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Marco Fiorini, Lorenzo Colombo

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A.I. KOMBOÏ: RE-IMAGINING XENAKIS' KOMBOÏ THROUGH CYBER-HUMAN CO-CREATIVE IMPROVISATION PRACTICE

Marco Fiorini

IRCAM - STMS

CNRS - Sorbonne Université

Paris, France

marco.fiorini@ircam.fr

Lorenzo Colombo

DKDM

The Royal Danish Academy of Music

Copenhagen, Denmark

lorenzo.colombo@dkdm.dk

RÉSUMÉ

Dans cet article, nous documentons une recherche artistique et scientifique dans laquelle nous réimaginons un morceau de musique contemporaine par le biais d'une pratique d'improvisation co-créative. Nous utilisons la partition originale de Iannis Xenakis, *Komboï*, comme une esquisse fondamentale, en extrayant des informations à la fois abstraites et structurées pour guider notre processus. En utilisant Somax2, un système d'IA cocréative pour l'improvisation issu du projet européen REACH auquel nous participons, nous avons reconstruit la partie clavier de la pièce et conçu de nouvelles stratégies d'interaction adaptée pour un percussionniste en direct. Cette approche met en jeu des paramètres de contrôle de plus haut niveau permettant de naviguer dans la partition, ouvrant ainsi sur un nouveau paradigme d'interprétation et d'interaction. La nouvelle pièce, *A.I. Komboï*, a été créée en juin 2023 au Klang Festival à Copenhague. Cet article détaille les techniques, méthodes et stratégies à l'œuvre dans cette reconstruction improvisée qui constitue un véritable processus de réimagination de la composition de Xenakis et ouvre de nouvelles voies dans les aspects créatifs, performatifs et pédagogiques de la musique mixte dans le domaine de l'interaction Humain-IA.

1. INTRODUCTION

In the field of contemporary music, the convergence of human creativity with artificial intelligence has opened up a new area of compositional explorations. This article reports on an artistic and scientific research project in this field, in which a percussionist and a computer musician have reimagined Iannis Xenakis' seminal work, *Komboï*, through a process of improvisational practice. Central to this was the use of Somax2 [10], a co-creative AI-based software designed for improvisation, to augment the compositional process through real-time co-improvised interaction. We used Xenakis' original score as a foundational sketch, serving as a model for the extrapolation of musical abstraction parameters. These parameters, extracted from the score, were then transposed into specific instructions within the framework of Somax2. This symbiotic exchange between human interpretive intuition and the

generative capabilities of artificial intelligence led to the development of a detailed and distinctive musical work, culminating in a piece that not only pays homage to Xenakis' original vision, but also explores new concepts of co-creativity and interaction. Through this case study, we aim to contribute to the set of musical practices involving real-time human-machine interaction systems [43]. By examining this case, we seek to provide a comprehensive understanding of the methodologies and artistic choices that have guided our creative and research process.

In the following sections, we will contextualise our work within the sphere of music for percussion and live electronics, briefly detailing the corpus-based concatenative synthesis paradigm and the tools available within this domain, and we will elaborate on our complete workflow, providing insights into the interpretive processes, technological details and creative decisions that ended up into the creation of *A.I. Komboï*¹. Subsequently, the results of this collaborative project will be discussed, reflecting on the broader implications and future prospects of these human-machine co-creative practices in the field of contemporary music composition and improvisation.

2. RELATED WORKS AND CONTEXT

Unresolved challenges are key to identifying possible new research directions. One such central challenge in computer music, as articulated by Miller Puckette, pertains to the need for a seamless mechanism that allows processes and representations of musical data to interoperate [49]. This work represents not only a personal take towards this unresolved challenge but also an exploration of the potential of human-machine co-creativity and improvisation practices, facilitated by state-of-the-art software frameworks like Somax2. It presents a novel perspective on processes that were traditionally undertaken using specialized tools designed for Computer-Assisted Composition (CAC), such as OpenMusic [1], or the bach [2] and dada [31] libraries for Max. These platforms offered an important approach for real-time interaction and co-creativity in music creation by integrating score following techniques [23] with computational approaches [17].

