Turning Perturbation Into Emergent Sound, and Sound into Perturbation

By Dario Sanfilippo

Abstract

In this paper I will discuss the implementation of cybernetic music systems based on feedback. As a case study, I will present my projects for human-computer interaction performance and autonomous interactive sound installations, LIES and SD/OS, describing their characteristics from a systemic perspective, their structure, and the concepts behind these works. Concepts such as complexity, self-dis/organisation, emergence and chaos are crucial to these works, as are those of autonomy and synergy. Feedback, a mechanism that makes the subversion of technology possible, is the key for the design of these systems and for establishing a strict coupling between environment, performer, and machine. It will be shown that in such music systems 'noise' can be the sole source of alimentation, and that sound affects itself, becoming a continuous perturbation for the spontaneous behaviour of such systems.

Keywords: feedback; cybernetics and systems theory; complexity; performance ecosystems; autonomous systems; human-machine interaction.

Introduction

The use of feedback for musical work is a practice that developed since the early 1960s in both academic and non-academic contexts, as well as in creative areas ranging from experimental to popular music. Such an approach, in many cases, is likely to be associated with Cybernetics and Systems theory from the 1940s to the present day and to the discovery in acoustics of the Larsen effect[1] that led to further studies in acoustical engineering[2] for the improvement of sound systems, studios, and recording techniques. Furthermore, practices emerging in the 1960s from hardware hacking and circuit bending have also contributed to the creative use of feedback, considering that these practices are often feedback-related.[3] Alternatively, other musicians have discovered feedback in music simply by experimenting with their equipment, without necessarily having a complete awareness of what was occurring, while also being able to understand the charm and potential of this phenomenon. Among the early composers who used feedback in their work were Robert Ashley (The Wolfman, 1964); John Cage (Electronic Music for Piano, 1964); Steve Reich (Pendulum Music, 1968); Alvin Lucier (I am Sitting in a Room, 1969); Gordon Mumma (Hornpipe, 1967) who worked extensively with self-constructed circuits; and David Tudor (Tone Burst, 1975), whose work is particularly relevant as he based many of his practices exclusively on feedback mechanisms. In the same period, Reed Ghazala was one of the pioneers of circuit bending, while in the Rock/Pop area examples include Jimi Hendrix (Can You See Me?, performed in 1967) and The Beatles (I Feel Fine, 1964).

Today, the advent of new technologies in the software and hardware domain makes it possible to model and implement feedback systems in which very particular theories and processes can be applied. A significant example is the remarkable work of Agostino Di Scipio, who implements Audible Ecosystems where a metaphor to living organisms can be made (Di Scipio, 2008), or projects like |., from Dario SanFilippo and Andrea Valle, where highly heterogeneous systems are designed, with feedback in the audio, control, analogue, and digital domain. (See Sanfilippo & Valle 2012a, 2012b, 2012c) In short, many feedback-based systems for audio and music creation exist, and many sound artists/composers consider feedback as a crucial notion at the foundation of their work. However, there are substantial differences in how such music systems can be implemented, in the approaches used, and in the conceptual frameworks applied. Regardless of whether these systems come from a theoretical approach or from empirical experimentation, those who work with feedback, in sound, will have a chance to experience a meta-instrument[4] emerging from his or her device: a new entity driven and fed by inner and outer turbulence which will express its personality.[5]

In the following sections I will briefly introduce the feedback mechanism and explore its implications, discuss the key concepts and ideas related to this artistic approach and conclude by describing key performance and sound installation projects from my practice that utilise feedback.

Feedback[6]

A basic definition of feedback takes into account the configuration of a system, provided with input/output, in which some kind of transformation is carried out, where the output is connected (fed

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back) to the input after a delay (namely greater than 0 seconds) (Rosnay, 1997). In *negative* feedback the input-output relation is inverse: an increase in the output causes a decrease in the input and vice versa. Thus, the response of the system to stimuli is that of compensation, and it will tend to be in equilibrium around a desired target. In a *positive* feedback configuration, the input-output relation is direct: if the output increases, the input increases and vice versa, if the output decreases, the input decreases. In this case, a deviation of the system in one direction will produce a further shift in the same direction, and the outcome will be that of magnifying the effects caused by the stimuli (Ashby, 1956; Gershenson, 2007; Heylighen & Joslyn, 2001; Heylighen, 2003; Wiener, 1948). The positive and negative feedback concepts can also be generalised as *causal relations* (Heylighen & Joslyn, 2001). In a system with a causal relation between two variables A -> B, a positive feedback occurs if an increase/decrease in A produces an increase/decrease in B and vice versa. On the contrary, a negative feedback occurs when an increase/decrease in A produces a decrease/increase in B and vice versa. For example, in the relation *infected people -> viruses*, an increase in the infected people will lead to an increase in viruses, which will in turn lead to an increase in infected people (positive feedback) (Heylighen & Joslyn, 2001). In the relation *rabbits -> grass*, more rabbits eat more grass, grass decreases and so will the rabbits, but a decrease in the rabbits allows more grass to grow, eventually leading to more rabbits, and so on (negative feedback) (Heylighen & Joslyn, 2001). Negative feedback is widely used in control and self-regulating systems (from thermostats to living organisms), and its major role is that of creating stability. Positive feedback, instead, displays typically unstable behaviour, causes exponential variations, and tends to self-organisation (Heylighen & Joslyn, 2001).

From a musical perspective, it is also important to make a distinction between internal and external feedback configurations. We can consider all the devices (from computer and analogue effects to microphones and loudspeakers) as comprising a system, and the space where sound takes place as comprising the environment. With internal feedback, the output is directly fed back into the input through the system, without the mediation of the environment; conversely, in the case of external feedback, feedback takes place through the environment in which the system operates. Internal feedback configurations typically set a system to be closed in relation to its environment; there is no energy exchange between them. With external feedback, however, it is possible to establish a coupling between system and environment where an exchange of energy and mutual influence takes place.

