at least to the 1960's, a considerable number of new works that investigate the subject (both artistically and theoretically) have emerged in the last twenty years, turning this corpus of knowledge from sparse individual initiatives into a more coherent field of artistic, technical and theoretical research. For instance, in the last few years at least five PhD thesis (to the best of our knowledge) from major occidental music research institutions

were dedicated to the topic (HOLOPAINEN, 2012; SURGES, 2015; KOLLIAS, 2017; SANFILLIPO, 2019; DI SCIPPIO, 2020), as well as many journals and conferences articles, such as the ones discussed throughout this paper.

Agostino Di Scipio is a pioneering contributor to the artistic and theoretical thought in the field. During the 1990's the author studied the use of digital audio feedback to produce non-standard synthesis models that he called *synthesis by iterative non-linear functions* or, for short, *functional iteration synthesis* (DI SCIPIO, 1990, 2002). From the early 2000's on, the author investigated what he defined as an eco-systemic paradigm for music composition, creating music works, such as *Audible Ecosystems* (DI SICPIO, 2003, 2011) and *Modes of Interferences* (DI SICPIO, 2006; BITTENCOURT, 2014), that focus on the coupling between computational systems and the physical environment through recirculation of audio signals, aiming to create emergent and self-organized musical forms. From his theoretical output the author elaborated the idea of 'sound as the interface' (DI SCIPIO, 2003), proposing that all the interactions between electronic/computer system and physical environment take place through sound itself, which become at the same time the perceptual object of the artistic endeavor and the emerging product of the structural coupling between electronics and environment.

To understand the similarities and differences among musical works based on audio feedback, Sanfilippo and Valle (2013) created a classification framework based on six categories. The authors then used said framework to evaluate a total of eighteen works from the classical 1960's analog systems in David Tudor's *Microphone,* Steve Reich's *Pedulum Music,* and Alvin Lucier's *I Am Sitting in a Room*, to more contemporary purely computational or hybrid systems in Agostino Di Scipio's *Audible Ecosystems,* Stelious Manousakis' *Fantasia on a Single Number,* Phivos Kollias' *Ephemeron,* or Sanfilippo's own works *LIES (topology)* and *SD/OS (dirac).* The categories proposed by the authors are: 1) information encoding: analogue/digital – regarding the technological nature of the systems implementation: analogic, digital; 2) information rate: audio signal/control signal – related to the type of signal used to control the system, that can be the recirculated audio itself (the first type), or some kind of sub audio signal (a control signal) obtained through analytical methods applied to the recirculate audio; 3) environmental openness: open/closed – regarding the openness of the system to receive audio information not generated or controlled by itself, for example, from microphones

positioned in the physical environment, from recorded samples triggered as stimuli, or from an external feedback loop coupled with the real-world environment ; 4) trigger mode: internal/external – concerning the origin of the stimuli that start the feedback processes, for example, from the system's noise in analogical equipment, or digitally produced events (internal); or from sources located outside the system's architecture (external); 5) adaptability: absent/present – given an environmentally open system (having an external feedback) it means the system's capacity to change its internal state (to adapt itself) in function of changing environmental conditions; 6) human-machine interaction: absent/present – concerning the assumption (or not) of a human taking part in the feedback and biasing its results while performing tasks such as: triggering the system, changing the environment, or varying the system parameters (play the system).

A subset of environmentally opened feedback systems adopts a design focused on the coupling between electronic (analog or digital) devices and acoustic music instruments. This approach seeks to explore variations in the acoustic response of the musical instruments to modulate the behavior of the feedbacck system as a function of the performer's actions. Early initiatives also dates from the 1960's, for instance the work *Hornpipe* (1967) by Gordon Mumma that implemented electronic feedback loops over sound emissions of a horn and its resonances in the acoustic environment (MUMMA, 2015). Among examples of recent artworks are Di Scipio's *Modes of Interference n.1 and n.2* (DI SICPIO, 2006; BITTENCOURT, 2014), Stelios Manousakis' *Palebla Resonoj #1* (2013)[1]. There is also a number of technical contributions to this topic dedicated to the development of augmented-instruments (OVERHOLT, 2011; OVERHOLT, BERDAHL, HAMILTON, 2011; ELDRIGE, KIEFER, 2017; SNYDER, ERRAMILI, MULSHINE, 2018; ÚLFARSSON, 2019; KIEFER, OVERHOLT, ELDRIGE, 2020).

Despite the growing interest seen in recent years, the use of audio feedback for musical applications is a relatively unexplored subject and an open space for innovative approaches, as well as for theoretical deepening and precise conceptualizations. For instance, Kollias (2018, 2021) points out the divergent terminology used by artists/researchers to define their works that share this common ground:

[1] http://modularbrains.net/portfolio/palpebla-resonoj-1/, http://modularbrains.net/portfolio/feedback-augmented-alto-clarinet/ , http://modularbrains.net/portfolio/feedback-augmented-sopranino-clarinet/ , consulted in 03/21/2022

> Approaches we can include under the term of self-organising music are described by several researchers-composers in several different names: feedback instruments (Morris 2007), audio feedback systems (Sanfilippo and Valle 2013; Kim, Wakefield and Nam 2016), feature- feedback systems (Holopainen 2012), audible ecosystemic interfaces (Di Scipio 2003), autonomous agents (Collins, 2006), performance ecosystems (Waters 2007; 2011), self-organising works (Kollias 2008, 2017), self-organised sound with autonomous instruments (Holopainen 2012), adaptive synthesis (Holopainen 2012), generative audio systems (Surges, Smyth and Puckette 2016), eco-compositions (Keller and Capasso 2006), site-responsive sonic art (KOLLIAS, 2021, p. 2).

Kollias himself advocates using the term *self-organizing*, stating that *feedback* is overused and "does not suggest any particular epistemology anymore" (KOLLIAS, 2018).

In line with the knowledge body described above, the following sections introduce two idiosyncratic artistic contributions to the field.

3. Contributions

The two systems presented in this article are based on modules of sound processing/generation that interact in feedback networks that are exclusively algorithmic/digital. This means that there is no coupling with the real-world environment in an audio feedback loop through electronic transducers. In the terms defined in the previous section: the system is closed and the feedback is internal. However, the systems adopt gestural interfaces to provide to human performers an efficient channel to carry out parametric changes to drive the overall system's behavior.

These networks can be described as time-variant in two ways: 1) when the parameters of its modules are mapped to control-signals that are extracted from audio generated by the other modules in the network, then changing its internal state in function of contextual conditions; 2) when the state of the system changes according to actions of a human performer. In this last scenario, two types of actions can be performed: changing modules' internal parameters, and changing the network topology.

