Study in three phases

An Adaptive Sound Installation

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ABSTRACT

Study in three phases is an adaptive site-specific sound installation that includes 22 solenoids placed on metallic arches that surround visitors and react to environmental perturbations, creating a self-regulating soundscape of metallic hits that serves to renew the visitors' acoustic perspective. Adaptivity is a crucial aspect of the work: Similar perturbations will not generally cause similar reactions from the installation based on past interactions, thus allowing evolution over time to play a key role artistically and technically. This article discusses the author's position on adaptivity in music interaction and composition and reports on the technical and artistic aspects of the installation.

APPROACHING ADAPTIVE SYSTEMS

An adaptive system is one capable of modifying its internal variables (state) as a function of its inputs in order to fulfill a task [1,2]. Adaptive systems are increasingly used in musical interaction because of their adaptability to environmental perturbations (noise, turbulence), thus creating a connection between audience and system. This connection is deeper compared with nonadaptive systems: In a generically interactive installation, the system directly reacts to the inputs; however, implicit feedback between output and input is relegated to a secondary, almost inconsequential, role. In adaptive systems, environment and system are structurally coupled [3], influencing each other in a circular way. We then consider them as living systems, as organisms. Our behavior toward them therefore differs: We are aware of our effect on a purely interactive installation. An adaptive system is not completely predictable in response, and we wonder if it is building its own knowledge of the environment and how. Therefore, adaptive systems especially in the arts can subvert power relations between humans and systems, allowing new and unexplored interactions.

Adaptive criteria have been successfully applied in several artistic installations (Agostino Di Scipio's series of works *Audible Ecosystemics* [4,5], Michelangelo Lupone's works [6,7], Dario Sanfilippo's series of works *LIES* [8,9], among others), highlighting the importance of further investigations into adaptive systems in music installations.

The most prolific sources of inspiration on these artistic and technological questions are found in systems theory [10], cybernetics [11] and the adaptive systemic feedback approach in music [12]. I have approached adaptivity through an ecological point of view [13], considering system and environment coupled via feedback processes. Then, in order to satisfy the condition that the adaptive system fulfill a task, I asked what "task" means for a musical adaptive system. The only way my system interacted with the environment was through sound (the only sensors for detecting perturbations were microphones), so I tackled this question by forcing the system to preserve the coherence of its sonorous output. A suggestion for achieving this coherence came from the idea of a dynamical score of interactions [14]—a set of interaction rules that dynamically change themselves over time, extracting features from external perturbations to drive the system to a new equilibrium, similar to Di Scipio's idea of composing the interactions of the overall work [15].

These observations led me to four interconnected considerations on musical adaptive systems in developing the installation: emerging behavior, style, system memory and entropic degeneration.

Emerging Behavior

At a global level, adaptive systems show coherence and some well-defined macroscopic properties deriving from local interactions, properties barely predictable solely on the basis of the rules that drive single parts of the system [16]. This means that adaptive systems show an emerging behavior. The emergence closely connects the system and its surrounding environment. If the former changes, the latter does too; this change is reflected in the system, in a constant process of adaptation.

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Style

The "style" of an adaptive system has been defined by Lupone in the context of sound installations [17] as the identity of the work—meaning, the organizational invariants of the acoustic material. These invariants answer to compositional criteria, e.g. temporal disposition of acoustic events, data correlation, congruence of control data coming from installation sensors, and relations between inputs and activated processes. The style is a set of rules (and exceptions) set by the composer and reflects the composer's artistic practice [18].

In my artistic approach, I require the musical adaptive system to preserve the style during its evolution—I ask the adaptive system to be style-invariant. Thus style rules should not change once the system is running, either through human intervention or via adaptation; nevertheless, the rules can be refined through analyzing coherence of the results both theoretically and acoustically. Style-invariance is verified at run-time: The installation needs to live in order to adapt to the environment, thus creating a concatenation of those rules and eventually showing the invariance.

Memory

The system may have a memory of its previous states. It is worth noting that the presence of a memory is not sufficient for the system to be adaptive. Taking as an example Alvin Lucier's famous sound art piece *I Am Sitting in a Room*, we can identify a memory because in any new iteration of the process the work preserves its past history; but it is not an adaptive work, since the system's internal variables are fixed. The memory of an adaptive system must be a connection between the system and its evolutionary history rather than a buffer where previous data is stored. The history of the installation's interactions with the environment will affect its response to any new perturbation, especially if there are similar perturbations over time.

