Environment-Mediated Coupling of Autonomous Sound-Generating Systems in Live Performance: An Overview of the *Machine Milieu* Project.

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ABSTRACT

Today, a large variety of technical configurations are used in live performance contexts. In most of them, computers and other devices act usually as powerful yet subordinated agencies, typically piloted by performers: with few notable exceptions, large-scale gestures and structural developments are left either to the performer's actions or to well-planned automations and/or composing algorithms. At the same time, the performance environment is either ignored or 'tuned out', ideally kept neutral with regard to the actual sound events and the overall performance process. This paper describes a different approach. The authors investigate the complex dynamics arising in live performance when multiple autonomous sound systems are coupled through the acoustic environment. In order to allow for more autonomous and adaptive – or better: ecosystemic *– behaviour on the part of the machines, the authors suggest that the notion of* interaction *should be replaced with that of a permanent and continuing* structural coupling *between machine(s), performer(s) and environment(s). More particularly, the paper deals with a specific configuration of two (or more) separate computer-based audio systems co-evolving in their autonomic processes based on permanent mutual exchanges through and with the local environment, i.e., in the medium of sound only. An attempt is made at defining a self-regulating, situated, and hybrid dynamical system having its own agency and manifesting its potential behaviour in the performance process. Human agents (performers) can eventually intrude and explore affordances and constraints specific to the performance ecosystem, possibly biasing or altering its emergent behaviours. In so doing, what human agents actually achieve is to specify their role and function in the context of a larger, distributed kind of agency created by the whole set of highly interdependent components active in sound. That may suggest new solutions in the area of improvised or structured performance and in the sound arts in general.*

Overall, the approach taken here allows for an empirical investigation of the mobile and porous boundaries between the kind of environmental agency connoting densely connected networks, on one hand, and the freedom (however restricted) in independent and intentional behaviour on the part of human agents intruding the ecosystem, on the other.

1. INTRODUCTION

The research documented here stems from the collaboration between two sound artists implementing and exploring complex dynamical systems in the context of live performance [1, 2, 3]. Born out of hands-on experimentation in the authors' private workspace, the collaboration started in 2014 and developed through different stages until 2016, when was given the project title *Machine Milieu*.

In usual "performance ecosystems" [4], computers and other devices act as powerful yet subordinated agencies, typically piloted by practitioners, such that large-scale gestures and structural developments arise from either performer's actions or well-planned automations and/or composing algorithms. To a large extent, the environment is either ignored or 'tuned out', perceived as ideally neutral with regard to the actual sound events and musical gestures. Our research aims instead at establishing a structural, multi-directional connection between the three main agential nodes in such a performance ecosystem performer(s), machine(s) and environment(s) as something entirely mediated by the sounding environment itself. The basic idea is to let every agency develop and sonically manifest itself as a function of all of the other agencies involved. Essential is an effort aiming at having the machines (computers) somehow make sense of what happens sound-wise in the local, shared environment, and act accordingly.

One may say, with an altogether different terminology, that the goal here is to create and situate a performative agency providing the conditions for the emergence [5] of a *self* through the perturbation and the exploration of the surrounding sound environment, the latter representing a complex structured ensemble standing for *non-selves* i.e., standing for *other selves* [6]: a coherent system develops a sense of its self as each of its components affects all of the others, while the environment to which it is structurally coupled is actively and inevitably influencing the whole process, i.e., the behaviour of the single components as well as their interactions [7]. In essence, this is a recursive process consistent with Gregory Bateson's definition of *information* as something built and processed by a (cognitive) system coupled to an environment [8]. The performative agency we aim to design and explore is a 'minimally cognitive' system [9, 10] that construes information about its surrounding in order to establish a positive, indeed constructive relationship with the forces present and active in the surroundings. (To what extent that may be pursued through 'feature-extraction' methods and 'sound descriptors' is, in our view, a central issue of theoretical as well as technical relevance, yet we will have to leave it for a more specific discussion, in another paper). In a batesonian perspective, a bit of information is notoriously defined as a "difference which makes a difference": a differential quantum that travels and spreads across a circuit and undergoes an overall process or recursive interactions and transformations. As an ensemble, the recursive process has no single site of agency, no specific site or centre of global and unilateral control over the ensemble or any of the single parts. However, while the interacting 'parts' let emerge a 'whole' a system that cannot be reduced to the single separate parts the emergent whole in turn may eventually bias or bend the individual parts in their further doing (*downward causation*) [11] and thus reinforce the ensemble in its consistent and distinct dynamical behaviour.