The feedback networks described below were not planned to be adaptative in a strict sense, it means their operational modules for audio processing/generation were not aimed to look for some sort of balance and homeostatic behavior with their environment (the network of modules), nor to

achieve some goal, but were designed to provide autonomous and complex non-linear behaviors that could be used as materials for music creation.

3.1. Frequency modulation network

The first time-variant feedback network presented here is an unfolding of the algorithm proposed by Valsamakis and Miranda (2005), described as two cross-coupled digital oscillators. The example below was designed as eight modules of frequency modulation synthesis (FM), in which the modulation signal for each module is the scaled weighted sum of all modules' output signal, as shown in Equation 1.

EQUATION 1 – Mathematical formalization of a networks' FM synthesis module.

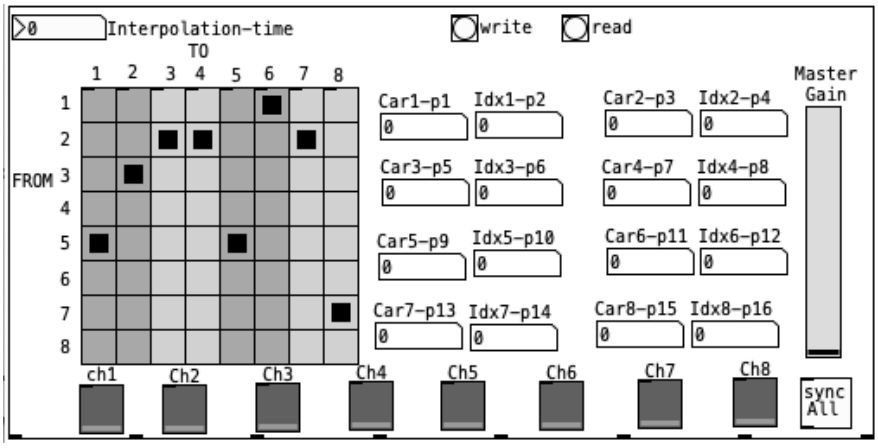
$$E_n = \sum_{m=1}^{8} A_m^n S_m$$
$$S_n = \cos\ (2\pi fp + En + \emptyset)$$

Where E_n is the input for a module n and S_n its output ($for\ n \in \mathbb{N};\ n = [1 \ldots 8]$. The amplitude coefficients for modulation signals are given by the matrix A_m^n in which n e m are indexes of the synthesis modules, *fp* is the carrier frequency in Hz, and $\emptyset$ is the initial phase of each module oscillator. Figure 1 presents the graphical interface of a Pure Data[2] implementation of this system.

Number boxes at the right of the interface in Figure 1 control the carrier frequencies and the amplitude coefficients for the modulation signal of each oscillator. The button matrix on the left controls signal routing between FM modules. The number box in the upper left provides time interval control for interpolations between matrix states. Faders are gain controls for each output channel (at the bottom of the interface) or to the general output (at the right).

[2] https://puredata.info/

FIGURE 1 – Graphical interface of the FM-based system implemented in the software Pure Data.



Although most of the parametric settings for this system produce just a broadband (almost white noise) sound, some specific configurations result in more varied sound dynamics. Due to the non-linearity of the system, one cannot predict the sound generated by a new parametric setting, as there is no correlation between sound features and parametric configurations, as well as minimal parametric changes can lead to completely different sonic results. Therefore, the task of finding sets of values that produce musically interesting sounds is a careful, handcrafted one, done by trial and error.

Some of the well-tuned parametric settings can result in perceptually static sounds with differences in timbre, noisiness, pitchness, and register; others yield dynamic streams of sounds, some with noticeable periodic patterns in pitch and/or rhythms, others with more complex or random-like dynamics.

Despite being wide-ranging in parametric combinations and highly unpredictable in behavior, the system is deterministic and specific results can be retrieved if the same initial conditions were provided. Using this feature, the author's approach to create a playable time-varying network was adapting a gestural interface that would allow for fast reconnections of its modules while the FMs' parametric settings are kept constant. This method provides limited, yet broad, fields of generated sounds that can be permutated or interpolated.

A commercial MIDI interface with 64 buttons organized in a 8x8 matrix was adapted to be a gestural interface for switching connections in the network (Figure 2), symmetrical to the one in the

graphical interface (Figure 1). The matrix rows represent modules output and columns their input. For the sake of simplicity, to reduce the number of possible connections and increase systems' playability, a constraint was added: each column accepts only one state, that is, each module can receive signal from only one module (with amplitude equals 1), while a module can send signal from up to eight modules. Input weighting is applied only during timed interpolations between matrix states, an implemented feature that can generate different emergent sound behaviors according to the interpolation time. This parameter can be changed through buttons in the rightmost column of the interface, which represent discrete time values in ascending order from bottom to top within a customizable range. The top row of buttons was assigned to store and retrieve eight matrix state presets.

This interface allows a performer to quickly switch between connection patterns and intuitively explore the field of sonorities of a FM parametric setting.

FIGURE 2 – Physical interface adapted to switch network connections through a 8x8 matrix that represents connections between FM modules' inputs and outputs.

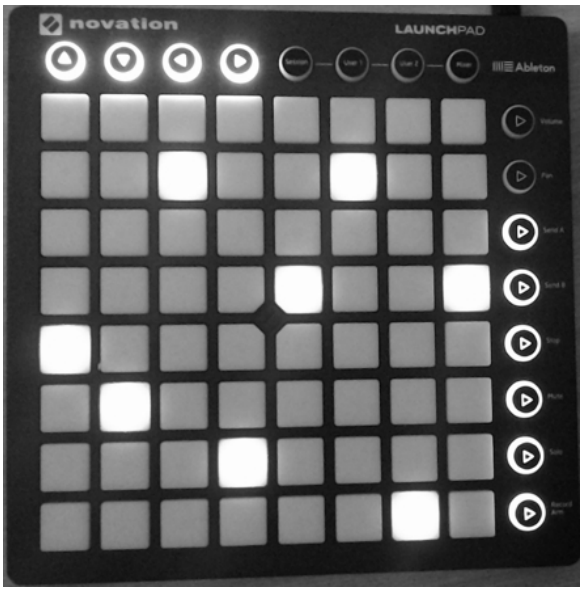


Figure 3 shows the spectrogram of three different patterns of network connections for a single FM preset in which the carrier frequencies for module one to eight are: 39, 0, 21, 5, 57, 25.84, 16.01, 0.44; and the amplitude coefficients for their modulation signals are respectively: 41808, 741, 10617, 13680, 171, 4715, 526. The respective network topologies are represented by the matrices in Figure

4, in which 1 means a connection between two modules and 0 their disconnection. Below each matrix a connection graph represents the same topology. Matrices A to C in Figure 4, as well as graphs A to C, correspond to the spectrograms in Figure 2, respectively, from top to bottom.