1. <https://www.youtube.com/watch?v=rUrYg-es7aI>

The paradigm of Corpus-Based Concatenative Synthesis (CBCS), exemplified by tools such as CataRT [56], now fully integrated in MuBu [55], has modernised real-time sound exploration in live performance and the CAC creative process. By exploiting large sound corpora, composers and performers have the ability to manipulate and concatenate audio segments, resulting in entirely new compositions. A recent addition to this scenario, the FluCoMa [65] package, provides a complete toolkit for manipulating corpora, offering new possibilities to computer musicians [11].

2.1. Music for Percussion and Electronics

Contemporary compositions combining percussion and electronics have evolved significantly since their emergence [52]. Early pioneers such as Bruno Maderna and Edgard Varèse opened the way with revolutionary works like *Musica sur due Dimensioni* (1952) and *Déserts* (1954). Karlheinz Stockhausen continued this exploration with *Kontakte* (1958-1960) [61], incorporating quadrophonic tapes together with piano and percussion. Noteworthy contributions emerged in the late 1960s and early 1970s : William Cahn's *Etude for Taperecorder and Percussion* and Hans Werner Henze's *Prison Song* marked crucial moments in the genre. Live electronics were first introduced in ensemble contexts, notably in John Cage's *Imaginary Landscapes* and *Credo in Us*, composed between 1939 and 1942. Mauricio Kagel with *Transición II* (1950s) extended this trajectory, integrating live electronics with piano, percussion and tape recorders. Stockhausen's pieces from the mid-1960s introduce live electronic elements, requiring multiple performers for their execution [62]. One example is *Mikrophonie I* (1964), which uses a single tam-tam with live electronic controlled by specific performers. Alvin Lucier's repertoire includes innovative intersections of live electronics and acoustic instruments, often incorporating percussion. His seminal work, *Music for Solo Performer* (1965), utilises amplified brainwaves for electronic resonance within distributed percussion instruments. This distinctive approach, along with others such as sympathetic resonance in percussion, distinguishes Lucier's contributions [30].

Advances in music development environments, notably Max/MSP and Pure Data in the 1990s, provided new possibilities for solo percussion with live electronics. The piece *Six Japanese Gardens* (1993) by Kaija Saariaho exemplifies this change, employing a pedal to activate electronic components, including pre-recorded sounds and live audio processing. In the following decades, compositions such as Ben Hackbarth's *Open End* (2007) expanded this structure. Hackbarth integrated sounds from loudspeakers controlled by a Pure Data patch with a solo vibraphone, using sound events triggered by a pedal to activate resonance properties within the instrument, similar to the techniques first employed by Lucier.

This evolution underlines the rich world of possibilities in contemporary music, illustrating the dynamic interaction between percussion and electronics [33].

2.2. Motivation

To enhance and extend the aforementioned paradigms, it is important to consider the emerging role of Artificial Intelligence and its contributions to the artistic and scientific domains. The idea of using the generative potential of AI in tandem with human creativity has opened up new musical exploration possibilities [22]. Recent surveys of Herremans, Chuan and Chew [36], Carnovalini and Rodà [19] and Hernandez [35] show how the integration of AI tools into the creative process is constantly growing, demonstrating the potential of AI-driven compositional techniques. In this connection of scientific and artistic fields, a central concept is that of the musical agent. This has gradually evolved into a taxonomy of diverse applications [63, 5] but, in music improvisation and co-creation, the Voyager system by George E. Lewis stands as an early successful embodiment, relevant even today [41]. Subsequently, through innovations like Omax [7] and the contributions of the REACH (Raising Co-Creativity in Cyber-Human Musicianship) project at IRCAM, this notion has been further refined. In particular, the project REACH represents one of the forefront examples on AI musical co-creativity [8] and interaction between humans and machine in cyber-human contexts [9], where Somax2 is one of the main software developed within this project. Other noteworthy human-machine systems for music composition and improvisation based on reactive agents developed through the years include Cypher [53], ListeningLearning [21], Virtualband [44], GenJam [13], The Continuator [48], Improtek [46] and Dicy2 [47].

