Playing Time-Variant Audio Feedback Networks

Adriano Claro Monteiro

Escola de Música e Artes Cênicas – Universidade Federal de Goiás
Campus Samambaia, Rodovia GO-080, Km 3/4 – 74001-970, Goiânia, Goiás

adrianomonteiro@ufg.br

Abstract

This article presents practical and artistic contributions to the field of computational music systems based on audio feedback networks. The works presented here have been used as instruments for music creation in the author's artistic practice. The article begins with an introduction to the research field on feedback and self-organized music systems. Later on, two systems are presented: the first is a network of cross-modulated sinusoidal oscillators (by frequency modulation), and the second is a network of transformation processes of pre-recorded sound samples.

1. Feedback systems in music

Since the 1960's, audio feedback has been inventively used in experimental approaches to music creation, from the use of Larsen effect [1] by rock'n'roll 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 [2]. 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 [3] and system theory [4] – that were popular at the time – for instance in works by Nicolas Schöffer or Roland Kayn [5] [6]

More recently, new approaches to the creation of autonomous 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 [7][8][9][10][11][12]. Some of the authors of these recent feedback based works also report influence from cybernetics and system theories and include to their theoretical framework the concept of autopoiesis introduced in the 1980's by thinkers such as Francisco Varella and Humberto Maturana [13], claiming an eco-systemic paradigm to define their art works[7][8] [14][15].

Concepts usually associated to generative autonomous feedback systems – that describe their features, behavior and outcome – are: causal circularity, non-linearity, self-organization, emergency, complexity and synergy [5]. In summary, these systems tend to exhibit *non-linear* behavior, which means that their output is not directly proportional to their input, yielding *complex* results with *emergent* characteristics that, even though are based on deterministic process, are difficult to predict. *Self-organized* is the term used to describe autonomous systems that exhibit global patterns of organization emerging from the interaction between its parts in parallel and distributed processes, and adapting itself to external conditions [16]. The term *synergy* describes the coupling of parts of a system under interaction of reciprocal influence in which cause and effect are mutually dependent (i.e. causal circularity). That produces an outcome not reducible to the sum of its functional parts (here, once again, the *emergent* feature is described).

Previous publications by Sanfilippo and Andrea [5], and Kollias [17] provide an comprehensive review of musical works in this field, as well as insights to understand their similarities and differences regarding technical and artistic characteristics.

As a contribution to this field of artistic research, this paper presets 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 for sound generation: the first is based on sound synthesis by Frequency Modulation (FM) [18] in a directed cross-modulation interaction, and the second is based on transformation processes of pre-recorded sound samples and adopts a interaction mediated through audio analysis algorithms.

2. Time-variance and instrumental properties

Sanfilippo [11] 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 in an attempt to achieve some sort of balance with it (usually through combined process of positive and negative feedback), or to better accomplish an explicit or implicit goal [19][20]. In this sense, an *adaptive* system is also a type of *time-variant* system.

The two systems presented in this article are based on modules of sound processing/generation that interact in feedback networks. The systems are exclusively algorithmic. This means that there is no coupling with the real-world environment through electronic transducers, except for the adoption of gestural interfaces to provide to human performers an efficient channel to carry out parametric changes in order 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 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/or complex non-linear behaviors that could be used as resources for music creation.

3. Frequency modulation network

The first time-variant feedback network presented here was designed with 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 showed in Equation 1.

$$E_n = \sum_{m=1}^{8} A_m^n \, S_m$$

$$S_n = \cos\,(2\pi fp + En + \emptyset)$$

Equation 1: mathematical formalization of a networks' FM synthesis module.

Being E_n 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.

Although most of the parametric settings for this system produce a broadband (almost white noise) sound that is of little interest to music creation, some specific configurations result in more varied and complex sounds. Because of its non-linear behavior, in which there is no correlation between sound features and parametric changes, and also due to minimal parametric changes can lead to completely different results, one cannot easily predict the sound generated by a new parametric configuration. Therefore, the task of finding sets of values that produce musically interesting sounds is a careful, almost handicraft 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. Taking advantage of this feature, the approach to create a playable time-varying network was adapting a gestural interface that would allow 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 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 constrain 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, by its turn, 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 the store and retrieve eight matrix state presets.

Figure 1: Physical interface adapted to switch network connections through a 8x8 matrix that represents connections between FM modules' inputs and outputs.

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 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 3, in which 1 means a connection between two modules, and 0 their disconnection. Matrices A to C correspond to 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 relatively long time spans (several minutes); the middle spectrogram (related to matrix B) displays alternations of complex spectrotemporal patterns lasting from some hundreds milliseconds to some 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.