The upper spectrogram (related to matrix A) shows a sound texture composed of gliding simple tones in periodic movements across the frequency axis that take long time spans (several minutes); the middle spectrogram (related to matrix B) displays alternations of complex spectrotemporal patterns lasting from some hundred milliseconds to a few seconds; the spectrogram at the bottom of Figure 2 (related to matrix C) displays a steady sound texture composed of almost stationary frequencies lasting about 100 milliseconds and mixed with a periodic noisy pulse train. Notice that small changes in the network result in widely different outputs, for instance, the single changed connection from matrix A to B, or the four changed connections from matrix B to C.

FIGURE 3 – Spectrograms of three sound samples generated by the FM feedback network using a same FM parametric setting but with different network topologies.

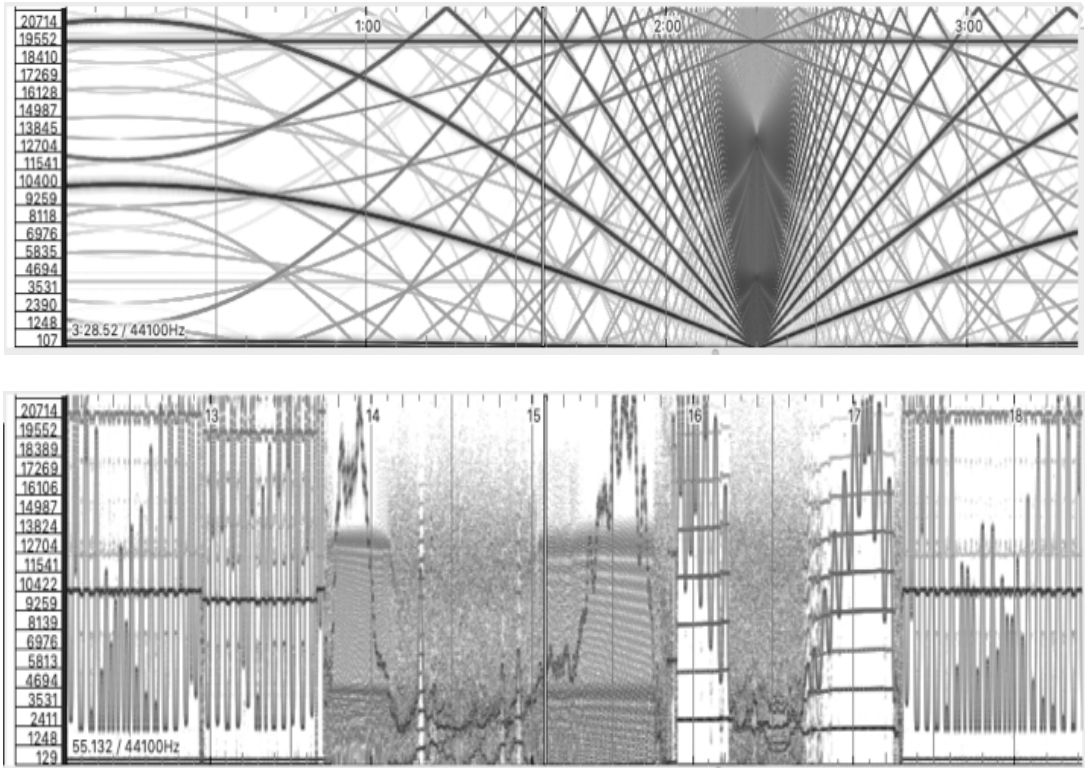


FIGURE 3 (cont.) – Spectrograms of three sound samples generated by the FM feedback network using a same FM parametric setting but with different network topologies.

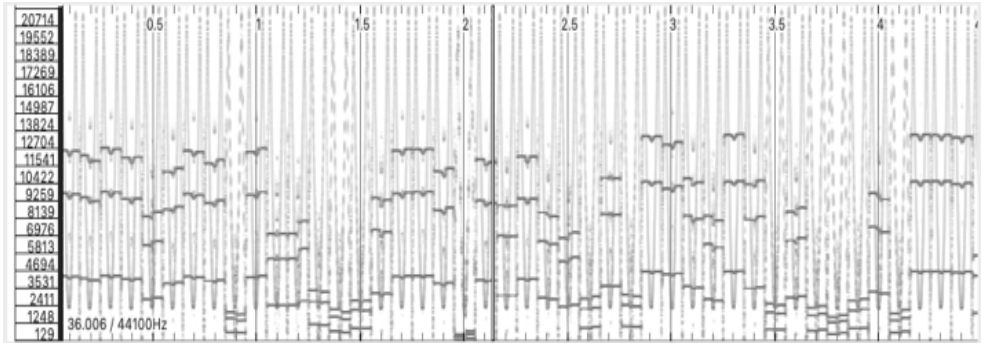
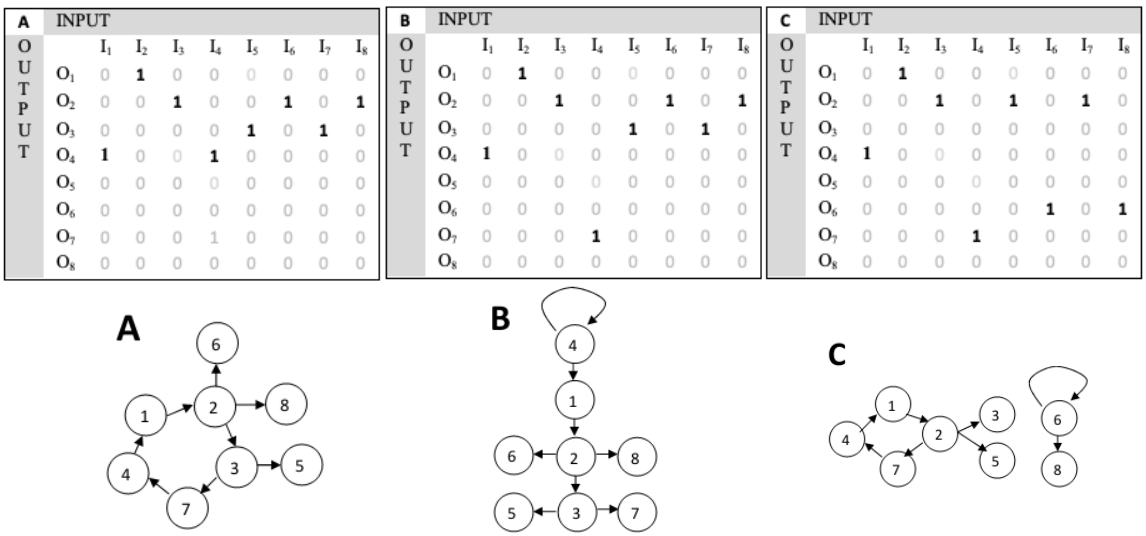


FIGURE 4 – Matrices representing the network topology for the sounds displayed in Figure 2.



