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The Application of Somax2 in the Live-Electronics Design of Roberto Victório's Chronos IIIc

A aplicação do Somax2 na eletrônica em tempo real de Chronos IIIc, de Roberto Victório

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Abstract: This article details the development of a computational patch designed for real-time processing in the composition of *Chronos IIIc*, originally written by Brazilian composer Roberto Victório for solo cello. In this version, the piece incorporates an additional layer of electronic elements. Initially, we provide a historical and structural analysis of Victório's compositional project. Following that, we explore the functioning of Somax2, a computational system dedicated to real-time improvisation embedding reactive multi-agent interaction and an AI model based on machine listening and statistical learning. Building on this understanding, we present the process of electronic realization of the piece, investigating how the parameterizations of available modules can replicate the interactions envisioned by the composer between the cello and

the orchestra in one of the versions of the work. Finally, we share results obtained during the execution of the design, highlighting relevant aspects of the performance.

Keywords: artificial intelligence. computer music design. musical performance. musical composition. live-electronics

Resumo: Este artigo detalha o desenvolvimento de um patch computacional destinado ao processamento em tempo real da peça *Chronos IIIc*, originalmente composta pelo brasileiro Roberto Victório para violoncelo solo. Nesta versão, a obra incorpora uma camada adicional de elementos eletrônicos. Inicialmente, oferecemos um relato histórico, seguido de uma análise estrutural do projeto composicional de Victório. Em seguida, exploramos o funcionamento do Somax2, um sistema computacional dedicado à improvisação em tempo real, fundamentado interações multiagentes e um modelo de Inteligência Artificial baseado em escuta de máquina e aprendizado estatístico. Com base nesse entendimento, apresentamos o processo de realização eletrônica da peça, investigando como as parametrizações dos módulos disponíveis podem reproduzir as interações concebidas pelo compositor entre o violoncelo e a orquestra em uma das versões da obra. Finalmente, compartilhamos resultados obtidos durante a execução do design, destacando aspectos relevantes da performance.

Palavras-chave: inteligência artificial. design de música computacional. performance musical. composição musical. eletrônica em tempo real.

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1. Introduction

The possibility of computers to act as musical agents has been explored since the beginning of the development of this sort of machinery. Dating from autonomous devices like musical boxes to Charles Babbage's Analytical Engine (Copeland, 2004, pp. 28-29), this has been a quite constant desire of scientific research (Turing in Copeland, 2004, p. 449). However, more than just obtaining data for later musical performance like the Illiac project did in 1957 (Hiller, 1959), it has been investigated since the 1970s how computers can be "free" to generate musical structures by themselves after human prompts, and most properly, by prompts also performed as musical structures, resulting in actual human-machine musical interaction (Lewis, 2007).

In this article, we continue this inquiry by reporting and reflecting on the computer music design of a live-electronics part for *Chronos IIIc*, originally written for solo cello by the Brazilian composer Roberto Victório. In doing so, we propose to describe the structure and functioning of Somax2, a Max-based system that uses concatenative synthesis to provide musical outputs after parameterized matches with the sound played by one or multiple performers in real-time. The system was developed initially to convey improvisational demands, so we present here its potentialities also for compositional uses, reflecting how the unpredictability of its results can be useful to musical discourses with a closed form.

Firstly, we proceed with a musicological description of Roberto Victório's original compositional process to demonstrate how our endeavor aligns with his initial intentions. We analyze another version of the same written piece with the support of his analytical writings, interviews, and discussions with former collaborators. Secondly, our aim is to present an introduction to the functioning of Somax2, providing practical and critical knowledge of its operation. This enables the reader to understand the computer music design reported in the last section.

This project is an interinstitutional research collaboration, connecting musical performance to software development. Consequently, it results not only in an experiment but also in an actual performable and performed piece, live-premiered at the *Simpósio Internacional Música Nova 2023* and recorded at the IRCAM Studios (*Salle Luigi Nono*). The video is available here: https://youtu.be/kHpMCB54HKI?si=bSRnI2O-cXau-fqP.

2. *Chronos III* by Roberto Victório

Roberto Victório is a composer born in Rio de Janeiro, Brazil, in 1959, and has been associated since 1994 as a Professor at the Federal University of Mato Grosso. His catalog comprises more than two hundred works and is nationally and internationally known for the energetic music and his long contact with the Bororo people from West Brazil, including many stays living in their villages. This connection transformed Victório's music, and its impact is evident in both its timbral and temporal aspects. In this section, we provide an introduction to the most played set of pieces among his works, the *Chronos* series. We present its main subject, features, and how this path led to *Chronos IIIc*, the focus of this article.