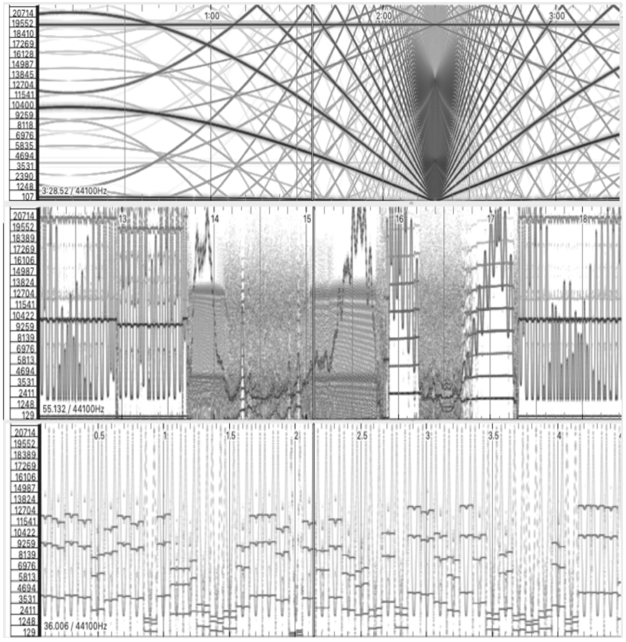

Figure 2: Spectrograms of three sound samples generated by the FM feedback network using a same FM parametric setting but with different network topologies.

A	INPUT								
OUTPUT		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	INPUT								
OUTPUT		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	INPUT								
OUTPUT		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

Figure 3: Matrices representing the network topology for the sounds displayed in Figure 2.

In Figure 4, 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.

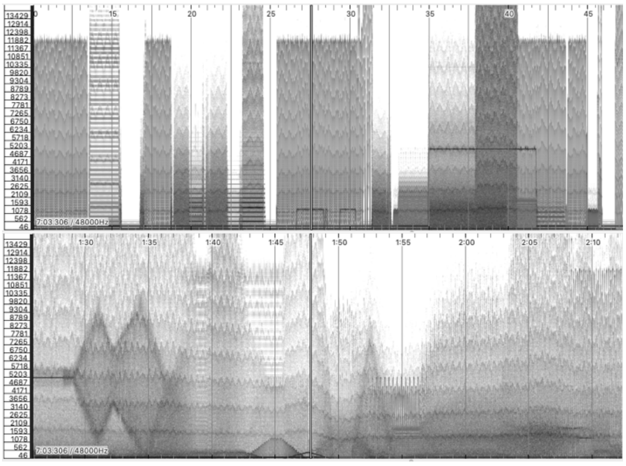

Figure 4: Two spectrograms of excerpts from a performance of the FM network using a small interpolation time (upper graph) and an interpolation time of a few seconds (lower graph)

Based on the author’s practical experience, an in-depth use of this instrument requires a long-term work of at least three steps: first, an empirical research to discover FM presets that resultant sounds 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 finally, using this acquired specific knowledge for music composition or improvisation.

4. 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 audio generation with direct signal feedback, this class of systems adopts a classical modular synthesizer architecture that allows for variability in the combination of audio processes, and it includes an audio feature extraction stage to generate control signals.

Figure 5 shows the general outline of the system. 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.

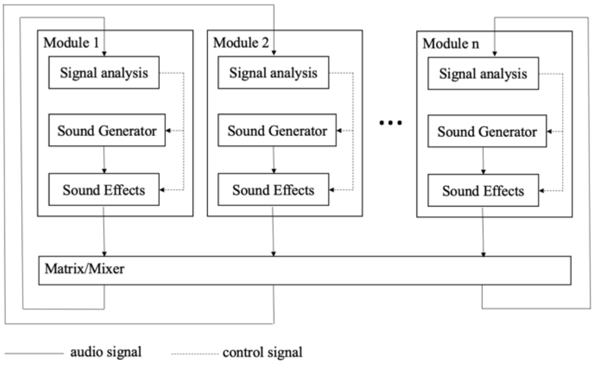

Figure 5: sample-based system architecture.

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 [21]. The resulting signals are mapped to control parameters in the following stages.

Two methods of sample transformation were applied in the generation stage: playing a sample with variable speed (a scratch-like effect), and a time-stretch plus pitch-shifter effect based on granular synthesis [22]. 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 an 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 it 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 aesthetic (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.

Figures 6 shows the interfaces of two modules implemented in the software Pure Data[1] that use a granular synthesizer for sound generation. In both of them, 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 6-A, while the one in Figure 6-B included a band-pass filter and a pan effect, both also linked to control signals.

In the networks composed with 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.