We call *music* the traces of such a process in sound.

It should now be clear why we are not referring to our collaboration simply as a *duo* (two human agents, each 'playing' its own device, overlapping its own sound output to that of the partner): it would be more appropriate to think of the overall performance ecosystem explored here as an integrated, hybrid organism, an 'assemblage' made of humans, machines and environment(s) as well as of a rich set of mediations and negotiations allowing for their interdependency. The structure of this assemblage is essentially that of a complex dynamical system [11, 12]. We believe that the realisation of a distributed and parallel interaction like the one described here, based on a tight sound relationship to the actual performance site, results in a peculiar performative approach and opens to innovative aesthetic developments in the practice of live sound art.

2. THE IMPORTANCE OF AUTONOMY AND FEEDBACK IN MUSIC SYSTEMS

The condition of mutual influence is fundamental and implicit in any notion of interaction. In our view, however, in order to achieve such a condition both humans and machines should be capable of autonomous dynamical behaviours so that they can act (sound-wise) in the environment while also adapting to the (sounding) actions of other forces and systems. In that sense, automated not to be confused with autonomous systems are not at all adequate: in designs based on pre-determined or stochastic scheduling of sonic events, for example exploiting pseudo-random number generators and other abstract formal rules, musical articulations are operated in a domain that is both independent of, and fundamentally (in)different to, the domain where musical action takes place namely, *sound*. Across the many levels of the performance ecosystem, we avoid relinquishing action to any such 'independent' agency, and try to lean as much as possible on sites of agency situated in the experiential milieu of sound, namely as constantly mediated by the surrounding environment. On a general level, defining autonomy in music systems is a rather difficult task [13]. In a bio-cybernetic view [7, 14] autonomous agency in a domain requires a structural openness, a constant exposure to an 'external' space. Different from automation, a fruitful notion of *autonomy* includes an operational openness to heterogeneous forces and actors in the environment: the system's necessary closure (defining its identity, its self) consists in a loop onto itself through the environment, which provides a pool of possible sources of information, and the space where other agencies are themselves active in their autonomic process.

Leaning on independent sources of information and agency leads to a lack of contextuality and coherence between sonic contents and musical developments. An approach based on autonomous dynamical systems can reveal crucial and perhaps necessary in order to avoid a certain lack of organicity and shape up a performative situation more consistent with the metaphor of a live (living) practice and a live (lived) experience of sound and music.

The implementation of multiple feedback delay networks is a very central factor in our practice, for the peculiar dynamical characteristics they exhibit seem well suited to human-machine interactions in the context of music performance [15]. In the particular case of *Machine Milieu*, we have a distributed and structural interaction between all of the variables and domains involved in the electroacoustic chain (as one can see by following the oriented arrows in Figure 1): from microphones and loudspeakers to the digital processes, as well as to the performers and the environment itself. The recursive interactions born in the feedback loops allow the overall process to develop from the micro-time scale properties (signal contours and related timbral percepts) to the formal unfolding and behavioural transitions in the systems. Because of the nonlinearities included at various levels (due to the particular audio transformations, as well as to the circuitry of the analog transducers involved), any slight perturbation recirculates in the process in a way that can potentially have significant short and long-term effects for all of the variables and domains, resulting in a very delicate and non-trivial coexistence and binding of all components in the live environment. When detected "differences" in the medium are truly informative (to use batesonian terminology, when information is indeed construed in the coupling of two systems), a larger process is started in the context of which sound is revealed capable of shaping itself in an organic and expressive way: thus, the agency of the overall system allows for not only the emergence of specific timbral or gestural shales, but also of larger-scale articulations (musical form).

Indeed, besides being central to any approach of physical modelling of sound [16, 17, 18], in a larger cybernetic perspective, feedback mechanisms [19] are reputed the key for the modelling of artificial forms of intelligent behaviour, perhaps aimed less at the simulation of something already existing, and more at the manifestation of emergent entities with their own personality (or, in our case, musicality). Information and computation, as referred to any entity having cognitive functions, were historically defined by Heinz von Foerster as recursive processes [20] in a system having sufficient complexity in dealing with the environment and the minimal requisite variance (as defined by W. R. Ashby [21]) in order to be stable and support its self.