2. 1. The *Chronos* Series

In 1994, the composer Roberto Victório was hired by the Federal University of Mato Grosso as a conductor for the University's Symphony Orchestra, a connection that would lead to a professorship in the following years. Besides the academic connection, this venture into the inner parts of Brazil brought Victório closer to the most isolated ethnicities enduring in this part of the country. The interest in ancestral rites was already present in Victório's Master's Dissertation, "Contemporary Music and Ritual," defended at the Federal University of Rio de Janeiro in 1991. Going back even further, this opportunity fulfilled a long-held dream of young Roberto Victório, who decided to become a composer after listening to Béla Bartók's "Divertimento for String Orchestra" at the

age of fourteen (Victório, 2023a, 3'50"). Bartók's influence becomes evident when observing the impact of ethnomusicological research on Victório's writing and the abundant use of alternated time signatures and complex rhythmic structures.

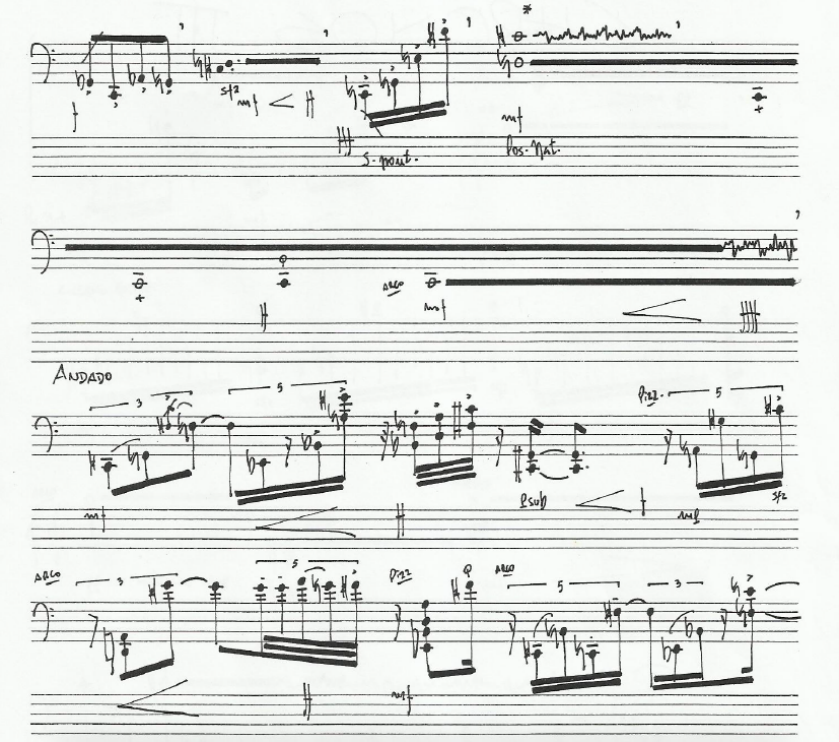
Therefore, being able to be close to the Bororo people was a watershed moment in his career. The Bororo are one of the hundreds of first nations living in Brazil's territory, occupying lands across the Mato Grosso state. According to National Foundation for Health, the ethnicity had in 2006 1392 people indwelling their communities (Serpa, 2021). While residing in the capital of Mato Grosso state, Cuiabá, Victório was able to delve deep into the countryside, making multiple visits and stays within their villages, participating in their many rituals. This experience was driven by the belief that anthropological research on this people's culture was naive in its approach to their musical practices. Claude Levi-Strauss (1957), for instance, had mentioned in his influential ethnography about the Bororo people how their belief in the spiritual power of rattles was relevant to the structure of the ritual but never described in which musical setting this instrument was played.

This gap was addressed scholarly in Victório's Doctoral Thesis developed at the Federal University of Rio de Janeiro state between 1999 and 2003, culminating in many articles and the book "Bororo Ritual Music and the Mythical Sound World" (2016b). This musical exploration was also evident in a set of pieces that started to be written in 1996 after his first ethnographic trips—the *Chronos* series.