This scientific and artistic research therefore aims to extend conventional compositional boundaries and their typical scenarios through human-machine co-creativity and improvisational practices.

2.3. Komboï

Komboï (in Greek : *κομβοι*, meaning "knots") is a 1981 stochastic composition for harpsichord and percussion by Greek composer Iannis Xenakis (1922-2001). Together with *Oophaa*, it is one of the only two compositions for harpsichord and percussion written by Xenakis. It was composed in collaboration with harpsichordist Elisabeth Chojnacka and percussionist Sylvio Gualda, who premiered it on November 22nd, 1981 at Metz Festival in France ². The composition, approximately 17 minutes in duration, features one harpsichord, one vibraphone, various percussion instruments, and terracotta flower pots.

The piece is structured into five sections, with distinctive instrumentation and interludes. The opening section introduces an ostinato on bongos and rising tone clusters on the harpsichord, where Xenakis juxtaposes ordered percussion sounds with pitched notes to create intricate textures. The remarkable second section, titled *Crystal-line*, melds harpsichord and vibraphone, showcasing their complementary sonorities (see Figure 1). The percussion

2. <https://brahms.ircam.fr/en/works/work/12825/>

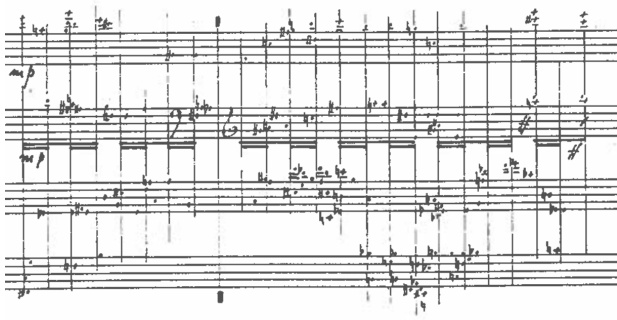


Figure 1 – One of the many knots, or clouds of notes during the piece, extrapolated from section 2, *Crystalline*. Both percussion and harpsichord play with the concept of density over a common beat, that is however not explicitly highlighted.

later incorporates flower pots, adding a new unexpected timbral layer. This integration of disparate elements exemplifies Xenakis’ exploration of musical knots on different musical axis, from the harmonic to the rhythmic one. Overall, *Komboï* offers a novel nuanced portrayal of the harpsichord and percussion, and has been described as revealing a more delicate aspect of Xenakis’ compositional style [34].

3. WORKFLOW

3.1. Corpus Creation

As thoroughly explained in [10], [15] and [16], Somax2 is an interactive system which improvises around a given musical material, aiming to produce a stylistically coherent improvisation while jointly listening to and adapting to live musical input. The system is trained on musical material selected by the user, from which it constructs a *corpus*, that will serve as a basis for the improvisation. In our case, this material consist of harpsichord MIDI corpora extrapolated from the original score, and treated as a sketching material to be recombined by the software in the live performance together with the musician on stage.

Differently from other CBCS systems like CataRT [56], Somax2 utilizes a notion of echoic memory in the navigation of the provided corpus and in the interaction process [10] [15] [16]; thus, it performs better with corpora that already have an internal structure and form. Xenakis’ *Komboï*, like many of his later works, is rooted in sieve theory. He developed the implication of this ancient mathematical theory in his composition during his time in Berlin in the 1960s [28] and published foundational material on it in [67] and [68], culminating in [69]. In Xenakis’ practice, this theory primarily deals with the creation of scales, offering a method to filter elements and construct musical structures. He applies the concept of filtering not only by passing elements through a sieve but also by using specific starting points and step distances. While pure sieve composition is a rich area of study, way beyond the scope of this research, it continues to offer new

perspectives on music generation techniques. In his PhD dissertation, Exarchos [28] detailed the relation between Xenakis and sieve theory from a compositional and practical standpoint, analysing the composer’s repertoire and practice. Ariza’s work in [4] exemplifies ongoing advancements in sieve theory and computer music, providing a Python implementation of Xenakis’ sieve process.