Entropic Degeneration

Since during its adaptive process the system can evolve toward disorder and noise, controls to prevent this entropic degeneration must be provided. There are many reasons why such a situation might occur, e.g. users introducing an excessive amount of energy into the system or the presence of chaotic perturbations within the environment. In any case, the system must be able to prune the inputs by interpreting them as not relevant to its evolution.

THE INSTALLATION

Study in three phases [19] is an adaptive sound installation inspired by the architecture of the Goethe-Institut metallic portico [20] in Rome. The artistic aim is to let visitors experience the space where the installation is exposed with a continuously renewed acoustic perspective, creating a connection between audience, installation and environment. Eleven couples of solenoids placed on the arches of the portico create a sonorous path that interacts with visitors, attempting dialogue with the environmental noises modifying the solenoids' behavior.

Artistic Concept

The installation has its deeper roots in my interest in and fascination with mechanisms and patterns on one hand and the world of microorganisms on the other. These concepts found their natural expression in established fields such as kinetic art [21] and physical computing [22]. These concepts can also be traced in my instrumental works such as *Piccolo inventario degli insetti* (Little inventory of insects) for ensemble and electronics [23] or *Autopsia su una marionetta* (Autopsy on a puppet) for ensemble [24]. In so saying, the multiple hits of the solenoids on the arches, driven by adaptive processes, create microrhythmical structures that can resemble a living insect's soundscape, thus creating another layer of integration and communication with the cicadas and natural sounds of the Goethe-Institut garden.

The title of the installation is a nod to the three phases of the alchemical process, referencing its most general and symbolic meaning of matter conversion. These phases have both a technical and an aesthetic meaning: They divide the work into three parts with three clear, different functions. The first phase (decomposition) is symbolized by the solenoids' impulses on the arches of the portico: Single sound clicks distributed along the path allude to the dissolution of the metallic matter of which the arches are composed. This phase includes the conceptual migration from visual to acoustic space: Visitors walking under the portico, before realizing that they affect the installation, are surrounded by clouds of impulses. The discontinuous and pointillistic soundscape contrasts with the continuity of the portico's material. In this way, a dialectical articulation is immediately created between two domains, that of sight and that of hearing. The second phase (purification) is symbolized by two microphones hanging between the arches: They capture all sound events in order to subject them to self-regulation processes managed by the computer. Finally, the third phase (recomposition) sends the results of the processing back to the arches, thus closing a loop and at the same time restarting it. The third phase, more than the other two, strongly exhibits the composer's will and the choices made to let a global behavior emerge from the system.

General Description of the Installation

The 28.8-m-long portico of the Goethe-Institut is made up of 11 iron arches 2.6 m high and 2.7 m distant from each other. Visitors enter through the upper garden, which leads to the beginning or the end of the portico, or through stairs on the main garden, leading to its center (Fig. 1). Twenty-two linear solenoids [25] were placed in couples on the arches, one couple per arch, all controlled by two microcontrollers (Arduino Uno) and specifically designed circuits. Two omnidirectional microphones were collocated under the arches to monitor the environment. Owing to their position, the microphones also captured the solenoids' hits on the arches; thus, the whole installation, after an initial noise burst, continued to resonate in a feedback loop (Fig. 2).

Fig. 1. The metallic arches of the Goethe-Institut portico. (© Claudio Panariello)

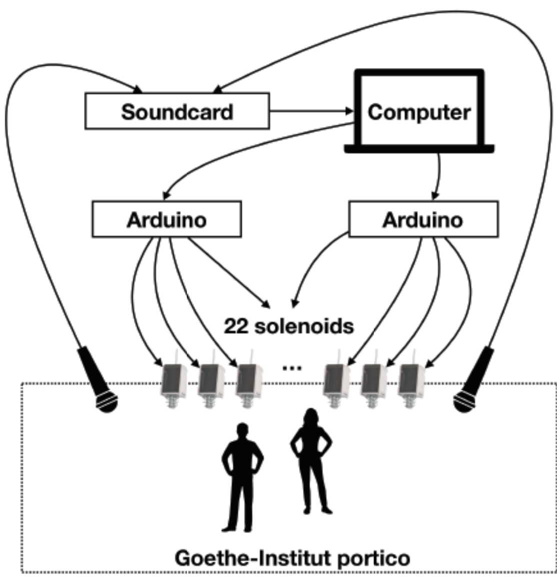


Fig. 2. Sketch of the general structure of *Study in three phases*. (© Claudio Panariello)