A system is said to be linear when its output (effect) is proportional to its input (cause). As an example, consider a snooker ball not subject to the forces of friction. If the ball is hit with a force *f*, it will have a velocity *v*. When the force is doubled, the velocity is doubled. In fact, many natural phenomena and systems in the world are intrinsically nonlinear with no proportional relation between causes and effects. As a result, in a nonlinear system, causes of reduced size can have greater effects, and, on the other hand, causes of greater size can have smaller effects. A feedback system is typically nonlinear, nonlinearity being the result of a process with *circular causality* (Gershenson, 2007; Heylighen, 2003). In such a configuration, effects are also causes (Heylighen, 2003), and there is a mutual relation between them. The causes are fed back to themselves through their effects, and the effects are the result of their combination with the causes, thus breaking the input-output linear proportion. Another important feature of feedback configuration and circular causality is that processes become *iterated*, leading to systems which are capable of self–alimentation. From a musical perspective, nonlinearity clearly emerges in feedback-based systems where small changes of internal variables can result in very different behaviour in the final output.[7] It is worth citing a clear example by the Japanese improviser Toshimaru Nakamura, who has worked with feedback systems for more than twenty years. Speaking about his performance with the *No-Input Mixing Board*, he describes in an interview how very slight adjustments to a knob can have huge effects in the overall outcome.

Interaction, interdependency, and synergy

Another fundamental property of feedback configurations is that of *coupling* (Ashby 1956). Two or more elements within a feedback loop are coupled because they operate in a situation where they mutually affect each other. From a systemic perspective, the concepts of interaction, interdependency, and synergy are crucial in order to understand a feedback system. A totality, which is made up of different components, interconnected by specific relations, shows certain behaviours thanks to the cooperation of all its parts. Any small changes in the organisation of the relational network can potentially change the identity of the system and radically alter its behaviour and identity. Any system of this type thus relies on all of its components, and each of the parts has a fundamental role in the global functioning of the system. The strict interaction between the components allows the combination of their properties, leading to new entities which are not the result of a mere summation of the properties of their parts, but the result of their synergy.

In most cases, high-level interaction in solo electronic performance can be described as a relationship occurring between the human and the machine, where (typically) gestural devices allow the performer to define actions that in turn produce reactions in the machine without taking into account a mutual influence. Conversely, Di Scipio has been able to provide an interesting perspective on interaction in music by describing it as a condition that occurs in the sound domain (Di Scipio, 2003); interaction occurs among sound materials, and feedback makes this condition possible.

Self-dis/organisation, homeorhesis, and homeostasis

Self-organisation has received many definitions in different contexts, such as cybernetics,

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information theory, thermodynamics, and synergetics among others, and although the term is widely used, there is not a generally accepted meaning (Gershenson & Heylighen, 2003). Here, I will delineate the main features of self-organisation to apply the concept to the musical domain as a property characterising feedback systems.

Self-organisation occurs when a system can organise itself autonomously, without an external entity (Ashby, 1947, 1962). According to this definition, any automated music system might be considered self-organising. To provide a stricter definition, therefore, self-organisation can be described as the emergence of coherent patterns at a *global* level out of *local* interactions between the elements of a system (Heylighen, 2003; Gershenson, 2007). Because of the recursive relations between the system's components, the self-organisation process is *parallel* and *distributed* (Heylighen, 2003), as it happens through the simultaneous action of all the elements, none of which play the role of coordinator. Self-organisation, therefore, is decentralised; it excludes the presence of an external element regulating the system. From this perspective, music systems in which elements are independent and in which automations are high-level processes of sound organisation, cannot be considered self-organised. If the state of a system is any configuration of its variables (that is, its general output), then self organisation can be thought of as the *autonomous* shift from one state to another, including the different behaviours arising from the state-shifting process.

A system can enter a stable state, in which either the behaviour is completely static or it shows dynamical equilibrium. Another situation is that of dynamical unstable behaviour, in which the system continuously shifts from one state to another. Such a distinction allows us to oppose self-organisation, described as a spontaneous increase in order, to self-disorganisation (Gershenson & Heylighen, 2003), leading to an increase in disorder and unpredictability (Gershenson, 2011). Self-organisation and disorganisation are in some respect analogous to 'homeostasis' and 'homeorhesis', the two terms indicating respectively a tendency towards stability, and a tendency towards evolution through a fixed or changing trajectory while the system shifts between different states.

Chaos, emergence, and complexity

Chaos is a widely diffused term that is often used as a synonym of 'unpredictability', yet the two concepts do not semantically coincide, as, although chaos implies unpredictability, the reverse relation is not always true. Firstly, chaotic behaviour can be unpredictable even if no randomness is involved. Secondly, in chaos, what happens now is an effect contingent on what took place before. More generally, chaos can be thought of as a highly dynamic behaviour where order and disorder coexist and *compete* (Anderson, 2005), and where a causal connection between past, present and future is established. Feedback can be modelled as a nonlinear iterated process, a formalism usually associated with mathematical models of chaotic systems (Kellert, 2008). In feedback systems, chaotic behaviour can occur at two different levels. In a situation of dynamical equilibrium, while there is an overall stability, the inner activity can be highly chaotic. On the other hand, if considering homeorhesis, each of the states that the system goes through can be chaotic.[8]

Complexity is yet another important concept that can be used to characterise feedback systems (Kellert, 2008). Although it seems to be a concept that has no generally accepted definition (Kitto, 2012), we can use the term to describe a particular behaviour and structure of a music system. Generally speaking, a relatively large network of simple and nonlinearly interacting components can lead to the achievement of complex and unpredictable results (Mitchell, 2006). Complexity, though, does not refer to a situation of total unpredictability; a complex system is said to be at the edge of chaos (Baranger, 2000), thus, in a condition where chaotic and non-chaotic behaviour can happen. Furthermore, a fundamental aspect of such systems is that their components are strictly interdependent, and the cooperation of all of them results in their identity. Feedback is an interesting case of how simple processes and behaviours can be interconnected to generate (due to nonlinearity and iteration) unexpected and new outputs, in some cases, with evolving forms that go through predictability and unpredictability. In this sense, it can be described within the framework of complexity.

