Technology-Mediated Musical Connections: The Ecology of a Screen-Score Performance

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ABSTRACT

This paper presents Puffin, an interactive screen-score system, and the development of a piece for the system with two instrumentalists. Puffin is designed to expose the interconnections between two musicians in a performance ecology and the role of the interactive artifact and musical score in that ecology. We conducted daily interviews with the instrumentalists during the study to understand the different interconnections that emerged among the instruments, musicians, and the score. We visually represent the resulting ecology by using ARCAA, a recently developed framework designed to study performance ecologies. In light of existing literature, this study offers new perspectives on some elements of performance ecologies: how different actors play different roles and perform different actions in different contexts; how a screen-score can act as a mediator; how a piece and a system are interconnected but distinct; and how the piece has some constraints in itself. Finally, we observed how autobiographical and idiographic design can coexist.

CCS CONCEPTS

• **Applied computing** → *Sound and music computing*.

KEYWORDS

Performance Ecology, Screen-Score, Musical Interactive Sistems

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1 INTRODUCION

A *performance ecology* can be defined as the set of all the human agents and instruments that compose a performance [14, 35]. From this perspective, the design of interactive technology for music performance should account for all the elements of such an ecology. At the same time, creating new interactive technology can overlap with the act of composing [19]. Therefore, accounting for the complex set of interdependencies in one performance is crucial to both interactive system design and music composition. In this paper, we analyze a performance ecology involving a system that manages the real-time creation of music notation, which we called Puffin. This case study involves the composer/designer (first author of this paper) with two instrumentalists, as participants, who collaboratively created a piece. This case study was developed with the aim to expand the understanding of internal dynamics in performance ecologies, answering the following question: *How can an interactive score system shape a performance ecology with multiple instrumentalists?*

2 BACKGROUND

2.1 Interactive Systems in Third Wave HCI

During the last decades, computing has been spreading to many aspects of human life, including everyday activities, art, and leisure [3]. Within this context, a variety of perspectives and reflections that are relevant to the study described in this paper emerged.

Some critique has been posed on the idea that people are merely *users* of a system. In particular, Bannon [2] argued that people have a broad set of values, motivation, and interests that should be accounted for when designing interactive systems. Therefore, the author proposed a switch from *human factors* to *human actors*. A similar critique on the term *user* can be found in a work by Rodger et al. [30], who suggested that "no such person that can be picked out as the instruments' prototypical user", as there is no real wrong use of an instrument. The idea of *correct use* has also been questioned in literature about technology appropriation. Appropriation was defined as "improvisations and adaptations around technology" [7], and has been discussed in the design of interactive music technology [22, 36]. Interestingly, within music technology, constraints [29] proved to be useful to stimulate creativity (e.g. [13, 20, 27]).

People also tend to use multiple artifacts in interconnected ways, and multiple persons can use the same artifact. To study these interconnections, the concept of artifact ecologies emerged [4, 17]. Jung et al., relying on Gibson's conception of ecological perception [11], initially defined a person's ecology of artifacts as the set of artifacts that a person "owns, interacts with and uses" [17]. Artifact ecologies were recently used to analyze multiple sonic interactions [10] and to study the set of objects that guitarists use [1].

2.2 Performance Ecologies

In the discourse on computer music performance, the idea of a performance ecology emerged as a way to conceptualize the complex set of agents that compose a performance, including makers,

performers, composers, and instruments. In this perspective, Gurevich and Treviño focused on the "relationships between composers, performers, and listeners as apart of a system", also considering history, genre, and context [14], and Waters discussed the variety of interactions among performers, instruments, and environment in performance ecosystems [35]. Rodger et al. supported that, to properly evaluate musical instruments, musicians should not be accounted as users, "but rather agents in musical ecologies" [30]. It is interesting to notice how Rodger et al. discuss their vision using Gibson's ecological psychology perspective [11].

Borrowing the concept of artifact ecology from HCI scholars, Masu et al. developed ARCAA, a framework to analyze digital music technology used in performance [23]. The framework comprises three levels (Role, Context, Activities) that should be used to connect all the actors with all the artifacts within a given performance ecology. Each level proposes a different question: 1) "Who is involved, and in which role?"; 2) "In which context is each actor involved?"; 3) "What kind of activities are the actors performing?" [23]. This framework has been recently used to analyze in detail the ecology of an interactive music system designed for a dance performance [25]. In this paper, we propose a similar study, investigating a performance with composer/designer and two instrumentalists.