Challenges of Installation

Given preexistent architecture, I considered how to integrate the installation concept therein. I aimed to be noninvasive and address aesthetic and practical aspects without neglecting visitors' safety. Practically, I needed to decide where and how to place the solenoids. After empirical testing, I positioned two on each arch (one solenoid per column) as shown in Fig. 3, having found that point to be most resonant. To fix the solenoids to the arches, I glued them into transparent plastic boxes into which two holes were drilled to let the axis come out (Fig. 4a). The boxes were fixed to the arches with a tape designed to resist mechanical tearing and changing temperatures (Fig. 4b). This tape provided stability for the 6-day duration of the installation and meant that no other invasive (or anti-aesthetic) support structures apart from the transparent boxes were needed. Furthermore, the transparent boxes allowed the audience to see the solenoids in action, enhancing the first phase (the decomposition concept) and adding a sense of baroque beauty in the mechanisms' placement.

Sonic Interaction

The portico of the Goethe-Institut is a passageway in the middle of the garden, accessed in multiple ways. Consequently, it was crucial to consider how visitors would enter it.

The garden is a small, peaceful oasis in the chaotic center of Rome, and the portico is an almost protected, secret space in that already confined area. At the same time, being made up of open arches, the portico does not exclude the rest of the garden from sight. It is a space that naturally invites people to walk more slowly and pay attention to the fountain and the trees. People entering the garden from the chaotic outside have time to release tension and slow their pace before arriving at the portico. I therefore imagined an adaptive soundscape adjusting itself to visitors' pace, responding to their perturbations or trying to catch their attention upon their approach. Visitors would then experience that confined space from unusual acoustic perspectives, having to interact with a massive yet gentle living organism. The installation adapted to environmental noises through a combination of two strategies, one based on generative algorithms and the other on negative feedbacks [26].

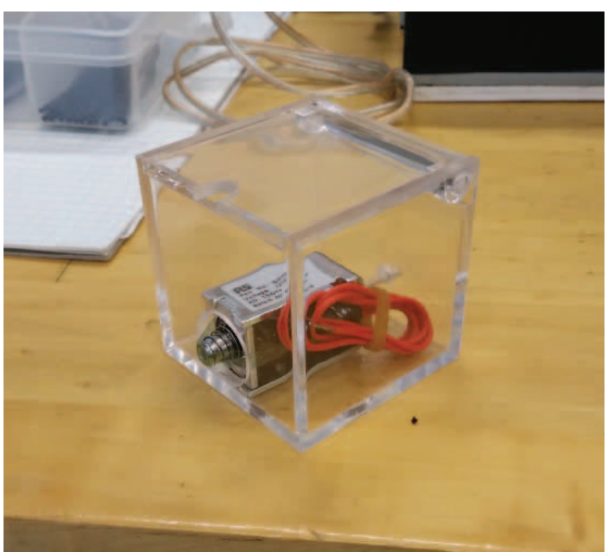
Overall microphonic input was divided into 11 frequency bands through 11 bandpass filters; a temporal shift was added on each band. The final result was a sort of spectral delay. The idea was to connect the bands to the 11 arches so that the amplitude on a frequency band crossing a certain threshold (determined while testing the installation in the portico) would activate the corresponding arch's solenoids. In this sense there was a correspondence between arch position in the portico and the sound events occurring under arches:

Fig. 3. Ideal resonating point on the vertical arch's pillar for the solenoid placement. (© Claudio Panariello)

Low frequencies activated one end of the portico and high frequencies the other, whereas medium frequencies activated the center. The temporal shift on each band was added to avoid triggering of the installation by any environmental perturbation that, in the absence of the delay, would simultaneously activate a couple of adjacent arches. This setup would activate them in a more complex way, also spontaneously creating rhythmic structures. When the first activation of an arch occurred, a sequence (generation) of solenoids' hits was created through simple L-system generative rules, one for each couple of solenoids. After the sixth generation, each arch started to propagate itself to its two adjacent ones. I imagined the portico as a circular structure; the arches adjacent to the first one were the second and the last. To avoid overly long sequences that might result from unrelated external events the length of the sequence was cut at a limit length.