The notion of complexity is strictly related to that of emergence, as the behaviour of complex systems is typically 'emergent' (Edmonds, 1999). Emergence can refer to organisational levels (Lewes 1874), to self-organisation (Varela, 1991), to entropy variation (Zureck, 1990), to nonlinearity (Langton, 1990), to complexity (Bonabeau et al, 1995a, 1995b; Cariani, 1991; Kampis, 1991) or to synergy (Corning, 2002). Here we will focus on the description of emergence referring to the organisational levels approach, as it seems to particularly fit the musical domain, since an analogy can be traced between low-level and high-level, and, respectively, micro-structure and macro-structure. According to this approach, a phenomenon is emergent when it manifests itself at a level *L-hi* as the result of components and processes taking place at a level *L-low* (Bonabeau and Dessalles, 1997)[9]

In feedback systems, the output of the system at the higher level results from the processes defined at a lower level, as the sound artist focuses on composing the interactions (Di Scipio, 2003). From a qualitative and holistic point of view, emergence refers to global properties arising from the interactions of lower level components, where the global properties are not directly related to those of the components (Mitchell, 2006). In this case, the synergy between the interacting components gives birth to an entity that is somehow different from the sum of its parts (Corning, 2002). It is more, but it is less too (Morin, 2005).((It is important to underline that an emergent system may also lose some of the properties of its individual elements, while also exhibiting new properties.)) Many important works by Di Scipio are particularly relevant in relation to the features described in this and previous subsections, as Di Scipio's approach aims at composing dynamical and chaotic entities where homeorhesis and homeostasis are competing criteria (Di Scipio, 2003), and where structures emerge from the sonic interactions in an environment.

Observations on the use of feedback for sound creation

To work in real-time with computers is now normal, and in recent decades has become a widespread practice in both academic and non-academic contexts. Today, hardware and software technologies provide many possibilities for the implementation of music systems. Computational and processing capacities improve constantly as costs become less restrictive, such that extremely powerful music programming languages with detailed documentation and support are now available for free. Besides the variety of ways to transform sound, an important possibility provided by these technologies is the creation of music systems that operate autonomously and are capable of unpredictable dynamical behaviour. Such systems can thus generally be used for the creation of sound materials for composition; for sound installations, generating sound and forms without a performer; and for performances in which the human and the machine are influenced by each other and the overall result comes from the cooperation between them. Hence, we might ask: what are the differences in using feedback to implement such systems instead of automated algorithms or other techniques?

Autonomous and self-sustaining non-automated systems

The most common approach for the implementation of autonomous systems in the digital domain is that of automation. Through the programming of algorithms driving high-level processes of sound organisation and transformation, it is possible to design machines that are dynamic and whose sonic outputs change over time without the need for actions performed by a human user. The use of feedback provides the possibility to implement systems with such characteristics, thanks to its iterative properties. In this way, processes are recursively applied to sound, and the overall behavioural and timbral outcomes (two aspects which become inseparable) are the result of both the particular low-level interrelations between the properties of the processes and the self-relation of those processes themselves. Moreover, feedback systems are typically self-sustaining and capable of operating without inputs. A consequence is that energy – the 'noise' present in acoustic, analogue and computational environments, respectively air, electricity or numerical leftovers – endlessly re-circulates when particular conditions are established (namely when positive feedback takes place and the system enters a state of self-oscillation). Hence 'perturbation', in the sense of turbulence or noise, is the only energy feeding these systems, while sound is a continuous perturbation of itself.

Non-random unpredictability

Indeterminacy has, for many years, been a technique widely used in music composition, performance, and sound installation. It is beyond the scope of this text to investigate the reasons why many artists use it extensively. Therefore, I will discuss the design of unpredictable sonic behaviour through stochastic algorithms and (non-random) chaotic feedback systems in order to underline the differences between non-causal and causal processes. In the first case, indeterminacy is achieved by means of random numbers, which are generated at different time scales and used to pilot parameters of sound transformation and the scheduling of events. If we consider the mapping between random numbers and parameters/triggers, there are the following general possibilities: one-to-one, one-to-many, many-to-many, and many-to-one. While it is possible to achieve very articulated results with such an approach, the overall design of these systems has a structure where no causal relation between past, present, and future takes place. Randomness and sonic processes operate over two distinct non-interacting domains; no matter what the output of the processes is, the random control signal is not influenced by it. Even more articulated stochastic systems implementing probability distribution matrixes, where the output is influenced by previous states, after a certain number of transitions, tend towards the mean, and eventually reach a stationary state.[10] Thus, previous states will no longer have an influence over the present state. On the other hand, in chaotic systems there is an intrinsic temporal relation between events, and, although their behaviours can be so unpredictable as to appear completely random, in particular situations it is possible to perceive an implicit flow in the short and long-term unfolding, even as a response to external perturbations. To put it in Di Scipio's words: "these systems have a memory" (Anderson, 2005, p. 17). This is an interesting characteristic from a musical perspective.

Organic sound

As observed by Di Scipio (2003), many algorithmic music systems are implemented so that their internal structure is linear; the components of the system – processes and generators – are not interrelated and no interaction occurs between them. This results in different coexisting sound streams, which are independent (or at least where a sound can affect another sound while it is not in turn influenced). A composer *can* put sounds together so that a sense of interrelation is perceived, but this would be illusory.[11] Creating a condition where the coexistence of sounds can leave traces of an explicit interaction can be musically important. Thanks to the coupling property of feedback, it is possible to design music systems where a constant mutual influence between sound streams is established – a network of interconnected processes, where local changes will have global effects, resulting in a multi-layered sonic whole acting as a single organic voice. Moreover, it is not surprising to realise that sonic features of a kind typically unrelated in linear audio systems (amplitude, pitch, spectral and temporal density, spectral noisiness, etc.), are instead deeply interrelated in feedback configurations. A modification of one can potentially lead to modifications in all the others.

Analogue complex dynamical systems

If we think of the implementation of a musical system that is autonomous and unpredictable, the first thing to come to mind would probably be an algorithmic computational device featuring automation and random generators. With feedback, however, it is possible to implement these musical systems through completely analogue, non-computational machines. The work of composer Toshimaru Nakamura is an example of how, through the use of elementary devices such as a mixer, it is possible to design systems that generate complex results. Other examples come from David Tudor who, through feedback, turned everyday analogue devices for sound transformation, such as guitar pedals, into a set of emergent sound generators. Similarly, in *Pea Soup* (1974), composer Nicolas Collins realised a self-regulating system using chained positive and negative feedback, respectively implemented as acoustic feedback, and phase shift delay controlled by an analogue amplitude follower (Waters, 2007). Agostino Di Scipio's sound installation, *Modes of Interference 4* is also based on woofers and piezos. Using four woofers and eight piezo microphones, several intercommunicating feedback loops were created by placing the piezos (inputs) inside the frame of the woofers (outputs). This resulted in a complex system made up of a few simple elements.

NICOLAS COLLINS – PEA SOUP (1974)

AGOSTINO DI SCIPIO – MODES OF INTERFERENCE 4 – THIS TRACK IS TAKEN FROM THE CD ATTACHED TO THE CATALOG "SOUND. SELF. OTHER / FIVE NEW WORKS BY AGOSTINO DI SCIPIO", GALERIE MARIO MAZZOLI, BERLIN, 2011.