2.3 Score and Music Technology

The evolution of music technology has overlapped with the use of scores in different ways (for a taxonomy of different use of score in interactive technology see [26]). We trace here two angles that are relevant to the work we present. First, open ended notations that emerged in avantgarde music practices have impacted the development of music technology and digital systems. For instance, these scores influenced the live coding debate [21], were used to design VR installations [22], or as inspiration to design new musical instruments [32]. Non-traditional forms of notation have also inspired the design of *screen-scores* [16, 24, 34]. Screen-scores have been defined as "new media manuscript" [16], in which musical scores are dynamically displayed in real-time on digital screens.

Second, the relationship between music scores and technology has partially overlapped, as many composers started to develop their own music systems. In many interactive pieces, indeed, "the distinction often blurs between instrument and composition on the one hand, and performance and composition on the other" [19]. In line with this idea, Tomas and Kaltenbrunner designed the *Tangible Score*, a new musical instrument in which they embed the score in "the physical layer of the interface" [32]. The system described in this paper aims to expose how music technology can subsume the function of a score by using a screen-score approach.

3 PUFFIN: A SCREEN-SCORE SYSTEM

Puffin is an interactive screen-score system designed to 1) expose how a digital interactive system can connect multiple human actors in the performance and 2) visualize how an interactive system can subsume the role of a score. Puffin is designed to be used in a piece with two melodic instruments and is composed of two modules, a Score Module and an Audio Module, that share data via OSC (figure 1). The Audio Module detects the notes that musician 1 plays and sends this information for transcription to the Score Module. The

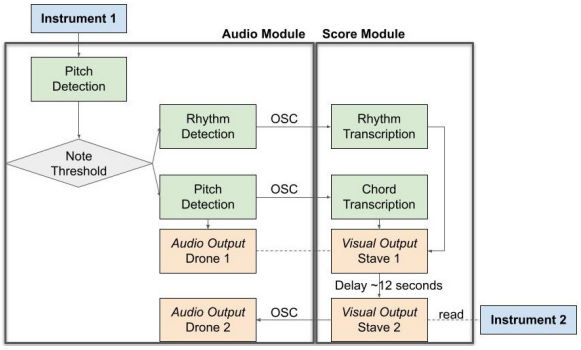

Figure 1: The architecture of Puffin

Score Module presents that information onto two staves (figure 2): the bottom stave represents the notes being played by musician 1, while the top stave shows the same information with a delay, for musician 2 to follow. Additionally, the Audio Module plays two drone sounds, each based on the notes from the respective stave.

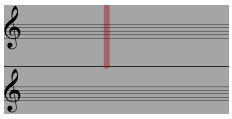

Figure 2: The two staves displayed in the Score Module

3.1 Score Module

The Score Module is implemented in Processing [1]. This module displays the two staves (figure 2), one for each musician interacting with it. There are two types of note representations, one for representing the notes played by musician 1 below a note threshold and the other for notes above it. The ones below the threshold are transcribed only rhythmically with square noteheads (figure 3, left). The notes above correspond to different harmonies, represented as chords with distinctive background colors (figure 3, right). The two types of notation aim to balance freedom (of choosing the actual notes) while keeping harmonic and rhythmic coherence. All the notes are spatially distributed over the horizontal axis of the staves to represent the timing. In this way, time could be represented without the need to previously know the length of the note as it would be required with traditional notation. After a predefined time span (by default 12 seconds), stave 1 is copied to stave 2 (on top); simultaneously, the transcription of musician 1 restarts from the beginning of stave 1. This mechanism is repeated in a loop, where stave 2 has always a delay regarding what was notated on stave 1. As the lengths of the staves manage the duration of the loop, the Score Module also manages the clock of the system and the synchronization of Drone 2.

Musician 2 reads from stave 2 (on top); she has to improvise with the notes of the chord, imitating what musician 1 rhythmically performed previously, creating a sort of *canon* [2]. Musician 2 can also

[1] https://processing.org

[2] A canon is a contrapuntal compositional technique that employs a melody with at least one imitation of the same melody played after a given time duration.

slightly modify the rhythms to create a variation in the repetition, as can happen in *fugues*. These elements also grant musician 2 some freedom and more space to include her own expressivity in the piece. To facilitate the reading process, a scrolling red line representing the time is displayed over the staves (as in figure 2).