The overall trend of the impulses sent to the solenoids self-regulated following negative feedback rules: If high input amplitude was detected, the impulses became more rarefied and the installation approached a more silent stage; if input amplitude was low, the solenoids were activated more quickly. However, if the input tended to zero, i.e. no new external stimuli arrived, the installation tended to be quiet, too. As a result, an excessively rich or a stimulus-free environment could lead the installation to die. I avoided this risk by programming an ordered and recognizable sequence of solenoids' impulses, disconnected from the environment, when needed to reactivate the installation. In this way, if the global amplitude was detected to be below (or above) a given threshold for a defined amount of time, the ordered sequence was activated. While this sequence completely bypassed the generative rules and the negative feedback loop, it did not disable the microphones. The entire portico resonated, creating a new series of events that, recorded by microphones,

a



b

Fig. 4. (a) Box with solenoid. (b) Box fixed to the arch. (© Claudio Panariello)

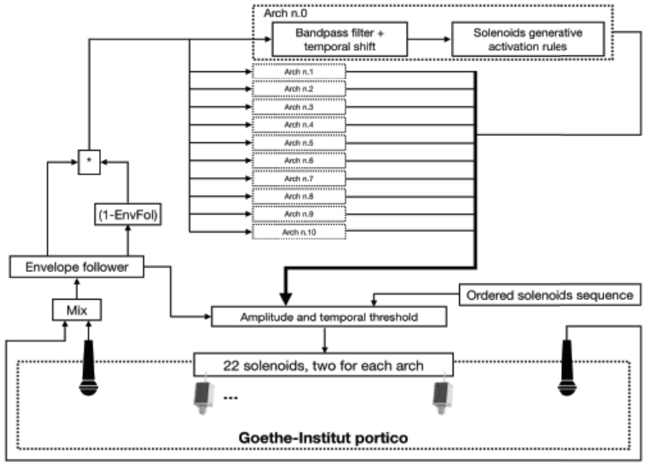


Fig. 5. Overall structure of the algorithm conceived for *Study in three phases*. (© Claudio Panariello)

reactivated the installation once the ordered sequence was finished and control passed back to the previously explained rules. The overall schema of the algorithm is shown in Fig. 5.

The negative feedback rules provided the installation an effective way to avoid environmental acoustic overload. A typical installation behavior is shown in Fig. 6a: The average number of activated solenoids is plotted as a function of the input amplitude: A perturbation occurring at second 10 causes the spike between 10 and 30 where up to 9 solenoids are activated. In that temporal window the negative feedback tends to have a high number of solenoid activations. When no other perturbations occur and the amplitude is low, the installation tends to a quiet state with low solenoid activity: Between 40 and 100 seconds, few solenoids are activated. The second environmental perturbation at second 100 causes a new increase in the number of activated solenoids, followed by a decrease since it is longer compared to the first one and, consequently, leads the installation to react in a negative way, avoiding acoustic overload. Figure 6b shows activation of the ordered sequence involving all solenoids (seconds 220–245). The amplitude detection is not inhibited, and the microphones are still monitoring the environment. When the sequence ends, the solenoids adapt again to the input amplitude (from second 245 on).

During testing in the garden just after setup, the installation reached an acoustic balance with the afternoon nature sounds of the garden. Notably, when the cicadas in the garden stopped singing, introducing a sudden silence, the installation responded by increasing its activity. Then it found a new balance with this quieter environment. During the exposure period, being personally present, I informally collected observations of visitors' personal communications, noticing that they found the interaction with the installation itself intriguing: As they arrived in the portico, they stopped and started to listen more carefully to the impact sounds generated on the arches, trying to understand how and why the installation was answering them in one way instead of another. Some looked carefully around to find light or proximity sensors that could explain the activation. When they realized that the interaction was due to nothing other than the acoustic signal (i.e. the microphones hanging from the portico), they were positively surprised. When a noisy audience led the installation to a quiet mode, thus forcing the ordered security sequence to start, the installation was briefly inhibited in its acoustic behavior. The sequence succeeded both in catching visitors' attention and in rebalancing the overall noise.