3. OVERVIEW DESCRIPTION OF *MACHINE MILIEU*

3.1 Setup

The main components and relationships in the *Machine Milieu* project are schematised in Figure 1. The overall

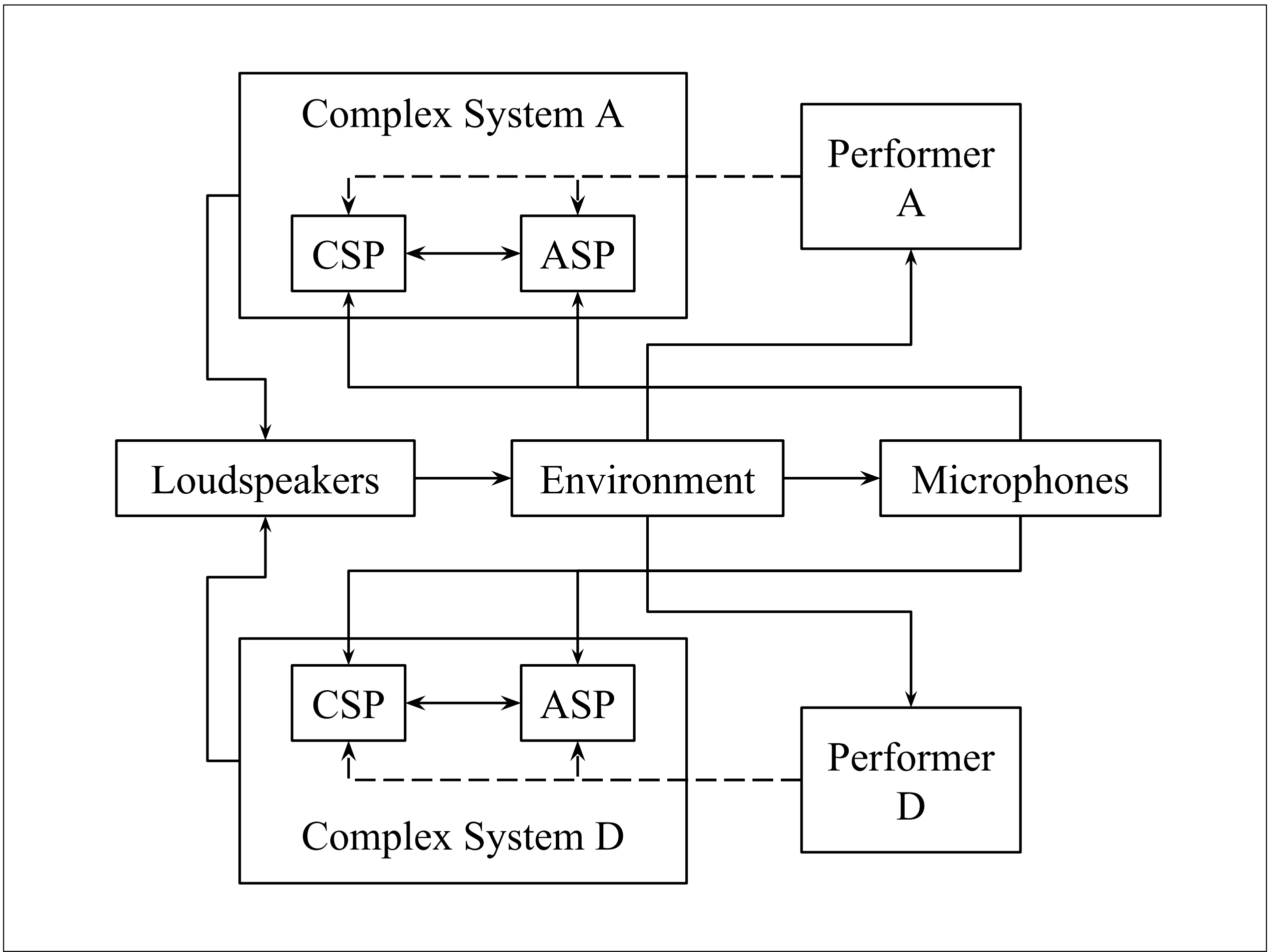

Figure 1. Overall configuration of the *Machine Milieu* project. Oriented arrows represent the signal flow across the network. By "environment" we mean here the performance room, with its specific acoustics, i.e., the spatial niche which actually shapes the sound produced by the loudspeakers (as well as by the performers and the audience). The "complex audio systems" are sound-generating systems consisting of time-variant networks of nonlinear processing units, interrelated through positive and negative feedback loops. Each complex system includes audio signal processing (ASP) units as well as control signal processing (CSP) units: the first include DSP algorithms meant to process sound signals; the second include DSP algorithms meant to analyse incoming signals and turn that signal descriptor data into control signals useful to drive the states variables of the ASP. These two subsystems are mutually influencing each other. By dropping the two "performers", we can still rely on an autonomous, unsupervised dynamical system.

setup includes two performers (called A and D); two sound-generating systems (real-time computer-operated signal processing algorithms) both including audio signal processing (ASP) as well as control signal processing (CSP) units; a set of microphones; a set of loudspeakers; and of course a performance space (Environment).