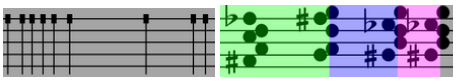

Figure 3: Left - rhythmic notation with square noteheads; Right - chords with distinctive background colors.

3.2 Audio Module

The Audio Module is implemented using Pure Data [3]. This module detects the notes by musician 1 using the Pure Data object sigmund [4]. The output from sigmund is then used to detect changes in the pitches, identifying new notes. Once a new note is detected, an OSC message is sent to the Score Module.

This module also generates two drones. Drone 1 is controlled by notes above a threshold (the same as new chords in stave 1) in real-time. Drone 2 is changed by OSC messages received from the Score Module, corresponding to new chords in stave 2. When the red playbar crosses a chord in stave 2, an OSC message with the corresponding is sent from the Score Module. The drone sounds are created with additive synthesis, combining eight different sawtooth oscillators playing the corresponding notes at four different octaves, with a pair of sawtooth oscillators per octave. To obtain some beats [5], the frequency of each individual component of the drones is changed randomly in a range of up to 6 Hz. Additionally, each component is individually modulated by an LFO at a different frequency. Finally, the sound of the drones is reverberated.

4 THE CASE STUDY

In the case study, the composer/designer of the system (we will use the term 'composer' for the sake of brevity) developed, together with two instrumentalists, one musical piece using Puffin. Puffin was primarily designed without any co-design process. However, the piece – the creative adoption of the system – was collaboratively developed with two performers as participants: one violinist (Francesca Zanghellini, female 22 years old) and one guitarist (Ardan Dal Rì, male 30 years old). Both performers have professional training and work experience with their instruments and are used to contemporary repertoire. Additionally, the guitar player is educated in electronic music. The guitarist assumed the role of musician 1 in the system and the violinist assumed the role of musician 2.

4.1 Methodology

In order to study technology in everyday contexts, Dourish argued for "detailed analysis of actual practice" to investigate the use of technology "moment-to-moment" [8]. In artistic contexts, these suggestions are particularly relevant. Indeed, close observation and collaborations with artists became important, and in some cases, artists became involved in the first person as researchers. Therefore, different design methodologies have been applied, notably *autobiographical* and *idiographic design*. Autobiographical design has emerged as "design research drawing on extensive, genuine usage by those creating or building a system." [28]. Such a design approach has been recently used to design a smart mandolin [33]. Idiographic design also proved to be valuable as a form of "interaction design that focuses upon responding to detailed personal accounts of individuals' practices" [15]. In a recent paper, Masu et al. explored both the autobiographical perspective of the composer and the idiographic approach targeting the needs of one specific choreographer; additionally, the authors analyzed and represented the performance ecology of the dance piece using ARCAA [25].

This paper follows a methodological approach similar to [25], of combining the autobiographical experience of the composer with the idiographic experience of other actors involved in the ecology (in this case, the two performers of the piece). The autobiographical perspective is related to the fact that Puffin is designed and developed by the composer, based on a core artistic idea that remained unchanged throughout the study. The idiographic perspective is related to the adjustments operated to the system according to some specific requests of the two performers and the fact that the actual piece was created with them. The composer led this creation but received input from the two musicians, and the piece was developed and structured during the study.

4.2 Study Setup

We conducted four sessions in which the composer and the two instrumentalists developed a short piece. Due to Covid-19 restrictions, the collaboration between the composer and the two instrumentalists occurred online (further details below). The guitarist and the violinist live together and have a small studio in their basement.

At the end of each of the four sessions, the composer interviewed the two performers using semi-structured interviews. The questions focused on the collaboration with the rest of the team, the relationship with the technology, and the connection with their instruments. The two performers were independently interviewed, and each of the four interviews with each musician lasted between 13 and 35 minutes. The interviews were analyzed following the procedure of thematic analysis [5] by the composer. Quotes from the interviews were translated to English as the original language was Italian. Additionally, the composer collected notes on his own perspectives. These notes were taken during and at the end of each session, aiming to prepare the session of the following day incorporating the feedback, better understand the ecology, and keep track of each stage of the study. The description of the four different sessions is based on the field notes.