We employed a computational method to generate 22 distinct MIDI corpora to feed it to the system. These corpora served as compositional material for real-time interaction with the live percussionist during performances. The process involved the utilization of the AthenaCL library [4] and MuseScore4³, which provided a flexible framework for creating and manipulating musical sieves. These sieves, based on Xenakis’ stochastic composition technique [26], formed the basis for generating rhythmic structures. We extended this approach by integrating stochastic pitch selection from a set of pitches defined by the sieves, thus providing the melodic and harmonic content for Somax2 to navigate the corpora. The 22 resulting MIDI Corpora (see excerpts in Figures 2 and 3) were then seamlessly integrated into Somax2 for real-time interaction with the live percussionist, and loaded in 2 different Somax2 players, with specific parameterization for each section of the piece, as later described in Section 3.4.



Figure 2 – Excerpt of a sieve reduction for section 2 (see Figure 1). The extended version of this sieve has been loaded into a Somax2 player as corpus material for the same section.



Figure 3 – Reduction and juxtaposition of the right and left hand of the harpsichord at the end of section 2 see Figure 1). In this section two Somax2 players have been used to play at the same time, with different tempo flows, to recreate the effect of a granular cloud of note drops.

3.2. Onset Detection

In Somax2, as in any concatenative synthesis or corpus based systems, onset detection plays a crucial role in segmenting audio files into meaningful discrete events. This process relies on well-defined segmentation of the training corpus, in the audio usecase. While other segmentation

3. <https://musescore.com>

levels are possible, such as beat or bar, onset detection typically serves as a prerequisite. Additionally, real-time listening modules in Somax2 rely on onset detection to handle input from live musicians. Detected onsets determine when to trigger new output and when to segment the input stream for analysis.

There are two cases of onset detection in Somax2: one is computed offline on a user-specified corpus of audio files, and the other is computed in real-time on input from a musician. Somax2 is designed to be genre-agnostic, capable of working effectively with a wide range of classes of sounds, from classical music to unpitched percussive sounds, modern pop/rock, speech, etc. To accommodate this diversity, the system employs different onset detection algorithms. Notable examples include `bonk` [50], a low-latency algorithm optimized for percussive sounds, and `yingb` [7], a statistical model based on the Yin pitch detection algorithm [25] for detecting onsets in monophonic audio signals. Given the complex characteristics of different percussion instruments, we utilized the `bonk` algorithm for conventionally "unpitched" instruments like drums and congas. For melodic pitched instruments such as vibraphone and flower pots, we employed the `ying` algorithm to achieve accurate onset detection (see Figure 4).

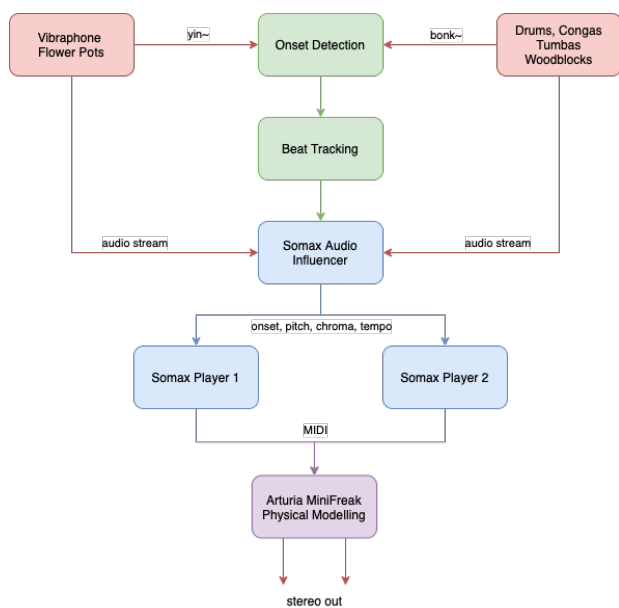


Figure 4 – Interaction scheme and signal flow for the setup of the piece. Audio signal is in red, onset/beat detection in green, Somax2 core modules in blue, MIDI and physical modelling in purple.