The interrelatedness among the involved components can be clarified as follows. Each of the two performers' actions is a function of the sonic context as perceived in the environment. The state of each of the two audio systems is dependent on the sonic context (captured through microphones and internally analysed) as well as on the performers' direct access to the internal values of both the audio and the control signal processing algorithms included. Finally, by making audible the computer processing output at specific positions in the local environment, the loudspeakers act as the very means that elicit the performance space's acoustical response, thus affecting both the performers and the computer processes.

In this general setup, performers may eventually be dropped out. In that case, we have an entirely autonomous and unsupervised ecosystem consisting in the coupling of computational devices, a number of transducers and the room acoustics.

3.2 Technical aspects

The complex audio systems implemented are time-variant feedback delay networks through which a number of nonlinear components are interrelated. Both positive and negative feedback mechanisms are established in order to maximise counterbalancing structures in the network and achieve higher degrees of variety in the resulting behaviours. The two audio systems could be divided into at least two subsystems, although they should always be considered as a single unit given their structural synergy. All signal processing is done through Pure Data Vanilla [1] and Kyma/Pacarana [2], and use exclusively time-domain processing methods, with the microphone signals as inputs. (Frequency-domain methods are set aside mainly for reasons of economy in computational load.)

The ASP units include:

– asynchronous granulation

[1] http://msp.ucsd.edu/software.html
[2] http://kyma.symbolicsound.com/

- various (re)sampling methods
- waveshaping (nonlinear distortion)
- feedback and cascaded FM
- PWM pulse-width modulation
- simple high-pass and low-pass filtering, as well as all-pass and comb filtering
- delay networks (FDN, feedback delay networks)

We dispense ourselves with the details: the listed audio signal processing methods, and the related control variables, will be certainly well-known to the reader. However, it should be noted that, while normally working in the sub-audio frequency range, control variables (CSP outputs) are actually worked out here as *audio* signals in our implementation. Therefore, while maintaining their *control* function, here they are occasionally mapped in the audible range and accordingly used as modulation signals (i.e., with audible spectral changes). It might also be worth noting that FDN configurations may act in several different ways: here, they are often used to dispatch signals across the set of audio processing methods, sometimes creating recursive paths, and thus contributing to articulate layers of sonic transformations through larger time frames; yet in certain circumstances they will also act in a more typical way, i.e., as reverb units (in which case included variables are those you would expect from a reverberator unit).

The CSP units involve either simple mappings or more elaborate transformations of data created by the real-time analysis and evaluation of a limited range of sonorous aspects in the audio signal. There is today a very large body of work on 'feature-extraction' and 'descriptors' (see related topics and broader questions in [22, 23, 24]) which represents for us a relevant shared common knowledge. However, in our project we do not rely on any library of descriptors or other existing resources of the kind. Rather, we prefer implementing ourselves simple but efficient methods matching specific requirements, that of implying very limited computational load (all processes must be highly efficient under real-time computation constraints) and that of coming up with a small but varied set of hypothesis on broad but auditorily important aspects of the sound in the performance space.

In our work, the main sonic features subject to tracking algorithms include:

- loudness
- density
- brightness
- noisiness
- roughness

Loudness estimations are obtained as RMS values calculated over subsequent windowed segments of the incoming signal (as an alternative, we sometimes integrate amplitude values over the signal chunks). Windowed segments can be of different sizes, and the size can also change during the performance as a function of some other control signal. *Brightness* and *noisiness* are calculated via original CPU-efficient algorithms operating in the time domain (zero-crossing rate, differentiation, spectral median) and/or via averaged responses of large-width band-pass filters. *Roughness* estimation uses peak envelope for the analysis of transients. In contrast with those, *density* is probably a rather unusual kind of descriptor, and is understood here in terms of RMS values calculated over multiple extended signal segments (in the order of few to several seconds), eventually correlated with peak envelope tracking (attack transients).