4.3 The four sessions: a description

Each session occurred as follows: 1) online (via a video conference platform), a moment of discussion in which the composer suggested some musical ideas that were afterward discussed (10-30 minutes); 2) in situ, the two instrumentalists rehearsed the suggested idea and audio recorded the session (figure 4); 3) online, a moment of collective discussion about the rehearsal; 4) online, individual

[3] https://puredata.info/
[4] Sigmund analyzes sinusoidal components of a sound, it can output a pitch estimate.
[5] The term beat is used in its acoustic sense, an interference that creates rhythmic patterns between two sounds of slightly different frequencies

interview with the two instrumentalists. Additionally, between the sessions, the composer listened to the recording outputs of the previous session and checked his notes to provide further feedback. This workflow allowed us to collectively develop a short piece (6 minutes) in four days using the interactive system. Additionally, between sessions 2 and 3, the composer and the guitarist had a meeting to fine-tune the system.

Figure 4: A rehearsal moment with a screenshot of the score.

In **session one and two** the composer proposed some tasks to start exploring the musical possibilities of the system. By listening to the musical material created in the first session, we created four exercises for session two that later became the structure of the piece in four main parts:

1) Without changing the drone, play with different rhythmic elements, starting with sparse events and progressively increasing the density. This part aims to onboard the audience by exposing the rhythmic imitation using few elements.

2) Play short melodies, changing the drone at the end of each *melodic sentence*. This part introduces the fact that the guitarist can play the drones. By listening to the first session, we understood that this part risked becoming very repetitive and limited it to only two short sentences.

3) Play only the drone without any other note in the middle, very slow to create a sort of *chorale*. The violin plays *al tasto*, or *flautando* to obtain noisy components in the sound.

4) Play only the drone, increase the speed to create a chromatic *ostinato* with very *staccato* notes; the violin also plays with different forms of short notes, from *jeté* to *pizzicato*.

Between sessions two and three, the composer and the guitarist spent a couple of hours fine-tuning the code to solve the problems that have emerged. We decided to perform these modifications after this session because the structure of the piece was defined; therefore, the guitarist's needs were clear. The improvements included 1) moving the threshold to control the drone one octave above to allow the guitar player more space for the melodic lines; 2) adding two filters to better separate the signal of the guitar above and below the threshold; 3) fine-tuning the thresholds for the rhythmic transcription. These modifications occurred in a co-design process where both the guitarist and the composer changed the code sharing the files with each other. Additionally, the violinist asked to include a notation of the first chord at the beginning of the line, even if it was continuing the previous chord. In this way, she could read the notes without the need to remember the chord associated with the color. We implemented such a function.

In **sessions three and four**, no significant modification in the structure of the piece nor of the system occurred. In session three, particular attention was paid to the violin gestures, refining the instrumental techniques for each of the four parts of the piece. This exploration occurred in collaboration with the violinist by discussing specific techniques in relation to the system, for instance, *Bartock pizzicatos* and *staccatos al ponte* for the beginning, *al tasto* notes and *flautando* notes for the third part and *jetés* for the transition between the third and the fourth part. Additionally, during the initial discussion in the third session, the composer asked to reuse some musical material that emerged during the first session, using the same intervals and atmosphere for the second part of the piece. Session 4 was a rehearsal of the piece.

5 RESULTS

We present here the results of the thematic analysis from the interviews. Eight themes emerged (in bold) with several subthemes (highlighted in italic in the text). We specify the day of the session for direct quotes (S1-S4).

Interaction with the composer. Two types of interaction with the composer emerged. Both instrumentalists mainly *followed instructions from the composer*. This element primarily emerged in the explorative first sections (S1, S2). Additionally, the guitar player was happy that they could *contribute to the piece*, in particular he appreciated that an idea that emerged during one of the sessions was integrated into the piece; the guitarist declared that, "if our ideas can contribute to the piece, that is very good" Guitarist - S2.

Relationship with the piece. As the piece was progressively defined, the interviews revealed a more clear relation with the piece and its musical form rather than with the instructions of the composer. *Understanding the scope of the entire piece* played an essential role in improving the musicality and gaining confidence, as the musicians "were more convinced about what to do" Guitarist - S3. Additionally, once the structure of the piece was clear, the violinist's relation with the violin improved: "My relation with my instrument was immediate, as I already knew what was going to happen" Violinist - S4. Finally, once the piece was defined, the violinist "was also less bound to the screen" Violinist - S4.

The piece represented a set of constraints in the performance. Once the structure was clarified, the piece itself imposed different constraints compared to the previous session, independently from the changes in the system: "Although the system is the same, as there are more rules in the piece, it's as if there are more elements" Violinist - S2. Such *constraints played the role of being a creative stimulus*, helping to structure the performance: "as there are more limitations, I had more ideas, [...] there are more elements that I can use." Violinist - S2.