The first *Chronos* was conceived as a single piece for flute and percussion in 1996 but was never performed until 2009 due to its technical demands. In 1998, after a commission from flutist Odette Ernst Dias for a piece for solo flute, Victório decided to follow the compositional path started in the piece of 1996 and assigned the title *Chronos II* to the piece, premiered in Colombia in 1999 (Victório, 2023a, 5'40"). The connection between both lies in the title *Chronos*, Greek for time, representing the attempt to embody the temporal dimension in its duality, either as metrical time or the spiritual time accessed in ritual practices (Victório, 2016a, p. 48). The same approach was employed in the subsequent commission received

by Victório from the Greek cellist Dimos Goudaroullis, also in 1998, which culminated in *Chronos III*, a composition for solo cello. This piece was premiered in 1999 at the VII International Cello Festival of Beauvais in France. Victório implemented a duality within the notation, highlighting a constant contrast between proportional notation, as seen in the first two lines of Ex. 1, and a more relative form of writing, where proportions are merely alluded to in the later lines of Ex. 1. This deliberate choice allowed ample space for each sound to develop into a distinct gesture:

Example 1 – *Chronos III,* page 1, lines 2-5.



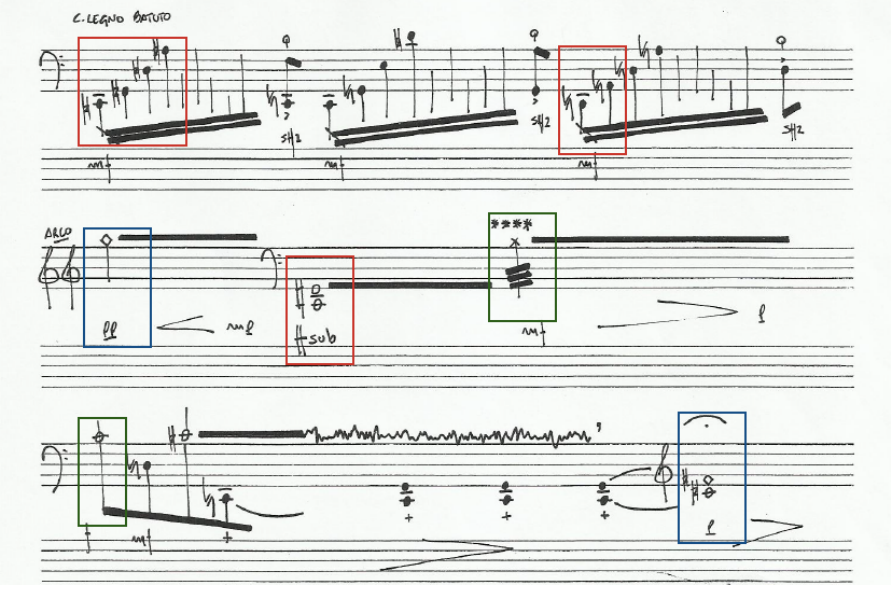
Source: Composer's Manuscript
Image description: 4 lines of the score with 2 lines of open notation and 2 lines of strict written rhythms.

The score does not have a single time signature therefore its rhythmic discourse is complex and intricate but still free to breathe and to give proper time for each gesture to be played. This writing is not only a composition device. Still, it is the expression of the composer's intent of bringing the temporality of ritual music to contemporary classical music, where the "time that governs each axis, and which has individual internal times, acts as a 'sectionalizer' and delimiter of borders, causing a closing at each stage, and

establishing a level of ideation that transforms into the actuality of the notation and pre-materializes in the performance" (Victório, 2023b, p. 73). This conception makes *Chronos III* a very energetic and gestural piece, where the sections never repeat themselves due to the freedom given to the cellist of creating a sense of time after their own affective experience in performing this ritual of sounds.

Victório also demonstrates remarkable gestural control in the piece, managing complex layers of timbers and different modes of attack in a frenetic alternance whilst keeping the fluency of performance. This is undoubtedly since he is a virtuoso performer; graduated in Guitar Performance under the guidance of the late Turíbio Santos, he was also an accomplished cellist, playing in many orchestras and ensembles in Rio de Janeiro when he was young. This experience is crucial to the level he reaches of combining complex writing to the playability of the pieces, which in fact give a lot of pleasure for the players. This also explains how he wrote such an innovative cello piece without consulting any cellist in the compositional process (Victório, 2023a, p. 23'02"). This hybrid formation is perceived in the way he incorporates gestures like the Barre chords from guitar playing to the cello (Ex. 2, red boxes) and the intertwined use of percussive layers (Ex. 2, green boxes) amidst the more conventional cello playing.