In actuality, as anticipated above, the analysis data are for us a source out of which, with a little signal processing, we can shape up multiple *control signals*. Indeed, the observed sonic characteristics are then combined or used individually and eventually mapped (linearly or nonlinearly) over value ranges compatible with those of control variables in the ASP algorithms. But they are, too, more extensively processed (via simple filters, delay units, etc.) to create a variety of viable control signals. We acknowledge a creative role in the shaping of several control signals out of one or anyway few sound sources: in this perspective indeed a broader conceptual shift is taking place from "interactive composing" to "composing the interactions" [1]. We also explore the idea of higher-order analytical data created by statistics and measurements of (lower-level) extracted information. Control signals based on higher-order data are especially useful to affect longer-term developments in the variable space, thus achieving a sense of global orientation across prolonged sound textures and global musical shapes.

Once applied to audio processing variables, control signals will affect either subtle or overt changes in the sound, and thus – because sound is the very source of control signals – they will loop back onto themselves, indirectly affecting their own subsequent unfolding. This is feedback in the low-frequency domain (second or higher-order emergent patterns heard as longer-term patterns or events). The specific final mapping is what will determine whether the relationship between variables and control signals makes for a positive or negative feedback loop.

It is important to notice that, as 'heard' by any of the individual ecosystem components, the sonic environment comprises 'one's own' sound (the particular component's) as well as the sound output of other sources in the environment (including the environment itself, if not acoustically dry or idle). Accordingly, of special interest is the generation of control signals based on feature-extraction methods somehow able to distinguish and track down, from within the total sound, those events or properties coming from one's own contribution in the total system and those coming from others.

3.3 Modes of performance

The complete resultant infrastructure can be seen as a densely interconnected network. Densely connected network systems have been fruitfully investigated in the context of algorithmically based live performance practices e.g., The Hub [25, 26] and the early League of Automatic Music Composers [27], and resurface today in collective live coding practices. In [26] a discussion is proposed as to the ecosystemic (or simply technical) nature of such networked performance situations. Here, we consider that in those examples the network interconnectedness typically relies on abstract, formal protocols of music data and their transfer along lines of digital connections (MIDI, OSC, etc.), if not on more general computer network protocols, un-related to music. Leaning on previous works [1, 2, 3], the main sites of agency in the network are better understood as components in a *sonic* ecosystem, i.e., they are structurally coupled in the medium of sound. The individual functions as well as the interdependencies among the ecosystem components remain under the spell of the permanent mechanical (acoustical) mediation of the local environment. Taking up anthropologist Tim Ingold's critique of the widespread notion of *network* (see [28], p. 70), in our case the connections out of which a larger dynamical ensemble is formed, are not between *nodes* but rather along *lines* (acoustical propagation in the air). Understood as ensembles relinquished in a physical (and hypertechnologised) environment, and acted upon (or let unsupervised) by human agents, such situated networks of sonic interactions make it difficult to tell what is the place and meaning of 'computing' in such configurations of humans and nonhumans [29]. At the same time, they allow us to emphasise the very materiality and situatedness of algorithmic structures, quite usually considered as purely formal constructions disconnected from and independent of any sensible context [30].

By entering the otherwise unsupervised autonomous system, performers have two fundamental ways through which they can interact with the machines. On one hand, they can operate directly on the ASP and CSP, namely by manually varying the variables in the audio transformation algorithms (via a computer GUI or an external controller), or by reconfiguring the mapping and the dispatching of control signals. Alternatively, performers can for example change the position of the microphones in the performance space, or creatively modify the frequency response of microphones with small resonators such as pipes or boxes.

Either ways, relying on an attitude of improvisation certainly represents a straightforward and consistent approach when it comes to performing with feedback systems [31, 32], especially in consideration that improvisation is itself intrinsically a feedback process (current actions are mostly determined by carefully listening and promptly reacting to whatever results from earlier actions). Indeed, we have often adopted a largely improvisational approach during the *Machine Milieu* sessions we were able to have so far. However we thought that some alternative ways of going should be considered: even when 'radical', improvisation may lead to higher-level patterns and gestural behaviours which all too directly connote (and delimit) the range of possible interesting situations. More particularly, we felt that improvisation would be good in order to explore specific aspects of the network dynamics in our performance ecosystem, but could prevent us from understanding and creatively investigating other aspects, specifically with regard to the potential autonomic behaviours it may engender.