Collaboration while not playing. *Discussing was a primary element of collaboration.* As the two instrumentalists understood the piece and the system more, they increasingly discussed the musical aspects and less the system itself. The instrumentalists also *commented on what just happened and redid parts*. Starting from the second session, they interrupted the rehearsal to discuss specific situations. In the last two sessions, they *listened to the recording* from the previous session. Finally, the two instrumentalists decided to *rehearse specific moments without the system*.

Interaction with the other instrumentalist while playing. *The two instrumentalists listened to each other.* The guitarist listened

to the violinist mainly from a general perspective "in terms of densities" Guitarist - S1. The violinist perceived that the guitarist was listening to her. The violinist also listened to the guitarist to better imitate him. Once the piece was structured, as in any musical performance, the two instrumentalists *"gave each other signals"* Guitarist - S3. Finally, in some moments, the guitarist also waited for the violinist before proposing new notes.

Relationship with the system. The two instrumentalists interacted differently with the system. The guitarist's interaction with the system was multifaceted. The Guitarist expressed the need to *understand the system*, stating that otherwise, it is difficult to create musically interesting results. Additionally, the guitar player was aware of his role as an "orchestrator" - S4 in the performance ecology. This mainly affected two performative elements: 1) the "harmonic perspective" Guitarist - S1 as he had to *think about the delay*; 2) the *control of the densities* including: "peaks, changing the speed, speeding up, slowing down" Guitarist - S2. The screen provided visual feedback, facilitating the control of the density and the delay. "I look at where the notes appear and when she does them." Guitarist - S3. Finally, the fixes to the system were briefly mentioned by the guitarist, who mentioned that he could interact better with the system afterward.

The violinist's interaction with the system, as expected, was focused on *reading the screen-score*. In such a relation, different nuances emerged. The violist had to balance the reading activity with the listening activity. "50% I listened, and 50% watched the screen." Violinist - S3. The notation balanced freedom and constraints, therefore it was perceived as a "guide" Violinist - S1, that combined some determined instructions with more open and free possibilities. The violinist also had to learn how to read in the context of the entire performance. "I metabolised the system better now, so it is more natural to follow it, and at the same time, I could listen to what Ardan was playing. So now I feel that I can pay the right attention to the various components" Violinist - S4.

Relationship with the instrument. The two instrumentalists interacted differently with their instruments. The guitarist relationship with the guitar was quite articulated. Due to the sensibility of transcription, in some cases, the system *limited the possibilities of the guitar*. To overcome this problem, the guitarist identified specific strategies: "play short notes, al tasto, with a sharp attack, trying to avoid resonances". Guitarist - S3. The guitarist also had to *balance the need to be expressive while playing the guitar with the need to control the system*, "I was not only controlling some triggers, but I was also playing" Guitarist - S2. However, in the last two parts of the piece, the guitarist solely controlled the system: "having the guitar or having a MIDI keyboard is *de facto* the same; from that part on, I stop thinking as a guitar player" Guitarist - S3.

From the violinist, some *limitations of some particular techniques* emerged; for instance, some *pizzicatos* cannot be performed fast.

General appreciation and being involved. Both musicians appreciated the experience. Overall, the violinist felt involved: "It all sounded very suggestive, and the system is quite captivating; I was very involved in the system" S1. Additionally, the guitarist expressed aesthetic appreciation of the musical results.

Possible improvements. In the last interview, the guitarist also suggested some possible improvements to the system. In particular, to add a MIDI controller and more drones.

6 DISCUSSION

6.1 ARCAA Representation of the Study

This paper describes the first case study using ARCAA to analyze and visualize a performance ecology with multiple instrumentalists (figure 5). Until now, the framework has been used to analyze a case with one musical instrument [23] and one dance performance with two dancers [25].

The representation helps to visualize how all **the actors play different roles in different contexts** (see 'Role' and 'Context' layers in figure 5), **and those different roles correspond to different activities** ('Activity' layer in figure 5). In particular, the two instrumentalists are part of the ecology in different contexts, not just when they perform, but also when they discuss musical ideas. The graphic allowed us to go beyond the individual relationships between the different actors and the system; it visualizes how **the screen-score system acts as a mediator between the two instrumentalists** performing different activities (red rectangles '1' in figure 5), where the guitarist *controls* or *plays* the system, while the violinist *reads* the resulting score. From the analysis, it also emerged that **the piece itself is an artifact** (with its four parts) – it is an element so important that we represented it as an artifact distinct from Puffin (blue rectangle '2' in figure 5). Such an artifact is deeply connected with the interactive system but also separated from it. As emerged from the interview, **the piece in itself has some specific constraints** that determine how to play (green rectangle '3' in figure 5). In the rest of the discussion, we zoom in on each of these points.