The aesthetics of the emergent machine and the subversion of technology

Generally speaking, the two substantially different approaches in designing music systems are those in which a sound artist operates in a top-down or in a bottom-up direction. In the first case, the designer of such systems has a target behaviour that tries to shape, through programming algorithms or other techniques, sound installations or generic sound creation. This leads to a system that acts in a way he or she wants during the development of a performance. On the other hand, the sound artist may operate in the low-level domain, applying certain criteria or doing experiments, and eventually interact with the resultant emergent behaviours. Such an approach is not meant as an action without intention; rather, it should be considered as having a fruitful view over the unknown that can potentially lead to new discoveries and solutions.

By using feedback as a fundamental mechanism to implement music systems, a sound artist adopts a creative approach that produces sonic entities that exhibit their own aesthetics. Such entities exhibit radically new behaviours that, though mediated by the implementation of the sound artist, can express their personalities unconstrained from centralising control. Working with such entities, therefore, implies a rethinking of the relationship between the human and the machine. It is no longer the case that the artist assumes total control over the machine; instead we encounter a respectful exploration of what the system can offer by driving it towards different behaviours. User and system cooperate in a non-hierarchical manner.

Strictly related to the possibility of achieving radically new results, we have the use of feedback as a mechanism to subvert technology. The idea that the technology we use is simply a neutral tool serving our creative ideas should be abandoned; the final outcome and the ideas our creative practices are based on are subject to the influence of the technologies we use. This is the case even if we implement our systems from the low-level, for example, designing our own electrical circuits or software in programming languages like Max/MSP, Pure Data, or even C.[12] Through the use of feedback, the hardware and software components in such systems are subverted, as their behaviours will be substantially different from the one they have been designed for. Microphones and loudspeakers will not be sound capturers and reproducers, and DSP units will not be transformers; all these elements become emergent sound generating components. Such a conceptual approach is different from the aesthetics of failure (Cascone, 2000)[13] or hardware hacking (Collins, 2006), as the behaviours of these systems are not to be considered as malfunctioning, nor the technologies are materially transformed. Instead, such systems might be considered as *functioning in extreme conditions*, meaning that they are pushed towards their limits, and in such conditions the original identity can be lost.

The LIES and SD/OS projects

As discussed, feedback is a technically simple configuration, yet it is a very powerful relational mechanism whose application has remarkable systemic results. In such systems, every effect (output) from each element in the network is, directly or indirectly, also a cause (input) for all other elements (Gershenson, 2007). This leads to the circular causality condition previously discussed in

'Feedback' Section as well as to iteration, nonlinearity and low-level interaction (Anderson, 2005; Di Scipio, 2003; Gershenson, 2007; Heylighen, 2003). These systems are autonomous and self-sustaining, and without external or centralised control they are capable of self-dis/organising themselves (Gershenson, 2007; Heylighen, 2003; Gershenson & Heylighen, 2003), generating stable or evolving multi-streamed patterns (Bregman, 1990). The nonlinear dynamics generate chaotic behaviours (Gershenson, 2007; Mitchell, 2006) and the systems operate on the edge of equilibrium and instability, between homeostasis and homeorhesis. The sound circularly affects itself, and is, together with the evolving morphologies, an emergent phenomenon of radical novelty (Bonabeau & Dessalles 1997; Di Scipio 1994; Mitchell 2006; DeWolf & Holvoet, 2005), where global properties and behaviours are unrelated to the properties of the individual elements. This synergy makes the system different from the sum of its parts (Corning, 2002; Morin, 2005), a holistic entity with its own aesthetics, an organic sonic whole whose result can be considered as non-conventional sound/form synthesis.[14])

In this section, the *LIES (Live Interaction in Emergent Sound)* and *SD/OS (Self- Dis/Organising Sound)* projects will be discussed. I will provide a basic technical description of the systems used, and will briefly discuss the concepts behind these works.

LIES (topology)

DARIO SANFILIPPO – LIES (TOPOLOGY) – PERFORMED AT THE CONSERVATORY OF PADUA, 9TH OF JULY 2011, FOR THE 8TH SOUND AND MUSIC COMPUTING CONFERENCE.

LIES (topology) is a human-computer interaction performance. Improvisation has a major role. It is meant, from a systemic point of view, as an aural feedback within which performer and system are engaged in a mechanism to establish interdependency between them. This performance follows nonlinear developments and results from the cooperation between two mutually influencing entities, constituting a unique meta-system. The approach of the performer is not as the controller of a subordinated machine (Di Scipio, 2002); rather, it focuses on exploring the identities of the system and the perturbations that can push it towards unexpected behaviours. In this work, a real-time cybernetic music system was implemented by means of feedback networks with digital processes and a delay of 256 samples for feedback loops.

The role of the performer consists of dynamically altering the topology of the feedback networks by varying the amplitude of the recirculating signals, and changing the relations between the components by modifying their parameters. These systems can be thought as a whole of nested recursive processes. Technically speaking, they act as a set of interacting recursive comb filters[15] with processes within the feedback loops. More generally, each of the loops can be described by a difference equation of the type

$$y(n) = P[bx(n) + ay(n-m)] \qquad (1)$$

where *y(n)* is the output signal, *P* is a generic digital transformation which might contain several sub-processes, *b* is the gain of the input signal *x(n)* (when present), *a* is the feedback coefficient, and *m* is the delay. In order to give a complete formalisation of such systems, we can first refer to a generic feedback delay network (Figure 1.) with fully connected topology that is entirely described by the following relations (Rocchesso and Smith, 1997):

$$y(n) = \sum_{i=1}^{N} c_i s_i(n) + dx(n)$$
$$s_i(n) = \sum_{j=1}^{N} a_{i,j} s_j(n - m_j) + b_i x(n - m_i). \qquad (2)$$