We explored two main alternatives. The first is actually just a small shift away from radical improvisation: because the two autonomous sound-generating systems were capable of exhibiting peculiar dynamical behaviours, we tried to contrast that attitude with our interventions in an attempt at forcing them to a somewhat more static behaviours (prolonged sonic textures, rich in short-term variations, but consistent and 'static' on the longer run). In systemic terms, this way of acting in the system is a form of negative feedback, and very difficult to realise: the artefacts and traces of such an almost impossible task actually resonate in the musical unfolding of the performance itself.

In the third approach, instead, there is a sharper separation between performer actions and the overall ecosystem process. The goal, in this case, is to do as least as possible in order to let the systems start sounding in the room thus eventually interacting between themselves. In this situation, each one system is actually interfering with its own sound as heard in the surrounding environment but through the other system. It was interesting to hear them creating sonic materials and gestures somewhat different form those generated when operating each for itself. After setting up the 'initial conditions' (tuning of variables, placement of microphones and speakers), we would let the overall process develop until satisfying behaviours emerged; eventually, when the potential seemed to have exhausted, we intervened slightly altering the setup and defining new initial conditions, letting the process manifest new emergent behaviours (we would then keep proceeding like that for a few times).

In retrospect, the three approaches taken are all consistent with the *Machine Milieu* project. They represent for us different ways to investigate the boundaries between, on one hand, the kind of environmental agency [14] connoting our performance ecosystem and, on the other,the (small but significant) margin of manoeuvre in the independent, targeted and intentional actions taken on by human agents. What remains constant, and central, across these different performative approaches, is the notion that the main system components involved (either including or not including humans) are permanently coupled to each other. Properly speaking, they do not interact there is no discrete event in space that can be called an interaction and that might be entirely independent in time from (few or several) earlier exchanges. Rather, there is a continuing flow of mutual exchanges or reciprocal determinations. Within an ecosystemic perspective, the notion of interaction is not at all satisfactory, and should be replaced by a notion of structural coupling (itself a term coming from general system theory, and more specifically connoting the way living systems use to deal with their environment [7]).

4. CONCLUSIVE REMARKS

In this paper, we have overviewed some artistic research issues central in the *Machine Milieu* project, in the context of which we explore the environment-mediated coupling of autonomous generative audio systems in live performance. By creating a hybrid (digital, analog and mechanical) assemblage for creatively experimenting with the interdependencies among situated autonomous systems, we try to open a space for performers and listeners to ponder questions of context awareness, ecosystemic dynamics, materiality of algorithms in daily life, while also empirically touching on more fundamental questions of autonomy and dynamical behaviour, on the other. We are inclined to consider such notions crucial in music systems intended for live performance, and this is especially true when as we do here one replaces a notion of interaction (nowadays too charged with misunderstandings and often treated in trivial ways) with the systemic notion of "structural coupling" (among machines, performers and environments). The implicit statement is that, in line with larger theoretical efforts today emphasising the environmentalisation of agency (or the agentivity of overly technologised environments) [14, 33], the realisation of a kind of distributed musical agency may result in an understanding of musical creativity as a phenomenon emergent and indeed ecosystemic.

Furthermore, the dialectical interweaving of individual action and autonomous ecosystemic processes, allows for a variety of performative practices to be explored which, on the sole basis of sound-mediated interactions, projects the interdependencies and codependencies of part and whole i.e., of systems and subsystems, as well as of structurally coupled but different domains to the level of larger scale developments in a performance: any notion of *form* becomes then closer to the ensemble of component parts either contrasted or harmoniously interwoven among them in their temporal and spatial activity. In the particular experience reported above, we have touched on this issue when contrasting the autonomic behaviours of unsupervised environment-mediated machines, against a direct and radical improvisation approach of practitioners entering the performance ecosystem.

In further work, we expect that approaches such as the one taken here may contribute to a deeper understanding of what can be considered *live* in sound art and music performance with live electronics. Different from other authors who have tackled this issue [34, 35], we are convinced that, in and of itself, the sheer presence of human performers in the context of and in the foreground of an overly technologised playground is insufficient to clarify hybrid assemblages merging human and machine agency such as deployed by in the *Machine Milieu* project. The implicit and unquestioned opposition of living (hence cognitive) vs non-living (hence non-cognitive) systems reflecting in other similar dualities, such as human vs. inhuman, natural vs. artificial, etc. is today probably untenable as a basis to understand what (or who) does live in live electronics. Maybe we should look for what is no more human in living systems, and what is already all too human in artificial (i.e., humanly construed) systems.

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