6.2 Different Roles in Different Contexts

This study highlighted how the instrumentalists are complex actors, not merely users of a system, rather musicians who can be happy to actively contribute to a piece as active actors and not just as users: "if our ideas can contribute to the piece, that is very good" Guitarist - S2. This element is not a complete novelty per se; on the contrary, it is aligned with Rodger et al. [30], who recently stated that performers are not users "but rather agents in musical ecologies". Additionally, a switch from *user* to *actor* has been proposed more than two decades ago [2] and was one of the theoretical foundations of the development of ARCAA in the first place [23]. However, although this point is quite evident in the literature on interaction design and music, few empirical studies analyze in detail the various roles of an actor in one specific ecology.

The two instrumentalists did not play the same role. The guitarist identified himself as an "orchestrator", while the violinist did not identify any specific role for herself other than a violin player. Such a distinction is influenced by the system's design, which transforms the performance of musician 1 (the guitarist) in a score for musician 2 (the violinist). We can also speculate that the personal background of the two instrumentalists reinforced the creation of such discrepancies. For instance, the guitarist has a background as an electronic musician and was able to operate changes in the system. This element probably allowed him to acquire a more complete understanding of the entire ecology. The violinist's background is mainly in classic or contemporary score-based music. Actors' background is not a layer in ARCAA, however it could become a new layer in an extended version of the framework, to provide a more