In the first relation we have that the overall output $y(n)$, it is made up of the sum of the signals $si(n)$, where $1 \le i \le N$, which are the outputs of the delay lines at the time n, plus a copy of the input signal which does not go through the delay lines and is sent directly to the main output. The second relation describes the output of each delay line, and we have that at the time n, the output of the delay line si, of length mi, is made up of the sum of the output signals from all the delay lines (si included) at the time $n - mi$, plus a possible input signal into the delay line si at the time $n - mi$. ci represents the output level of each delay line, while d and bi are the levels of the input signals. ai,j represents all the feedback coefficients which make up the feedback matrix, while N, the order of the network, is the number of delay lines involved. Starting from this case where we have a network with all possible feedback loops, we will be able to implement networks of any topology by choosing the right coefficients for the feedback matrix. And yet, we have to consider that in the systems implemented for these projects, each feedback loop contains one or more processes, and these can operate with no input signals. Thus, we can omit the input signals and add a processing matrix in the previous relations, which can be rewritten as follows:

$$y(n) = \sum_{i=1}^{N} c_i s_i(n)$$
$$s_i(n) = \sum_{j=1}^{N} p_{i,j}[a_{i,j} s_j(n - m_i)]. \quad (3)$$

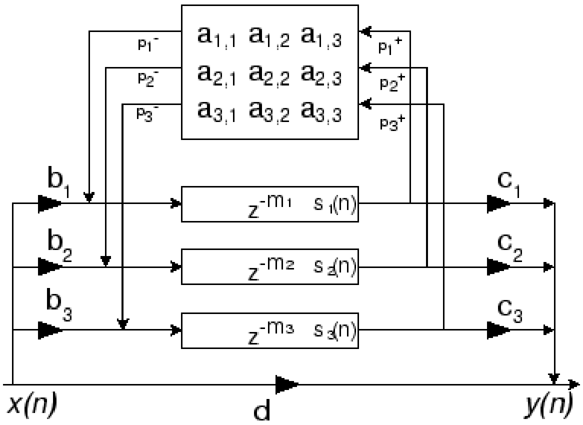


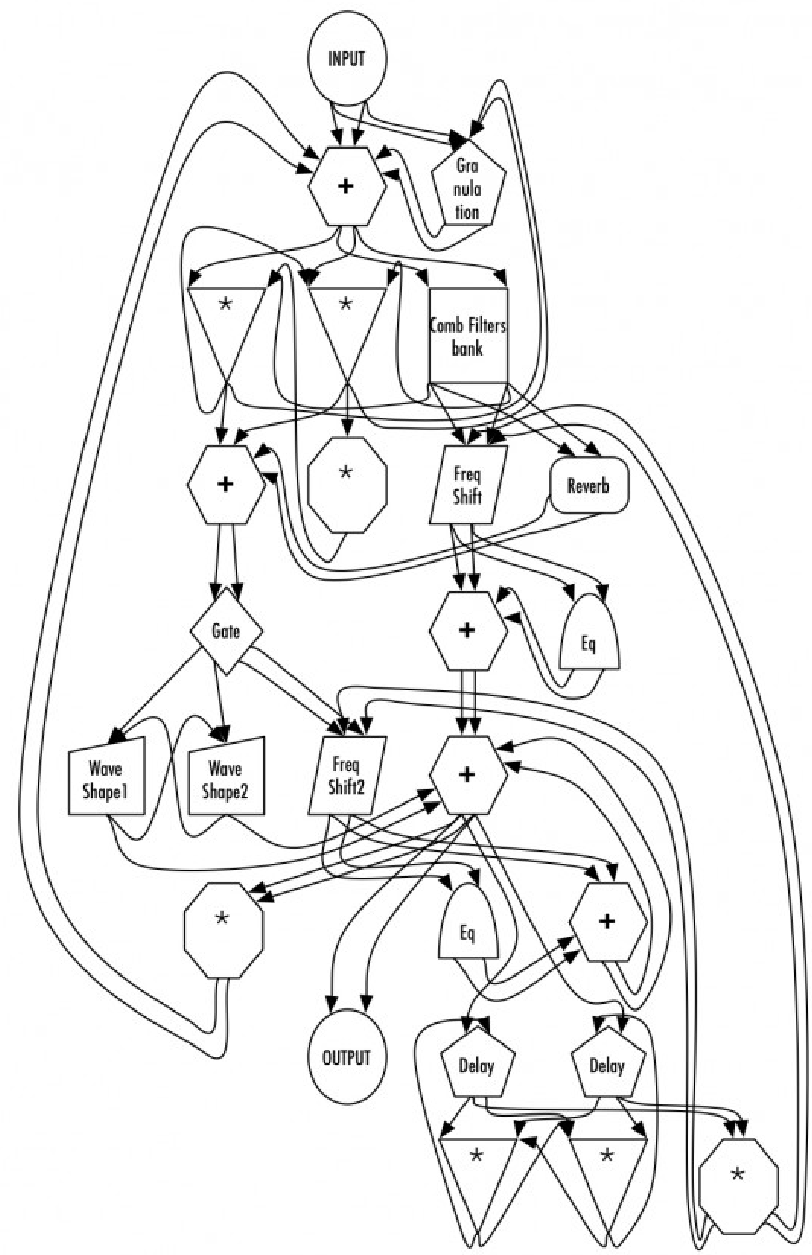
FIGURE 1.: GENERIC FEEDBACK DELAY NETWORK.

Processes in the system include ring modulation, frequency shifting, granulation, EQ, wave-shaping, sub-bit depth and reverb (see Figure 2.). All temporal parameters in the DSP processes are within the 0-30 milliseconds range. This means that the system is, in theory, unable to produce individual sound events through time, as sounds within that range are perceptually merged (Moore, 2008). This design has been chosen so that long-term audio events emerge thanks to operations in the micro-structure/temporality of sound, and not because of high-level scheduling. Furthermore, no random generators are present in the process with the explicit aim of achieving unpredictable behaviours out of a non-stochastic design.[16]

FIGURE 2.: *LIES (TOPOLOGY)* DIGITAL FEEDBACK NETWORK DIAGRAM.

In this diagram, objects represent the processes in the network, while arrows indicate the signal flow. The "+" object is to be considered as a mixer where the amount of different signals summed up can be adjusted. The "*" object is a ring modulator in the case of the triangle, and a gain in the case of the octagon shape. For the sake of simplicity, the attenuation processes and polarity inverters performed in each feedback loop are not shown in the diagram.

In the system, there are four intercommunicating sub-networks of the type shown in Figure 2., where two signals from two nodes of each sub-network are taken, and two input signals are provided for each sub network, with a total of 8 input/output signals.[17] It is possible to use the system in stereo, quadraphonic or octophonic setups, and generally, when two or more sub-networks are operating, the sound of each of them, as well as their interactions, will be heard. Figure 3. shows the global configuration of the work, and as can be seen, it is also possible to use external analogue feedback through microphones and loudspeakers. In this case, the system can generally be defined as a whole set of Larsen feedbacks within which a summation of digital recursive processes described in (Equation 1.) take place.