3.3. Real Time Beat Tracking

Identifying the regular pulse, or beat, in music is a fundamental task, akin to tapping one's foot in time to a piece. While humans often perform this task effortlessly, automating it in computer systems has proven challenging. As Masataka Goto noted in [32], "the hierarchical beat structure that exists in the minds of performers is not explicitly

expressed in the music itself". Developing a real-time beat tracker presents an additional challenge, as it must rely solely on past and present information without access to future data. This requires a causal approach, where predictions of future beat locations are made based on historical information alone.

Somax2 incorporates an integrated beat tracker developed by Laurent Bonnasse-Gahot, which draws on models by Edward Large and John F. Kolen, as well as Petri Toiviainen [14, 40, 64]. However, the quality of the results of this beat tracker on audio signals were not appropriate for our specific task. Consequently, this beat tracker was not utilized in testing and performances.

After thorough research, the `btrack~` implementation by Adam M. Stark [60] was chosen as a suitable real-time beat tracking algorithm for experimenting with Somax2. This model combines tempo induction methods by Davies and Plumbley [24], along with dynamic programming by Ellis [27]. The algorithm, available under GNU License, was adapted and compiled for the latest version of Max/MSP as an external object and integrated into an experimental version of Somax2 for testing with live audio inputs.

The inclusion of a Max/MSP external for beat tracking offers several advantages. It allows for the routing of tempo information from both audio and MIDI influencers to the players in Somax2. Additionally, each player can transmit their own tempo information, enabling tempo feedback within the group. This addition is expected to enhance the tempo performances of the system and ensure its maintainability in future developments. One could argue that the addition of a new beat tracker goes against the maintainability of the system. However, this turns out to be perfectly integrated, since, as mentioned earlier, Somax2 already has a beat tracker, although not optimized for our specific case. This addition therefore relies on an external Max/MSP object that turns out to be compiled once and available on several iterations of processors and systems (e.g., even on the new Apple Silicon ones) without requiring special maintenance. In addition, the form of the data output from the new object is homogeneous with Somax2 previous beat tracker, ensuring the integration, portability, and eventual future maintenance of this prototype.

3.4. Interaction Strategies with Somax2

3.4.1. Navigation Model and Influence Match

The Somax2 system diverges from purely generative approaches by directly constructing improvisation material on the original musical data, eschewing the development of an independent model. This methodology involves segmenting the musical stream into *slices* and subjecting each to a detailed analysis based on various musical features, such as harmony, melody, and beats. The resulting multilayer representation forms a *corpus* (as described in Section 3.1). The corpus with its features will serve as the core of Somax2 navigation model.

From the sequence of slices, a statistical sequence model is built, expressing the motivic organization, the musical structure with its repetitions and variations. While other statistical models based on variable markov models [66] or Factor Oracle [6] have been used in previous projects, Somax2 uses a statistical model based on n-grams [10], enabling non-linear exploration of the original data through multilayer representation of each feature of the corpus analysis. This statistical model thus accounts for short-term memory and continuity when recombining patterns at generation time, while storing the original musical content along with the multilayer feature analysis and sequence model in the corpus.

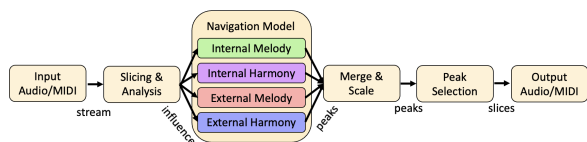


Figure 5 – An overview of the steps through which Somax2 generates its output at each given point in time, reacting to the incoming influences from a live musician. Source [29].