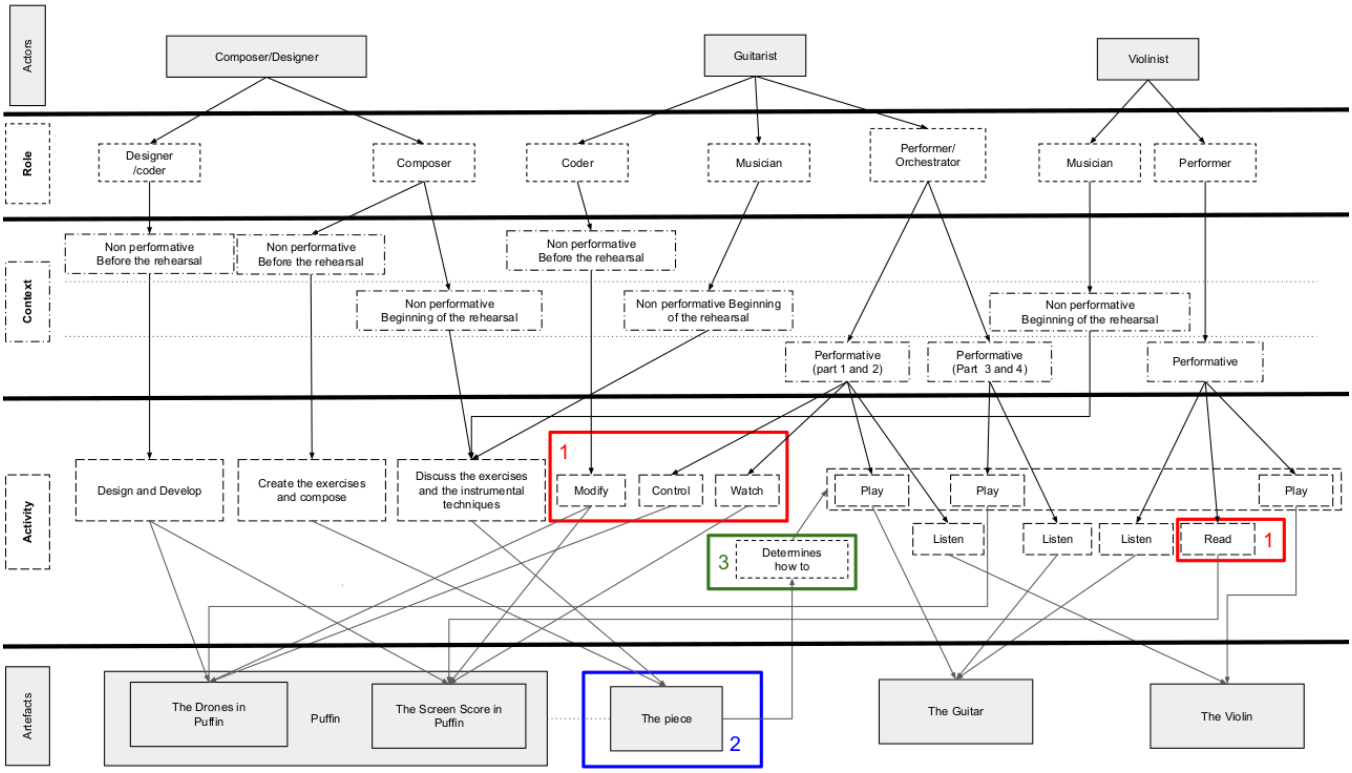

Figure 5: A representation of the overall performance ecology using ARCAA

deep perspective on the roles. The term "orchestrator" derives from classical musical jargon. In interactive music technology debate, classical terms have been already used to describe mapping strategies; for instance, a musician can control algorithmic processes "analogous to conducting" [12]. However, such metaphors have been mainly used in a simple one-to-one interaction; we support these metaphors can be useful also to understand the relationships that an actor has with the entire ecology and not only with one specific piece of technology. ARCAA can support the inclusion of such metaphors in the analysis of a performance ecology using them to identify the different roles that each person plays.

6.3 Different Activities for Different Roles

Different roles correspond to different activities, in particular, the instrumentalists performed a variety of different actions without interacting with the system. Such actions are necessary to effectively and musically interact with the system. For instance, the instrumentalists needed to discuss musical aspects of the performance, "we spoke more about the musical aspects" Guitarist - S3. The two musicians also needed to rehearse specific moments without the system and listen to the recordings. All these actions occurred outside the traditional framing of a performance. However, all these moments are part of the ecology of musical creation. In the ARCAA representation, we can see different contexts, a *performative context*, in direct interaction with Puffin, and a *non-performative context* where all these activities occur. Based on this element, we support expanding the scope of investigation on performance ecology to include the interactions that occur in the preparation of the performance. It has been discussed that considering cultural aspects such as history and genre [14] should be accounted for to understand a given performance; we simply propose to add another element, including all the non-performative interactions (e.g. discussing, listening, recording) as core constituents of a performance ecology.

6.4 Screen-Score Artifact as a Mediator

One of the core ideas of the system and the piece is to expose how a digital interactive system can connect multiple human actors in the performance ecology [30, 35]. Indeed, Puffin transforms the actions of one performer into guidelines for the other performer. Therefore, the score on the screen becomes the element that connects the two performers, creating a sort of *canon*, a delay of musical elements within the same performance ecology. Musically, the system is inspired by one of the most ancient compositional strategies of western music tradition: imitative counterpoint, canons, and fugues. The piece is also connected to a more recent electroacoustic repertoire that used delays in a structural way, creating imitative counterpoints, such as *Dorian Reed* by Terry Riley [6] and *Ricercare una melodia* by Jonathan Harvey [7].

Puffin offers a different perspective on such a compositional approach by combining the use of screen-score with structural use

[6]Exemple of one performance https://www.youtube.com/watch?v=29U9SkOg9is.
[7]Exemple of one performance https://www.youtube.com/watch?v=sxHZ_UN5BKE.

of delay and repetition. Electroacoustic pieces like *Dorian Reed* and *Ricercare una melodia* used manipulation of the sound of an instrument to create the delay. Puffin generates a score that asks a second performer to play with a delay what the first performer just played. From an instrumental perspective, the piece recalls the tradition of imitative counterpoint and fugue, but at the same time, the technology mediates this relation, determining the connections in the overall performance ecology. In ARCAA such connections are visible with the different actions that connect the instrumentalists with Puffin (one controls it, the other reads from it). Such an approach also represents a new perspective over traditional design and use of screen-score systems, as it is used to create connections between performers on a stage and not to give them instructions (e.g. [16]). It is true that in some cases, screen-scores can be affected by some performative actions (e.g. in [18], the performer can control the score with a pedal, and in [9], the score is affected by emotional biosignal measurements). However, the role of a score as an ecological delay that mediates the relation between two instrumental performers represents a new approach to screen-score.