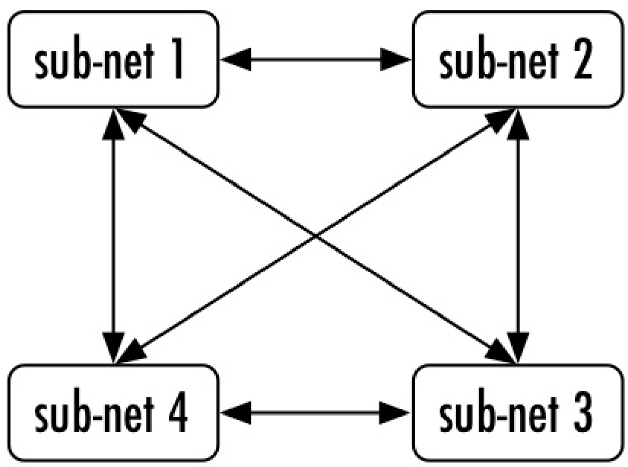
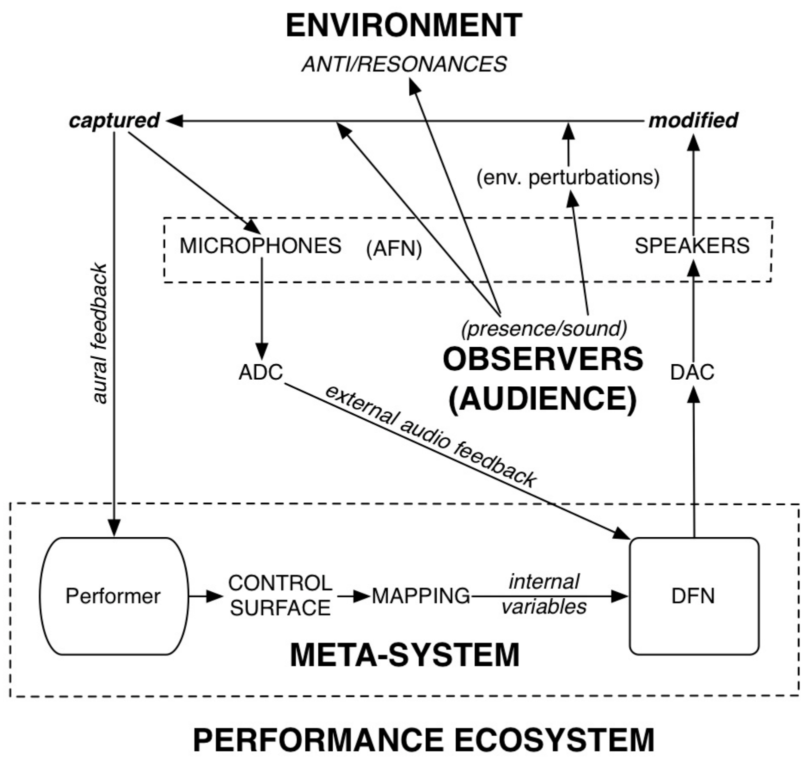


FIGURE 3.: *LIES (TOPOLOGY)* OVERALL FEEDBACK NETWORK SCHEME.

FIGURE 4.: *LIES (TOPOLOGY)* GLOBAL CONFIGURATION.

The environment is captured through microphones and is sent into the system, after being converted into a digital signal. The digital feedback network (DFN) transforms the signal and sends it back into the environment, modifying it, where it is then captured recursively. AFN stands for



analogue feedback networks The performer is within this process and acts as mediator by changing the internal variable of the system through a control surface, which is in turn mapped to the system's component parameters. As can be seen in Figure 4., the elements within the broken line act as a single meta-system, while the audience is a perturbation inside the environment.

LIES (distance/incidence) 1.1

DARIO SANFILIPPO – LIES (DISTANCE/INCIDENCE) 1.0 – VIDEO EXTRACT OF THE WORK PERFORMED IN GRAZ, AUSTRIA, ON THE 30TH OF MAY 2012, FOR THE MITTWOCHS EXAKT CONCERT SERIES.

LIES (distance/incidence) is in some aspects similar to the previous project, but it necessarily works with both analogue and digital audio feedback networks. Here, the digital network consists of transformation units with processes such as frequency shifting, shelving EQ, recursive nonlinear distortion, reverb and comb filtering; however, feedback coefficients are below the self-oscillating threshold, the feedback delay is set to 1024 samples, and each unit has a different sensitivity to the intensity and spectral profile of input signals.[18] The analogue feedback network consists of two microphones, two or more loudspeakers, and one or more subwoofers (See Figure 5.). When enough amplification is provided, self-oscillation occurs and the digital network enters an operating state. The two interdependent and interacting networks thus act as a single complex sound generator. Here, too, no randomness or automated processes are implemented in the system, but, unlike the performance project previously described, the internal variables of the system are static. The performer interacts with the system through the microphones by varying the distance from the loudspeakers and the angle of incidence with which they capture sounds. This alters the relation that the system has to itself, and explores the anti/resonances of a 3D environment that is constantly mediating the whole process, resulting in an interdependency between environment, system and performer (Di Scipio, 2011), which can be called a 'performance ecosystem' (Waters, 2007).

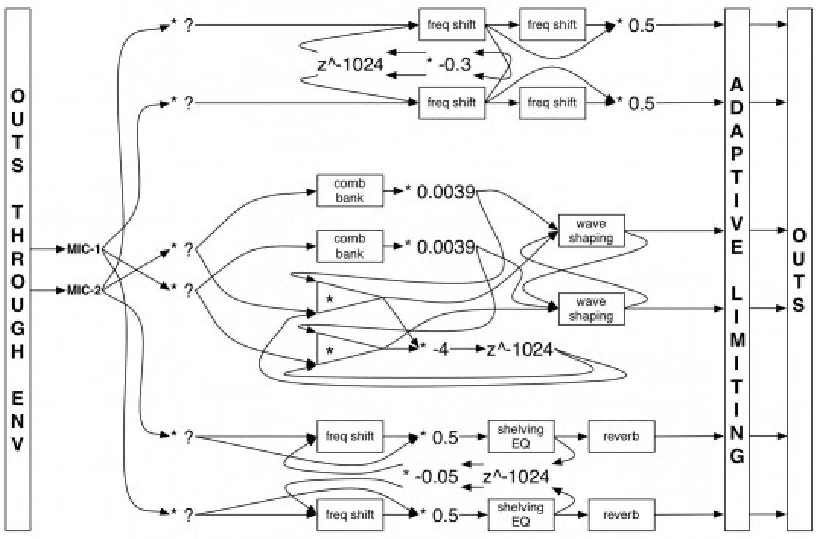


FIGURE 5.: *LIES (DISTANCE/INCIDENCE)* FEEDBACK NETWORK.