A

OUTPUT \ INPUT	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8
O_1	0	**1**	0	0	0	0	0	0
O_2	0	0	**1**	0	0	**1**	0	**1**
O_3	0	0	0	0	**1**	0	**1**	0
O_4	**1**	0	0	**1**	0	0	0	0
O_5	0	0	0	0	0	0	0	0
O_6	0	0	0	0	0	0	0	0
O_7	0	0	0	1	0	0	0	0
O_8	0	0	0	0	0	0	0	0

B

OUTPUT \ INPUT	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8
O_1	0	**1**	0	0	0	0	0	0
O_2	0	0	**1**	0	0	**1**	0	**1**
O_3	0	0	0	0	**1**	0	**1**	0
O_4	**1**	0	0	0	0	0	0	0
O_5	0	0	0	0	0	0	0	0
O_6	0	0	0	0	0	0	0	0
O_7	0	0	0	**1**	0	0	0	0
O_8	0	0	0	0	0	0	0	0

C

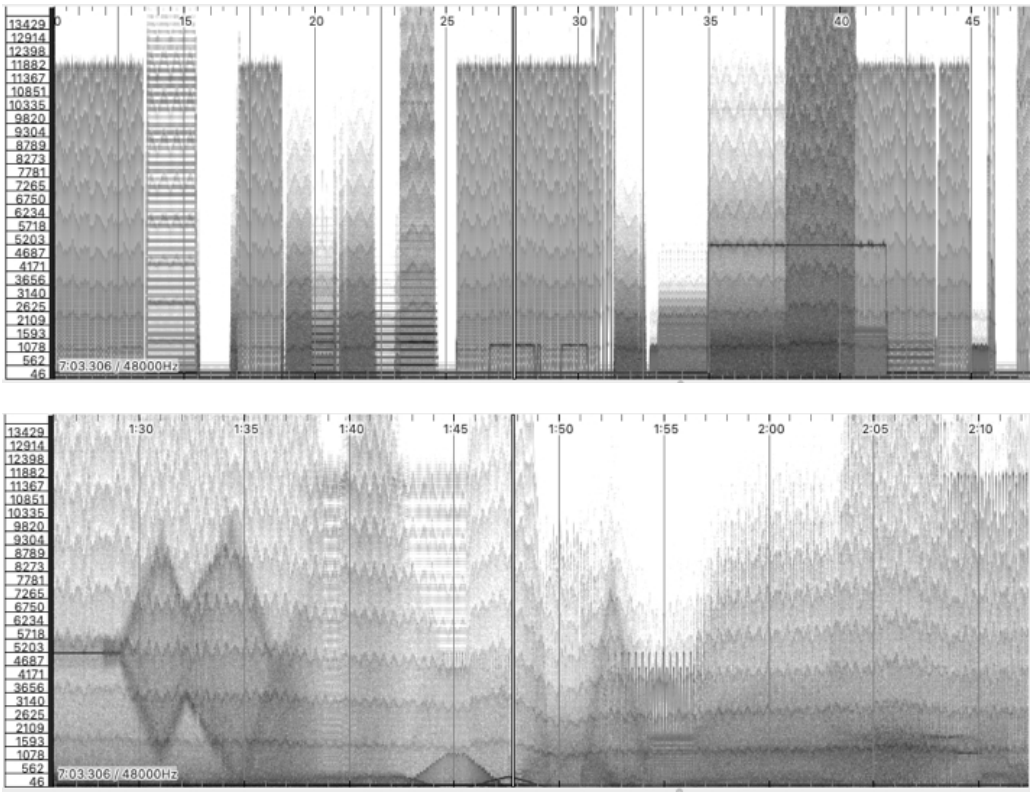
OUTPUT \ INPUT	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8
O_1	0	**1**	0	0	0	0	0	0
O_2	0	0	**1**	0	**1**	0	**1**	0
O_3	0	0	0	0	0	0	0	0
O_4	**1**	0	0	0	0	0	0	0
O_5	0	0	0	0	0	0	0	0
O_6	0	0	0	0	0	**1**	0	**1**
O_7	0	0	0	**1**	0	0	0	0
O_8	0	0	0	0	0	0	0	0

In Figure 5, two spectrograms generated from segments of an improvised performance with the FM network are presented. The delimited blocks of contrasting spectral content in the upper spectrogram are the products of a performance with short interpolation time between matrix states (about 5 milliseconds). The bottom spectrogram shows the results of longer interpolated transitions (about 2 seconds) that produce gradual changes in spectral content, like saturation and filtering patterns, glissandi effects, or the emergence of a periodic pulse displayed on 1'55" in figure's timescale.

Based on the author's practical experience, an in-depth use of this instrument requires three steps: first, an empirical research to discover FM presets that sonic results would fit the artist's aesthetic judgment; second, the exploration and memorization of matrix patterns, and the

internalization of possible playing gestures in order to articulate meaningful sound changes in a musical context; and third, using this acquired specific knowledge to compose or improvise music.

FIGURE 5 – Two spectrograms of excerpts from a performance of the FM network using a small interpolation time (upper graph) and an interpolation time of a few seconds (lower graph)

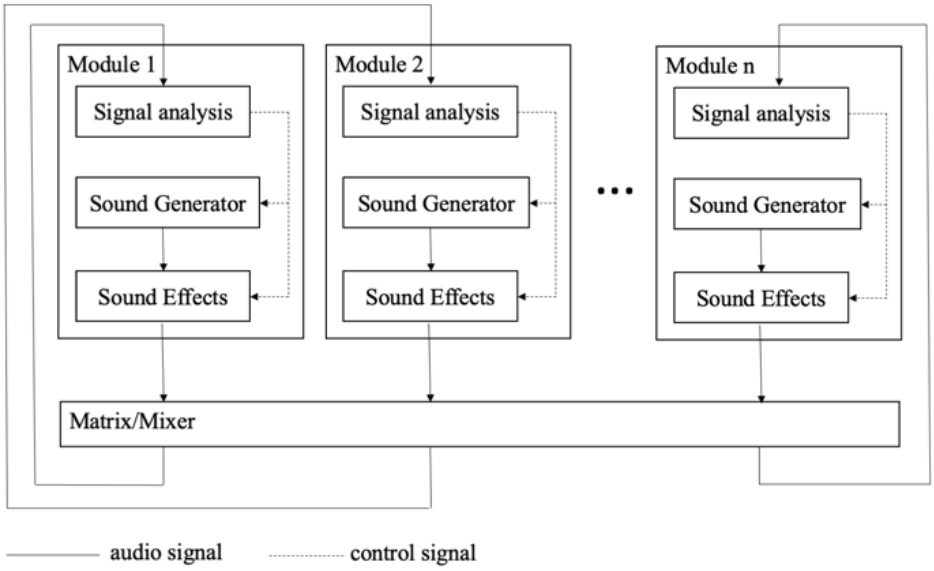


3.2. Sample processing network

A second class of time-variant feedback system was designed based on transformations of pre-recorded audio samples. Unlike the system presented in the last section, that has a single method of sound generation with direct audio signal feedback, this class of systems adopts a classical modular synthesizer architecture, that allows for variability in the combination of audio processes and includes an audio feature extraction stage to generate control signals.