During interactions with a musician, Somax2 engages in real-time segmentation and multilayer analysis of the live input stream (see Figure 5), consistent with that done previously offline on the corpus material. This segmentation and conversion of a real-time audio stream from a musical to a symbolic domain, generates what are called *influences*. These influences contain a representation of the signal, according to the multidimensional system, that allows the navigation model to make comparisons between the input data (converted in influences) and those recorded in the corpus, loaded into a given Somax2 player.

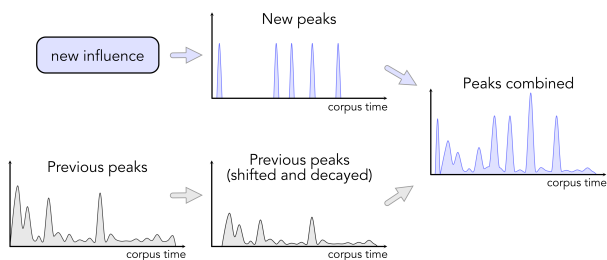


Figure 6 – The mechanism of memory peak profile update at the occurrence of each new influence. Source [10].

Any matches between the influences arriving in real time and the material contained in the corpus produce activations, called *peaks*, in the sequential memory, where the input aligns with the model. These peaks, akin to probability distributions, signify potential output candidates, and are present on each of the four dimensional levels of the statistical model, allowing a complex balancing of influences (see Figure 5, the four levels correspond to internal melody, internal harmony, external melody, external

harmony). It is important to note that as new influences arrive, previous peaks are shifted, decayed and combined with incoming new ones, thus creating a short-term echoic memory system that continues to influence the navigation model, as shown in Figure 6.

Somax2 co-improvisation process is thus defined by the interplay of these three fundamental concepts :

- *slices* : short segments of the corpus ;
- *influences* : multilayer data derived from real-time analysis of the input stream ;
- *peaks* : dynamic memory activations.

The system’s ability to dynamically balance its internal logic, shaped by self-listening, with external input from the musician results in a coherent yet unpredictable musical output. This co-improvisation process convincingly simulates the presence of an active agent in the collaborative musical experience, offering a nuanced blend of coherency and unexpectedness [18].

Unlike other generative systems, Somax2 preserves the fine-grained complexity of certain musical aspects by integrating them directly into the model, offering a specific approach to generative music, which differs from the current trend of deep learning models, like Google’s [37, 51], positioning the human-in-the-loop [45] in a fundamental role of responsibility and awareness of their musical gestures.

3.4.2. Signal Processing and Analysis

The percussion performance is captured and sent in real-time to the computer running Somax2. As shown in Figure 4, the signal is analyzed using Somax2’s system of influences [10] [15] [16], categorizing onset (tempo), pitch (melodic content), and chroma (harmonic content). As mentioned in Section 3.2, different algorithms are applied based on instrument tuning, with `bonk~` for non-tuned and polyphonic material, and `yin~` for melodic sections.

3.4.3. Rhythmic Synchronization

The piece encompasses sections with distinct rhythmic character. Various techniques are employed to achieve precise synchronization. For synchronized rhythmic interventions with different meters, the beat tracker introduced in Section 3.3 was used, complementing Somax2 reactive capabilities. Each corpus was created with different time and rhythmic subdivisions, according to the various sections of the piece, as described in Section 3.1 and as shown in Figure 2. Somax2 interaction parameters were used to control in real-time the flow and adapt the response of the system, according to its navigation model (see Figure 5). In particular, the *output probability* parameter has been highly used to control the density of the material played by Somax2, while the different *weights* for internal or external melodic and harmonic layers controlled the listening direction of the model itself, balancing the different incoming influences (as detailed through the navigation model in Section 3.4.1). Rhythmic strategies implied also

the changing of different tempo in the players, as well as the use of the *cut* parameter to enhance the temporal synchronisation of the players and the live musician (see Figures 7a and 7b). This particular parameter works on the flow of onsets, controlling whether the currently played event should be interrupted or not. By turning it on, the current event is interrupted when a new onset arrives, triggering immediately the generation of a new event, and enforcing temporal synchronization via the beat tracker. Thanks to these strategies we were able to structure different temporal synchronization levels, and we could recombine the corpus based on the related interaction strategy for each section. Furthermore, thanks also to its *continuous* mode, Somax2 is capable of overturning the interaction system based on reaction to influences (described in Section 3.4.1) and propose material, not only waiting to react to an incoming musical input, but starting the interaction, and then dynamically adapt to it as new influences arrive [29].