This diagram shows the signal flow of the version 1.1 of this work. The “?”s indicate that the input gain for each sub-network is to be adjusted according to the environment characteristics, in order to properly calibrate the system and achieve working behaviours.

SD/OS (presence)

The *SD/OS (presence)* sound installation implements the same system as in *LIES (topology),* but using only specific configurations of the internal variables for each version of the work. Here the system is free to express its own aesthetics and autonomous character, with a particular emphasis given to fragile and unstable behaviours and sensitivity to external factors. The internal variables of the system are fixed, yet dynamical outcomes can be achieved from the interactions of the sonic flows. Using acoustic feedback through microphones and loudspeakers, a coupling with the environment is established, resulting in a system whose behaviour is mediated by the characteristics of the environment itself (anti/resonances) and perturbed by the sonic events within it (audience, etc.). The system thus affects (listens to) itself through the space, and the audience un/intentionally modifies the environment and possibly adds perturbations (noises). The core concept of this work highlights how the system performs different behaviours when its self-relation is altered. Namely, the position of microphone(s) and loudspeaker(s) is chosen so that they point towards each other, creating a direct connection through an acoustic flow. The major role of the audience constitutes physically interfering with this connection by standing in between the system’s terminals (microphone and loudspeaker). The audience, therefore, is not a passive listener, but an active element in the final result.

DARIO SANFILIPPO – SD/OS (PRESENCE) 2.0 – PRESENTED AT THE BANGOR UNIVERSITY FOR THE INTER/ACTIONS SYMPOSIUM, 10TH-12TH OF APRIL 2012.

SD/OS (self-motion) 1.0

FIG. 6. SD/OS (SELF-MOTION) – PHOTO OF THE INSTALLATION RUNNING AT THE CONSERVATORY OF

LATINA FOR LE FORME DEL SUONO FESTIVAL, 22TH OF MAY-2ND OF JUNE 2012.

SD/OS (self-motion) is a sound installation implementing a system based on analogue audio feedback networks. The attempt for this work is to reduce the setup to a certain number of basic elements, which eventually build a network of interacting nodes. The system implemented in this sound installation is realised using an equal number of electro-dynamic microphones, piezo microphones, loudspeakers, and amplifiers. Loudspeakers face upward and the piezo microphones are placed over the woofers, while electro-dynamic microphones point towards the loudspeakers, perpendicularly, at a distance of about 0.5 meters. The network topology is bi-circular with two overlapping feedback loops: one with piezo and monitors, the other with microphones and the same monitors. Both loops take the longest path. For example, if we consider a 3rd-order network, the path is as follows: in1-out2-in2-out3-in3-out1-in1. (See Figure 7.) This results in longer feedback delays, and as a consequence acts as a smoothing factor in the dynamical behaviour of the system, while, on the other hand, it maximises the possibility of emergent phenomena, since the number of peaks in the spectral profile of a feedback loop is proportional to the delay length. The loop with piezo microphones operates at the minimum level possible to let self-oscillation occur, while the loop with microphones is immediately below the self-oscillating edge. Being in an edge-state between operating and non-operating is what makes the system particularly delicate and sensitive to external perturbations in the environment. Piezo microphones produce sounds, which in turn excite them, resulting in further effects to the outgoing sound. The changing sounds can either trigger or suppress the feedback loop between microphones and loudspeakers, while the Larsen tones can in turn dampen, suppress or reinforce the loop with piezo microphones. This establishes a contrast/support relation between the two loops, and as a result produces a dialectic between the emergence of sound, and the emergence of non-sound.

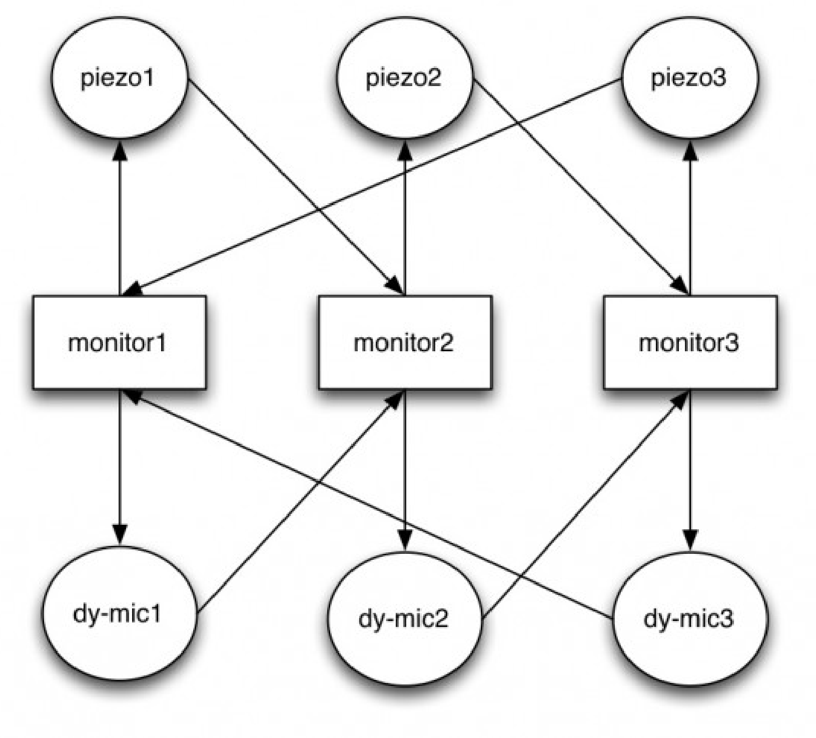


FIGURE 7.: *SD/OS (SELF-MOTION)* FEEDBACK NETWORK SCHEME.