Figure 6 shows the system's general outline. A feedback network is based on the combination of at least two modules. Each module is composed of three parts: a feature extraction stage, a sound generation stage, and an effects/post-processing stage.

FIGURE 6 – Sample-based system architecture.



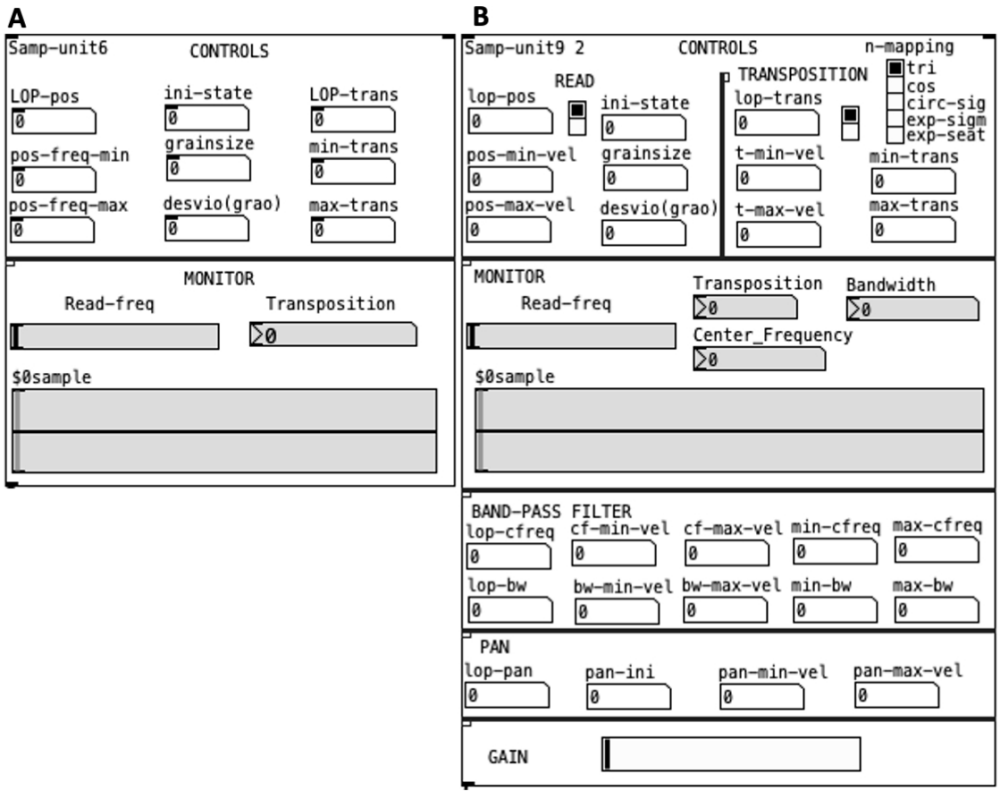
The feature extraction stage converts modules' input signal to control signals by applying temporal or spectral measurements on the weighted sum of all modules' output signals, such as RMS, spectral centroid, noisiness, spectral roll-off, among others, described in the specialized literature (BULLOCK, 2021). The resulting signals are mapped to control parameters in the following stages.

Two methods of sample transformation were applied in the sound generation stage: playing a sample with variable speed (a scratch-like effect), and a time-stretch plus pitch-shifter effect based on granular synthesis (TRUAX, 1994). In the effect/post-processing stage, a chain of audio effects is applied over the signal obtained from the generation stage, for example, variable state filters, modulations (amplitude modulation, ring modulation), panning, among others.

The instantiation of this general architecture in a unique configuration, i.e. the definition of audio processes and the mapping of control signals, was treated by the author as a matter of artistic choice that is related to the specific practical context for which the system is intended, as some decisions (such as the selection of pre-recorded samples or the methods for sound generation and effects) have dramatic consequences in sound aesthetics. The choice of feature extraction algorithms, as well as the mapping of their outcome to sound synthesis/effects parameters, showed less influence on the overall aesthetics (the resultant sonority), but it was crucial for the temporal dynamics of the system, and, consequently, for the sound forms that emerge from system's interactions.

Figure 7 shows the interfaces of two modules implemented in the software Pure Data that uses a granular synthesizer for sound generation. In both, sample read position and transposition rate are parameters linked to control signals obtained from analysis of modules' input (which means the audio coming from other modules in the network). Effects were omitted from the module in Figure 7-A, while the one in Figure 7-B included a band-pass filter and a pan effect, both also linked to control signals.

FIGURE 7 – Interface of two sample-based modules implemented in Pure Data.