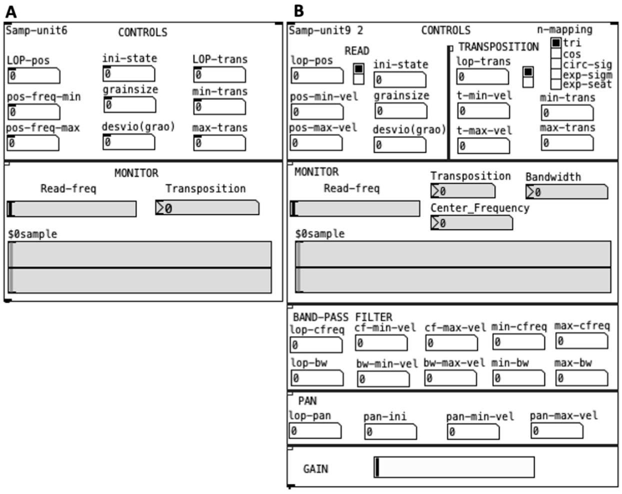

Figure 6: Interface of two sample-based modules implemented in Pure Data.

Figure 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 6-A.

The modules were fed with sound samples which spectrograms are shown in Figure 7. 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 masking tape; and the third sound sample, in the lower spectrogram, is a single cymbal strike with a drumstick that created a complex and inharmonic resonance pattern.

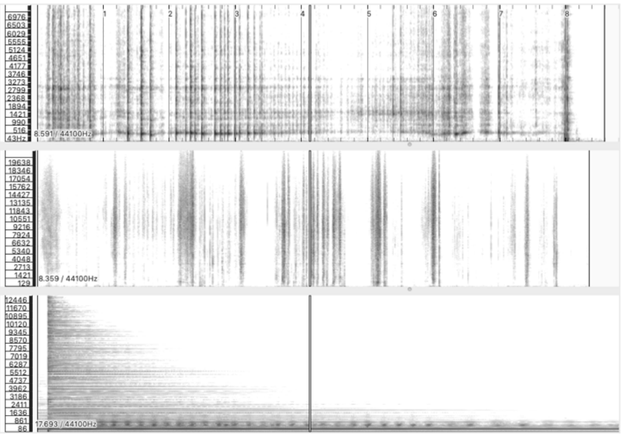

Figure 7: Spectrograms of three sound samples used to generate the examples of Figures 8 and 9.

For the network's output displayed in Figure 8, the transposition rates of the granulators were set to 1 (no

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[1] https://puredata.info/

transposition) and their sample read position was modulated by a control signal. 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.

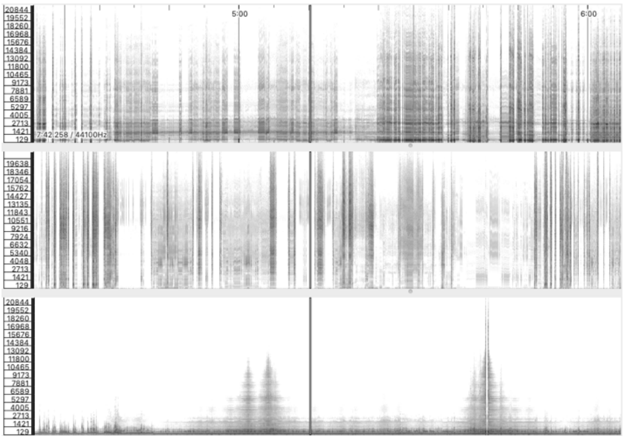

Figure 8: Spectrograms of the output produced by a sample-based feedback network composed of three modules of the type displayed in Figure 6-A fed with sound samples displayed in Figure 7, first example.

Figure 9 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, being the broadest the third spectrogram (from up to bottom, related to the cymbal sample) and the narrower 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 8, 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.

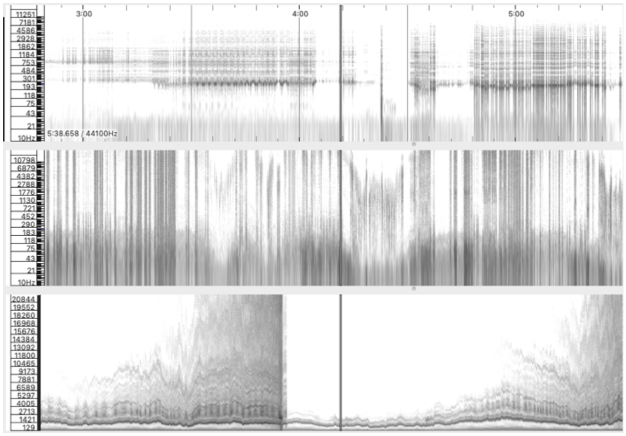

Figure 9: Spectrograms of the output produced by a sample-based feedback network composed of three modules of the type displayed in Figure 6-A fed with sound samples displayed in Figure 7, second example.

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).

5. Final considerations

The audio feedback network systems presented in this paper are contributions to the artistic research on autonomous generative music systems. They are snapshots of works in continuous development or transformation according to contextual and idiosyncratic needs that are characteristic of an artistic practice. From a technical point of view, future developments would be towards creating new specific implementations for the sample-based network architecture, or including post-processing/effects in the FM network.

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