CONCLUSIONS

The installation *Study in three phases* is a work that adapts its behavior to external perturbations in a constant musical dialogue with the environment. The self-regulating processes created a memory of past events, while the pruning operations managed to avoid entropic degeneration; the installation disclosed its emergent behavior showing coherence in terms of style. Beyond the mere presentation of adaptivity used with artistic intent, I wish also to raise questions about which characteristics the output of a musical adaptive system should have in terms of musical form and style. Related to this, how does such a system behave in a musical context? How do we behave in its presence (implicating perceived autonomy and power relations)? Interestingly, the installation's

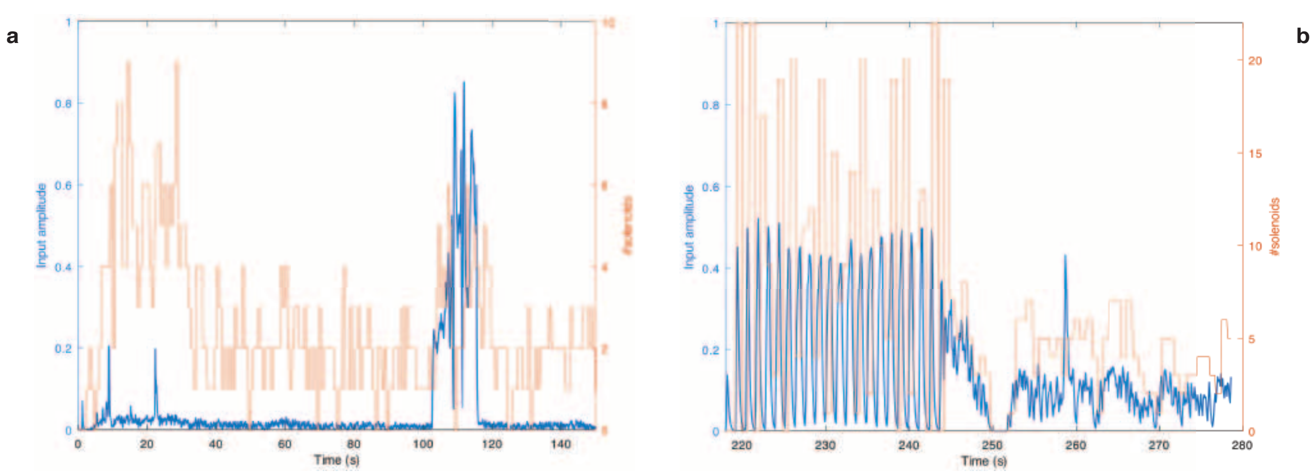


Fig. 6. Average number of activated solenoids (lighter line) as function of the detected overall input amplitude (thicker line). (a) A typical installation behavior. (b) Behavior after activation of the ordered solenoids' sequence. (© Claudio Panariello)

output showed coherence when presented in other venues and environments [27]. This outcome, although acceptable on the practical level, can be interpreted as a consequence of too-restrictive rules that did not permit a deeper dive into adaptivity. This leads to the open question of whether the system should show the style of the author who designed it or it should evolve its own style. This is almost to ask whether the adaptive system should escape the control of its author or not. Again, this is a matter of hierarchies and power, not only in relation to audience–installation interaction but also to author–opera interaction. Possibly, implementation of a musical adaptive system based on an artificial neural network (ANN) could indeed increase the potentiality of adaptation: The system would be able to organize its internal structure using, for example, perturbations as a training set and eventually showing its own style. The emergent behavior of such a system could take unexpected interactive directions.

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17 The definition can be found in Lupone's documentation of his installation *Gioco Delle Risonanze*.

18 Gabriele [2,14].

19 At the first exhibition, the installation was presented with the Italian title *Studio in tre fasi*. It premiered at ArteScienza 2017, "Il Giardino dei Suoni Segreti" (Rome, 17–22 July 2017). See video at www.vimeo.com/327037884 (accessed 3 May 2020).

20 A portico is an arcade consisting of a colonnade and a roof structure above it. In this article I refer to it using Italian terminology.

21 See Zimoun for a recent example: www.zimoun.net (accessed 3 May 2020).

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24 Both *Autopsia su una marionetta* and *Piccolo inventario degli insetti* can be heard at www.soundcloud.com/claudiopanariello (accessed 3 May 2020).

25 A linear solenoid is a common solenoid with a metallic axis through its coil, providing a linear actuation. When an electric current flows through the coil, the axis is retrieved into it; an optional spring helps the axis return to resting position when no current is running.

26 The code is written in the SuperCollider programming environment: https://supercollider.github.io. See www.github.com/claudiopanariello/studio-in-tre-fasi (accessed 3 May 2020).

27 For example, at the Festival "Stanze di Musica," at which the installation adapted to the spaces of Casa della Cultura e delle Arti in Camerota (Salerno, Italy, December 2019).

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