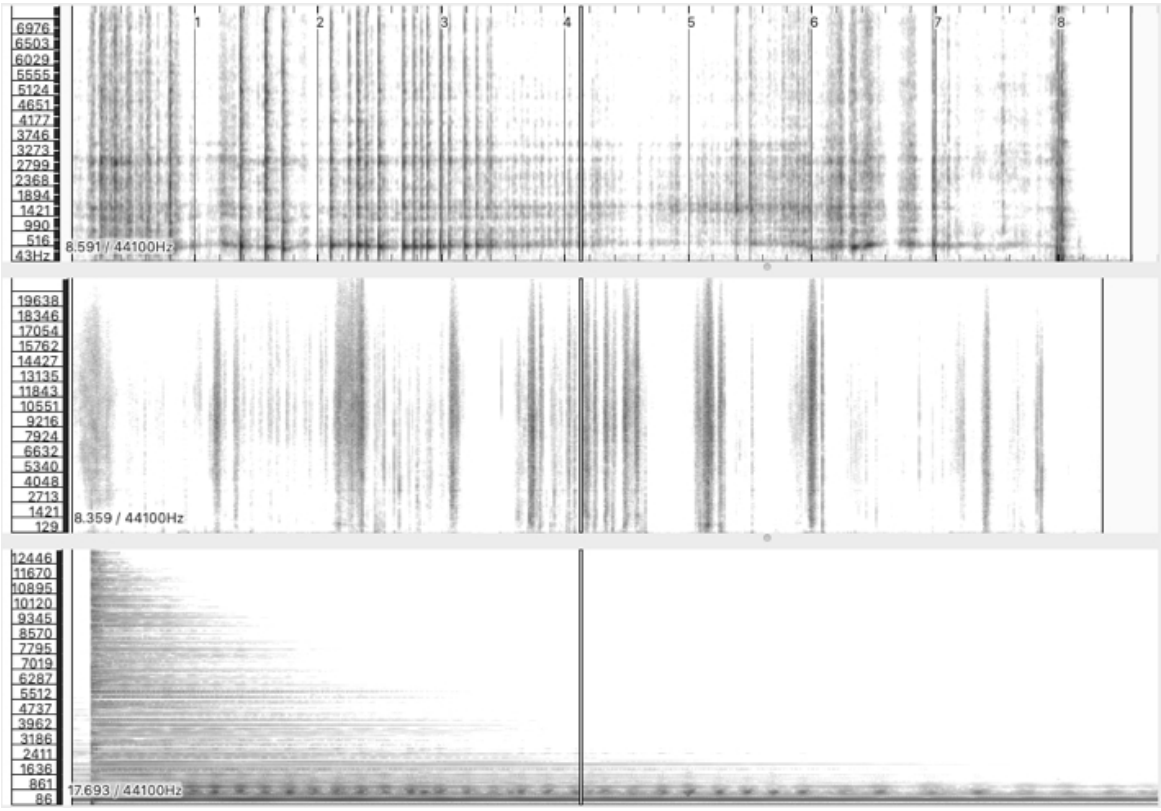


In the networks composed of these two modules, the audio driven interaction mostly influenced the temporal dynamics of sound transformations that are operated by audio processing methods (unlike the FM network in which audio feedback defines the instantaneous qualities of the sound synthesis, as well as its evolution over time). The result is a new sound texture formed by transformed chunks of the original samples.

Figures 8 and 9 show three spectrograms generated from selections of audio recorded from a performance of a network composed of three modules of the type illustrated in Figure 7-A.

The modules were fed with the sound samples, which spectrograms are shown in Figure 8. The sound represented by the top spectrogram is a sequence of percussive pulses with resonance peeks ranging between 300Hz and 600Hz that were obtained from impacts of two plastic cups; the sound represented by the middle spectrogram consists of white noise bursts resulting from the manipulation of a piece of masking tape; and the third sound sample, in the lower spectrogram, is a single cymbal strike hit by a drumstick which created a complex and inharmonic resonance pattern.

FIGURE 8 – Spectrograms of three sound samples used to generate the examples of Figures 10 and 11.



For the network's output displayed in Figure 9, the transposition rates of the granulators were set to 1 (no transposition) and their sample read position were modulated by control signals. The result is a shuffle of time-stretched or time-compressed segments from the source samples which creates a continuous sound texture with fluctuation in rhythm and density, showing moments of greater or lesser activity and the prevalence of one or another module's output.

FIGURE 9 – Spectrograms of the output produced by a sample-based feedback network composed of three modules of the type displayed in Figure 7-A fed with sound samples displayed in Figure 8, first example.

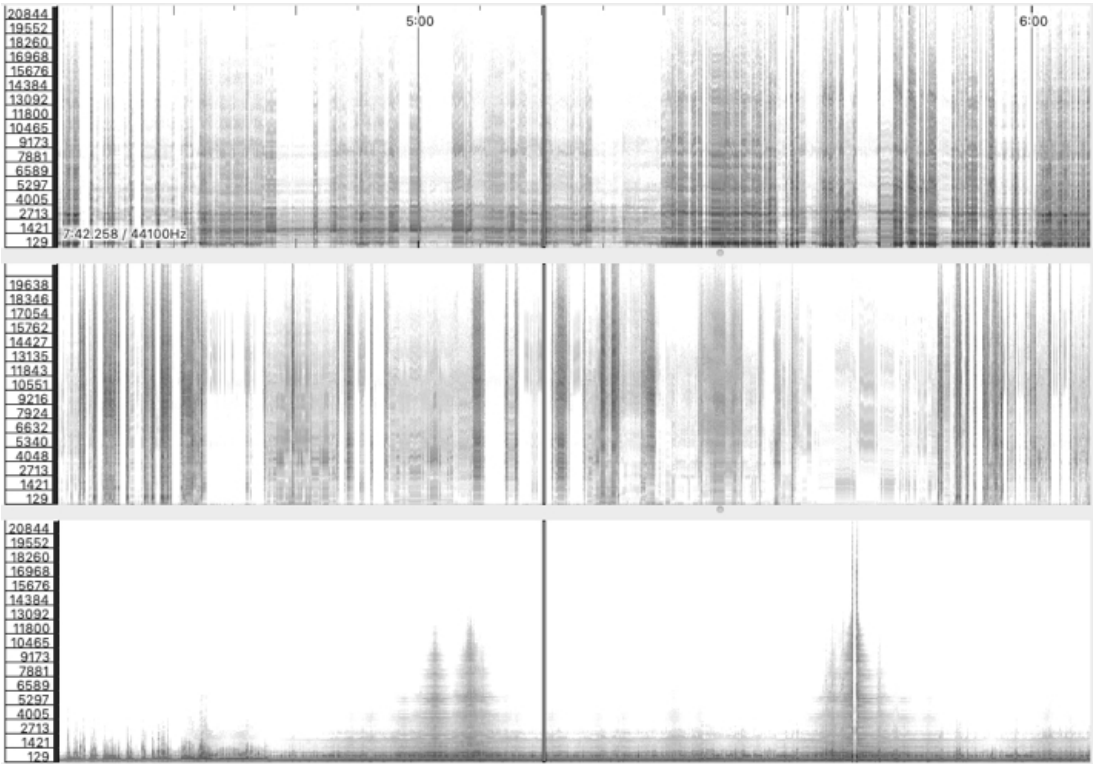
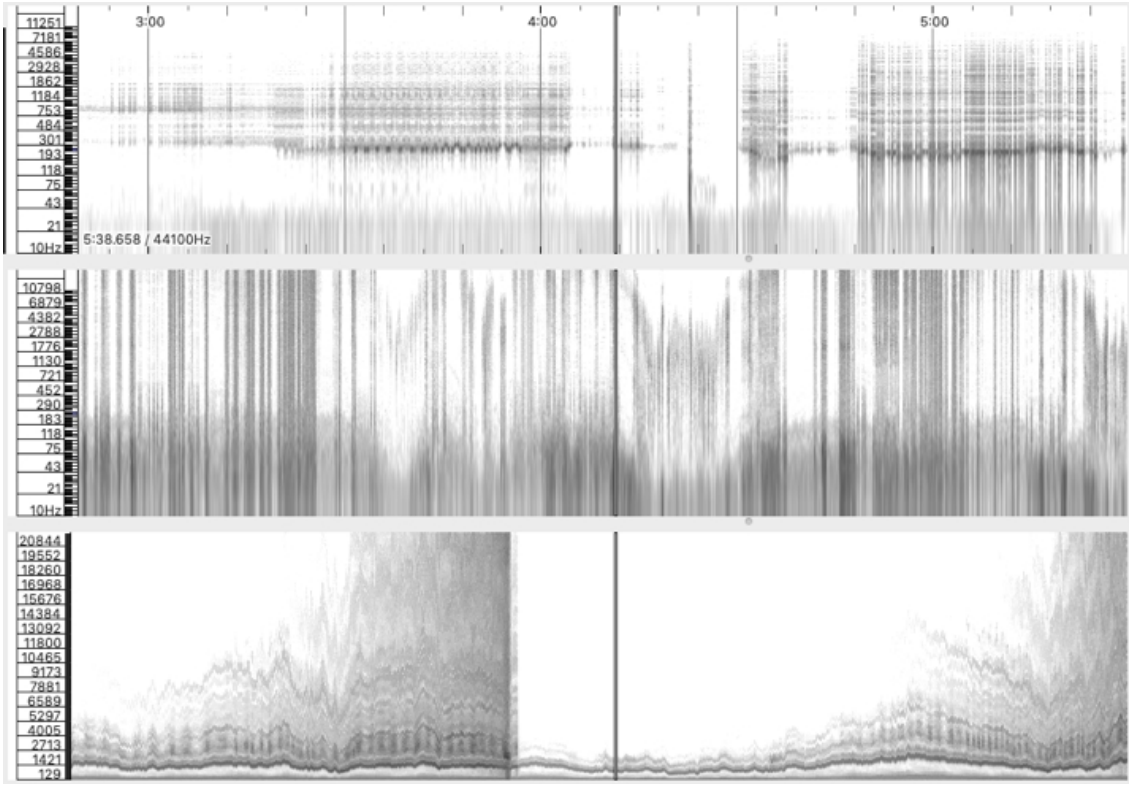