3.4.4. Corpora and Cues

22 MIDI corpora have been used to align with Xenakis' compositional processes and rhythmic interactions. These are loaded into 2 Somax2 players during the performance. 16 cues facilitate corpus loading and piece navigation. Player characteristics are dynamically adjusted in cues, enhancing the interpretative nuances. Dynamics are controlled via the Arturia MiniFreak's ⁴ master volume potentiometer, spanning from piano to fortissimo. The Novation Launchcontrol XL ⁵ facilitates real-time interaction with cues and internal Somax2 parameters.

These strategies establish a framework for a successful integration of live performance and Somax2-generated elements, ensuring a faithful yet co-creative rendition of the piece by following the original score while playing and manipulating the different parameters (see Figures 7a and 7b).



Figure 7 – Overview of the same Somax2 player in two different sections of the piece. Note the different settings of the interaction parameters as described in Section 3.4.3

4. <https://www.arturia.com/products/hardware-synths/minifreak/minifreakv>

5. <https://novationmusic.com/products/launch-control-xl>

3.5. Technical Setup

For the performance at Klang Festival ⁶ at the Royal Danish Academy of Music in Copenhagen on June 6th, 2023, the percussion ensemble comprises a vibraphone, two wood blocks, two bongos, three tumbas, four tomtoms, a bass drum and seven flowerpots. These instruments are captured using overhead narrow condenser microphones, with each group of percussion instruments assigned to a separate microphone pair (see Figure 8).

The audio from the percussion is routed to an Ableton Live session, and then to a second computer running Somax2. Two computers are used to separate the tasks : on the first one, we captured the percussion sound sources and grouped them as pairs of stereo signals, according to the different percussion groups played in every section ; these signals are sent to the second computer which is in charge of the performative co-improvisation side, running Somax2 and being controlled by one of the performers.

Somax2 serves as the core generative co-creative system for the performance. A Max/MSP patch facilitates real-time communication between the external musician and the software. The Somax2 players are set to MIDI mode, allowing them to interact with the pre-transcribed MIDI corpora corresponding to different composed sections (as discussed in Section 3.1). The MIDI output is sent to the Arturia MiniFreak for sound generation, and then delivered to the front of house as a stereo signal.

To reconstruct the harpsichord sound in *A.I. Komboi*, a digital harpsichord tone was synthesized using physical modeling techniques based on Karplus-Strong string synthesis [38, 39, 58] on an Arturia MiniFreak hardware synthesizer. The Arturia MiniFreak was chosen for its versatility and capability to combine dual digital sound engines with analog filters, modulations, effects, and two oscillators. It features a VST version (MiniFreak V) for advanced preset management and seamless integration with the physical keyboard. Additionally, it provides MIDI in and out functionality, crucial for sending MIDI messages from the Max/MSP patch used in the performance. A Novation Launchpad XL is used to control Somax2 parameters and navigate the piece, with a direct connection to the Max/MSP patch.

4. DISCUSSION

Focusing on Iannis Xenakis' composition *Komboi*, our goal was to reimagine this seminal piece through the lens of co-creative improvisation. The use of the AI-driven software Somax2, was a central contribution in this research. This software proved to serve not only as a tool for pure improvisation, but it also facilitates a compositional approach to the creative process. This exemplifies a typical paradigm of contemporary music composition by extending both compositional and improvisational practices, where *comprovisation* is already well established as a form

6. <https://klang.dk/2023/program/lorenzo-colombo-debutkoncert>

6. ACKNOWLEDGMENTS

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