6.5 Piece and System as Distinct Artifacts

The second purpose of the system and the piece is to explore how an interactive system can subsume the role of a score (as suggested in [19, 31]). The tangible score project by Tomas and Kaltenbrunner exposed such a characteristic by transforming the "inherent score to the physical layer of the interface" [32]. In Puffin, the inherent score is exposed on a screen from two different perspectives: 1) the system is the score for the violin; 2) the system visualizes the core musical idea of the piece – the imitation between two instruments.

Puffin was designed with an implicit but clear musical idea that represents the musical mechanisms underlying the piece. From this perspective, this system followed Cook's guideline suggesting to create a piece, not just an instrument [6] – the piece is a contemporary form of *canon*. However, in its form, the actual piece was developed and determined along with the instrumentalists in a second stage, and other pieces could be created with Puffin. Based on this, we support that, in our study, the relation between a musical piece and a new music technology artifact is shaded, one is deeply bound to the other, but there is a distinction as some constraints can be determined by the piece rather than the technology itself. As the violinist reported: "Even though the system is the same, as there are more rules in the piece it is like if there are more elements" S2. Furthermore, understanding the scope of the entire piece helped the instrumentalists to perform with their instruments. "My relation with my instrument was immediate, as I already knew what was going to happen" Violinist - S4. We hope that this blurred distinction between Puffin and the piece provides a new nuance on the shaded boundaries between musical pieces and music technology. ARCAA facilitated us to reflect on this point by allowing us to identify the piece as an artifact in the bottom layer.

6.6 Specific Constraints of the Piece

The piece created a set of rules that impacted the activities of the performers. As the violinist declared, the piece created the most important constraints. It is interesting to see how, especially for the violinist, such constraints acted as a support "as there are more limitations, I had more ideas [...], there are more elements that I can use." Violinist - S2. The fact that a set of constraints can stimulate musical creativity is aligned with other studies on music technology (e.g. [13, 20, 27]). However, the distinction between constraints of a system and constraints imposed by a piece offers a new perspective on the role that constraints play in a digital music performance.

6.7 Different Design Approaches Coexisting

In the study presented in this paper, two design perspectives coexisted. The autobiographical perspective (as described in [28]) was predominant in the creation of the system and of the piece, as the relation with the western legacy of imitative counterpoint, canon and fugues, reflects one of the main musical interests of the composer. We acknowledge that repetition and imitation can be structural elements in non western musical tradition (e.g. the Javanese Gamelan), however the western perspective represents the personal biographical experience of the composer. Indeed, the composer spent many years of his time as an undergraduate studying historical music where repetition is structural in the creation of the form of a piece, including counterpoint, canon, and fugue. Additionally, the composer had curated the electronic component of the two aforementioned electroacoustic pieces for public concerts. At the same time, an idiographic perspective (as presented in [15]) was used to tailor the piece to the two instrumentalists. Some feedback affected the piece and the fine-tuning of the system, and some ideas developed by the performers during the rehearsals generated one new exercise that was integrated into the final piece.

The balance between autobiographical and idiographic elements finds parallels with a previous study with ARCAA in a dance performance [25]. In that case, the development of a system primarily followed an idiographic process targeting the artistic ideas of the choreographer, who was the main author of the piece, and the autobiographical approach represented the choices of the sound designer (who was the developer of the system, and the first author of the study). In the present study, the importance of the two approaches is reversed; the autobiographical approach was predominant, and the idiographic element supported the tailoring of the system and of the piece.

7 CONCLUSION

In this paper, we described a novel interactive screen-score system designed to expose connections in performance ecologies and a new case study on ARCAA [23] with two instrumentalists. In the study, we could observe and discuss many relationships between the various actors and artifacts in a performance ecology. The methodology of this study is inspired by a previous paper on sound design in dance performance ecology [25]. Additionally, this paper provides a highly detailed example of how the technology is used "moment-to-moment" [8].

By discussing the study, we analysed *how different actors play different roles and perform different activities in different contexts; how a screen-score can act as an ecological mediator; how a piece and a system are interconnected but distinct; and how the piece has some constraints in itself.* Finally we observed *how autobiographical and idiographic design approaches can coexist.* We support that this paper can contribute to understanding ecological perspectives of

music performances, and could support designers and composers working with interactive systems for music performance.

Future works can include new versions of the system, adding more possibilities and a MIDI interface, as suggested by the guitarist, or a version of the system that can run on a server allowing remote performances. We also hope that this paper will inspire more studies investigating in detail performance ecologies.

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