Conclusion

This paper can be considered as a survey on feedback systems, where theoretical concepts as well as creative practices and techniques have been discussed. In this framework, some observations inherent to the aesthetics of feedback have been proposed, and this will hopefully serve as a stimulus for further analysis on this practice. Such an approach to sound creation puts us in a different position in relation to what perturbation can be; rather than thinking of it as something to be filtered and cancelled, in this context it is considered a creative source, and what comes out of this approach is, as was observed by Di Scipio (2008), a realisation of von Foerster's *order from noise* principle (Von Foerster, 1960). The opposition between simplicity and complexity is to be abandoned, as these can actually coexist and merge in such systems. Furthermore, the subversion of technology through feedback can be a constructive practice to discover new solutions in sound art. This does not imply a material alteration or malfunction; subversion occurs through pushing the technology towards its functional extreme so that its former identity is lost. Sound was considered from a different perspective: as a manifestation of anarchy, as a source of fruitful perturbation capable of shaping itself, and not as a passive material to be organised.

Footnotes

1. The Larsen effect (from the scientist who first studied the phenomenon, Søren Absalon Larsen) happens when, if enough amplification is provided, the sound captured from a microphone connected to a speaker is reproduced and again captured, recursively, resulting in a positive feedback generating tones (called Larsen tones) from the iterated amplification of a signal. [↩]
2. C. P. Boner has published several papers throughout the '60s on the behaviour of Larsen phenomena related to room acoustics. See for example Boner 1966. [↩]
3. Collins introduces his book on hardware hacking (2006) as "[…] a guide to the creative transformation of consumer electronic technology for alternative use" (p. XIII). Circuit bending is commonly referred to as the "art of short-circuiting", practically altering the circuit of a device through creating new connections and adding variable resistances or other devices in order to modify the signal flow [http://www.anti-theory.com/soundart/circuitbend/]. With circuit bending and hardware hacking it is likely to create closed loops in the circuits, and thus feedback. [↩]
4. Something which goes beyond what it formerly was and displays new characteristics. [↩]
5. David Tudor referred to his feedback systems as being his friends, and he was possibly one of the first who considered a music system as an entity with a personality. He also described his research as an attempt to discover what was already inside the devices he used (Tudor cited in O'Connell 2008), and in this way expressed the concepts of emergent, radically new behaviours, and sound out of noise. [↩]
6. Chapter 2 of the present article is based on a chapter from a paper presented at the International Computer Music Conference in 2012. See (Sanfilippo & Valle, 2012b). [↩]
7. It is worth citing a clear example by the Japanese improviser Toshimaru Nakamura, who has worked with feedback systems for more than twenty years. Speaking about his performance with the No-Input Mixing Board, he describes in an interview how very slight adjustments to a knob can have huge effects in the overall outcome. "No-input, Sachiko M and Toshimaru Nakamura," www.youtube.com/watch?v=Tl8IMc-8-N8, starting at 5'05" (uploaded on 2006). [↩]

8. The term homeostasis was first introduced by biologist Walter Bradford Cannon in his work The Wisdom of The Body (Cannon, 1932) as an extension of the idea of milieu intérieur by Claude Bernard (Bernard, cited in Bonobeau and Dessalles, 1997), who first formulated the concept. The definition by Cannon seems to coincide with the birth of biological cybernetics (François, 1999), although the term was eventually generalised by Ashby as a property of all systems in dynamical equilibrium. (Ashby, 1942) The term homeorhesis was first coined by C. H. Waddington in 1940 to describe a property opposed to that of homeostasis. [↩]
9. As an example we can consider the shape that emerges in a flock of birds: each bird locally interacts with the nearby birds and this influence is indirectly distributed over all the birds; they all influence each other. None of them is aware of the global shape that arises from the low-level behaviour. [↩]
10. "However a stochastic process has a direction, it is a motion towards the mean […]". J. Bronowski cited in (Di Scipio, 1994) citing (Morin, 1972). Translation from Italian. [↩]
11. The situation I refer to is that in which the inter-relation between sonic events is given by the composer: she/he puts together sounds according to what she/he feels hearing them together (or according to some other approach which might not be based on aesthetic sensibilities). If you take the composer away, there is no longer a relation between sonic events unless the characteristics of the sounds themselves produce audible interferences, such as in the phenomena of beats (the interference of two sounds of slightly different frequencies). [↩]
12. Salvatore "Antirez" Sanfilippo, a professional programmer, described to me how the programming language or database used in a project can influence the final result. [↩]
13. Cascone (2000), when describing the aesthetics of failure, states that "[…] more specifically, it is from the "failure" of digital technology that this new work has emerged: glitches, bugs, application errors, system crashes, clipping, aliasing, distortion, quantisation noise, and even the noise floor of computer sound cards are the raw materials composers seek to incorporate into their music" (p. 13). [↩]
14. (See Di Scipio 1994 for his formulation about sound and form. [↩]
15. The name of such filters comes from the particular shape of the spectrum they generate, resembling that of a comb. [↩]
16. As the feedback coefficients can be greater than unity, in order to prevent blow up, adaptive attenuation is applied to levels exceeding 0 dBFS. Signals can temporarily reach higher values, but the system has been tested in many configurations. Results are stable (non-exploding) and safe from clipping, as 32-bit internal resolution is used to represent signals and sounds are appropriately scaled before being sent to the digital-to-analogue converters. [↩]
17. See Figure 3. for a scheme of the overall network. [↩]
18. For further details on the implementation of this work see (Sanfilippo, 2012). [↩]

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Bio

Dario Sanfilippo was born in Agrigento, Italy, in 1983. He is a freelance composer, performer and sound artist whose research is focused on the study and exploration of complex dynamical feedback systems for non-conventional sound synthesis, improvised human-machine interaction performances, and autonomous sound installations. His work and research has been presented in international festivals and contemporary music events such as AudioArt Festival, Curva Minore Festival, Acoustic Fields Festival, AudioVisiva Festival, Quiet Cue concert series, Live!iXem Festival, Logos Foundation series, as well as Universities like Naples' L'Orientale, Music and Performing Arts University of Vienna, University of Graz (IEM), Bangor University, Queen Mary University of London; selected for international conferences such as International Computer Music Conference 2012, Sound and Music Computing 2011, Digital Music Research Network 2011, Colloquium of Musical Informatics 2010 and 2012, INTER/actions Symposium 2012; and published by record labels such as Creative Sources, Die Schachtel and Idroscalo, and journals such as Computer Music Journal. He graduated in Music and New Technologies at the Conservatory of Trapani, and is currently attending the Master's Degree in Electronic Music at the Conservatory of Naples, in the class of Agostino Di Scipio.

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