Figure 10 shows the result of a performance where both parameters in all modules (sample read position and transposition rate) were modulated by control signals. The modulation range for the transposition vary, the broadest is the third spectrogram (from up to bottom, related to the cymbal sample) and the narrowest is the first spectrogram (related to the plastic cups sample). Transposition modulations can be seen in the curves traced by spectral peeks or by more energic spectral bands. As in Figure 9, chunks of the original samples are stretched or compressed and reorganized in new sound textures. A formal organization emerges with two processes of spectral saturation in the last spectrogram (cymbal sound) while the first two spectrograms (plastic cups and masking tape sounds) alternate between moments of high and low density of sound activity.

FIGURE 10 – Spectrograms of the output produced by a sample-based feedback network composed of three modules of the type displayed in Figure 7-A fed with sound samples displayed in Figure 8, second example.



Meaningful performative actions with this specific network relied mostly on changes in modules' parameters related to the audio generation/transformation processes, or related to the mapping and post-processing of control signals. Switching connections between modules showed less musical interest, as it affected the behavior of control signals on a small temporal scale without showing significant qualitative differences (it is noteworthy that this characteristic is related to this specific implementation and variations of the proposed architecture would result in different instrumental affordances).

4. Comments on artistic usage

While both presented systems provide a reactive human-machine interaction, they are different with respect to their instrumental affordances. The FM-based system is highly responsive to performer's actions and is also predictive, as far as the association between parametric configurations and resultant sounds are learnt by the performer. Parametric configurations entail distinctive but

stable sound textures, even if their rhythmic/sound patterns take minutes to close. This makes this system very suitable for uses that undertake highly controlled results.

Conversely, the sample-based system showed dynamic sound results with surprising changes over time, even over constant parametric configurations. This implies less control over sound details, yet its variations are likely to happen within a predictable range of possibilities.

In a qualitative description: the FM-based system sounds like a regular synthesizer, very machine-like and constant, while the sample-based system presents a more 'organic' result, sounding like a landscape of autonomous 'sound organisms' interacting and generating emergent sound textures from their unexpected individual behaviors.

The artistic usages of these systems by the author are illustrated trough comments on the composition processes of two acousmatic electroacoustic pieces: the first entitled *Rito soturno* (2012-2015), composed using the FM-based system only; and the second entitled *Uma canção para o fim do dia paulistano*[3] (2016), composed using the sample-based system only. Both examples were the very first artistic applications of the respective feedback systems.

For the composition of *Rito soturno,* three instances of the FM-based instrument were used. The outputs of the FM modules of each instance were routed to a spatialization algorithm designed to octophonic or quadraphonic configurations of speakers. All the music was based on consecutives parametric changes carefully selected and programmed to happen according to a digital score/script. A fundamental formal intention to the composition was to create layers of continuously morphing sound streams spinning around the audience.

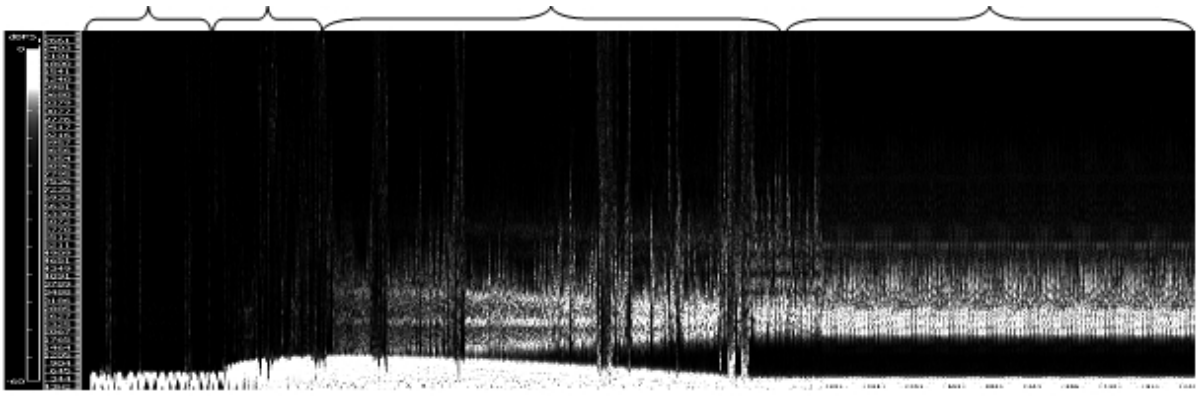
The technique used to generate morphing sounds was to assign long interpolation intervals between state changes in the signal routing matrix. An interesting feature of this technique is that different interpolation time intervals generate different emergent sound dynamics, which is a result of the system's non-linearity. In other words, a short or long time interval not only result in fast or slow transitions between two sound textures (related to states in the signal routing matrix), but they may create different trajectories between these two target states, passing through unpredictable sonic results throughout the process. Then, even transitions between parametric states are potential new

[3] In a free translation to English, the pieces title would be, respectively: *Grim Rite* (Rito Soturno) and *A Song for São Paulo's End of a Day.*

(an unknow) materials that required a careful selection.

Figure 11 shows a spectrogram that exemplifies a parametric transition applied to one of the sound layers in *Rito Soturno.*

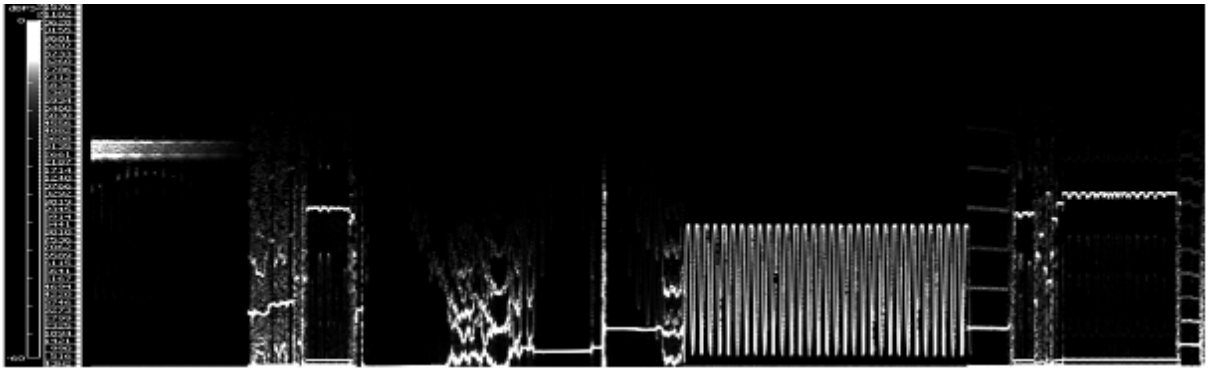
FIGURE 11 – Spectrogram of a sound layer from *Rito Soturno* (generated by the FM-based system) during an interpolation process between two states of the audio routing matrix, which represents the morphing sounds used for the composition of the piece. Brackets over the spectrogram signal stages of the transformation process.



The brackets over the spectrogram in Figure 11 mark important moments of this transition that last about 30 seconds. The first bracket indicates the sound spectrum related to the initial matrix state: a motor-like low frequency humming, while the last bracket marks the spectrum of the target: an even lower mechanical humming added to a mid-high noisy (also machine-like) component. The transition between these states is very non-linear: the low humming quickly increases its spectral band towards higher frequencies (second bracket) before returning to a lower register in a slow and smooth curve (third bracket). In the third bracket area, a noisy and higher component appears in a gradual fade-in, represented by three separated peaks regions that gradually converge to fuse in one broader spectral band. Also in the third bracket, some spurious noisy events that seem to be disturbances of the higher band gradually increase in frequency (i.e. number of occurrences) to the point it stabilizes and fuse with the higher band in a continuous drone.

Although most of the composition of *Rito Soturno* explored this sort of non-linear transitions and morphing sounds, some parts of the music also incorporate instantaneous parametric changes, as shown in Figure 12 containing the spectrogram of a sound layer of *Rito Soturno* with contrasting and rapidly changing sounds.

FIGURE 12 – Spectrogram of a sound layer from *Rito Soturno* (generated by the FM-based system) showing instantaneous changes between different types of sound being permuted.



Uma canção para o fim do dia paulistano was created after a commission for a one-minute piece by the experimental music label *Seminal Records*[4]. Sound samples were selected from a field recording in the city of São Paulo and fed four of the sample-based modules connected in a network (an implementation similar to the one in Figure 7-A). A single parametric configuration was provided for each module and the system's output was recorded for about fifteen minutes. Finally, after careful listening, the author selected a continuous one-minute segment from the recording. No radical interventions were performed, such as editing or sound transformations, and, after mixing, that one-minute segment was considered the final musical product.

The intention of this less interventive creative approach was to explore the system's potential to generate emergent sound forms that would sound like a human-made musical form. This characteristic was, of course, an exception to the system's general behavior. Though the system did generate a one-minute segment of continuous audio that met these criteria, most of its behavior sounds more as a 'soundscape of artificial sound life' with no human/narrative-like dynamic or proportions (if no intervention is performed, like changes in the parametric configurations). Even so, the listening experience can be very interesting without expectations to find a discourse-like (a human-like) form or rhythm[5]. The fruition is similar to that of being in front of (or immersed in) a natural land(sound)scape, with moments of great stability and redundancy, some disruptive minor events, and sometimes great global disruptive events.

[4] https://seminalrecords.bandcamp.com/album/sr-3-anos

[5] Of course, this statement is very personal with a clear bias from the author's personal experience.

It is also important to note that the description above is also a result of the design planned to system's modules: to provide spectromorphological (SMALLEY, 1986, 1997) variations of pre-recorded materials, in line with some aesthetic principles of the electroacoustic music genre. Hence, different interpretations of the general architecture (see Figure 4) would not likely meet this description – for example, if one decided to design sound generation modules based on variations of pitch figures and metrical rhythms. In other words, musical characteristics are not only results of the feedback architecture itself, but also largely rely on the intermediate processes used.

5. Final considerations

The systems-based audio feedback networks presented in this paper are contributions to the artistic research on autonomous generative music systems. They are snapshots of works in continuous changes according to contextual and idiosyncratic needs that are characteristic of an artistic practice. Both were designed as time-variant, non-adaptative, digital only and environmentally closed systems. Their use in the artistic works presented here aimed to explore their potential for composing music for fixed media, regarding the most prominent and interesting qualities that the author discovered when experimentally dealing with each system. However, other artistic uses, such as live performances, improvisations, or recontextualizations in hybrid artistic genres have been done or planned by the author, which le(a)d to transformations of the technical implementations presented here.

From a technical point of view, future developments would lean towards creating new specific implementations and searching for more meaningful control interface (human-machine interactions) for the sample-based network architecture, including post-processing/effects in the FM network, among others.

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ABOUT THE AUTHOR

Adriano Claro Monteiro is a Professor of Composition and Music Theory at the Escola de Música e Artes Cênicas (School of Music and Drama) of the Universidade Federal de Goiás. Doctor in Music by the University of Campinas (UNICAMP), he works in areas such as music composition, computer music, analysis of 20th and 21st century music, interactive music systems, multimedia installations and performance, systematic musicology. ORCID: https://orcid.org/0000-0002-6629-0317. E-mail: adrianomonteiro@ufg.br