Example 2 – *Chronos III*, page 3, lines 3-5.



Source: Composer's Manuscript
Image description: 3 lines of the score with Barre chords (red boxes), percussive sounds (green boxes), and harmonics (blue boxes).

The polyphony of his writing for a solo instrument becomes complete when he incorporates vocal and whistle sounds, along with numerous natural and artificial harmonics (Ex. 2, blue boxes). These sounds are derived from the sacred flutes played in Bororo rituals, marking moments in the dialogue between singing shamans. They contribute to a rich texture that has the capability to transform a single cello into a complete ritual setting (Victório, 2016a, p. 52).

2. 2. The Expansion Formula in *Chronos IIIb* and An Analysis of Its Interactive Relations

The *Chronos* series reached its tenth and final piece in 2002, as the composer concluded the cycle with the kabbalistic number planned since its inception (Victório, 2023a, 14'07"). All the pieces were performed at significant festivals and venues worldwide, serving as a musical account of the myriad discoveries Victório made during his years of expeditions to Bororo villages. He even composed *Chronos V* for marimba within their lodge. However, in 2010, he received a commission from cellist Fábio Presgrave to write a new piece for cello and string orchestra, to premiere with the Fukuda Camerata at the Campo do Jordão Winter Festival that year. Consequently, he chose to revisit the solo cello piece, creating a full orchestration for strings to be played alongside the original solo cello piece, resulting in what became *Chronos IIIb*.

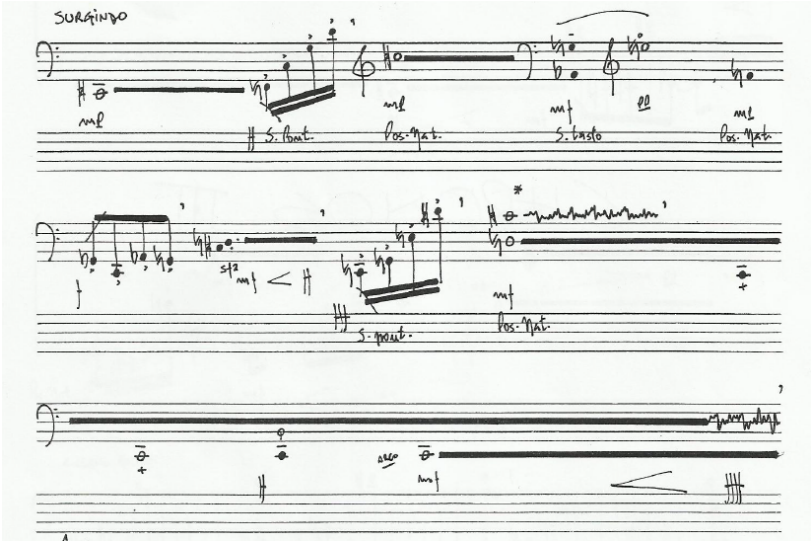
This marked the inception of a compositional formula applied to five of the ten pieces, including eight instrumental variations for *Chronos IX*, originally composed for two cellos (Victório, 2016a, p. 58). Beyond a simple arrangement, each version assimilates the distinctive features of the instruments for which they are composed in such a way that:

> each version sounds almost like a new work, not only due to the timbral connections of each formation, but also due to the spatial occupations used in each version, the gestural dilations – especially in the versions with harmonic instruments –, the coverage of each intervention forming new flashes and new sound arcs, as well as the very different chord superposition relationships in each montage. (Victório, 2016a, p. 54)

Considering the demands of playing with an orchestra, the primary addition in this version was the inclusion of time signatures in many passages where the composer had previously refrained, providing freedom to the cellist (Victório, 2023a, 26'15"). Nevertheless, there are still sections where the score lacks bar lines, necessitating the use of the full score for each musician in the orchestra. This requirement demands significant commitment and attention from each player, resulting in a highly active chamber music environment[1]. Consequently, these numerous additions, coupled with the insertion of orchestral interludes during the solo cello fermatas, introduce a completely new dynamic to the music. In many passages, the cello part, which previously served as the main line, now resembles an accompaniment. From this general outline we can point more precisely the specific procedures the composer used to create an orchestral setting from a solo cello part.

In the initial section (Ex. 3), the solo cello fades in a low C#, and in the first three lines of the piece, long notes are steadily sustained while short gestures interrupt the continuous flow with abrupt energy injections:

Example 3 – *Chronos III,* page 1, lines 1-3.

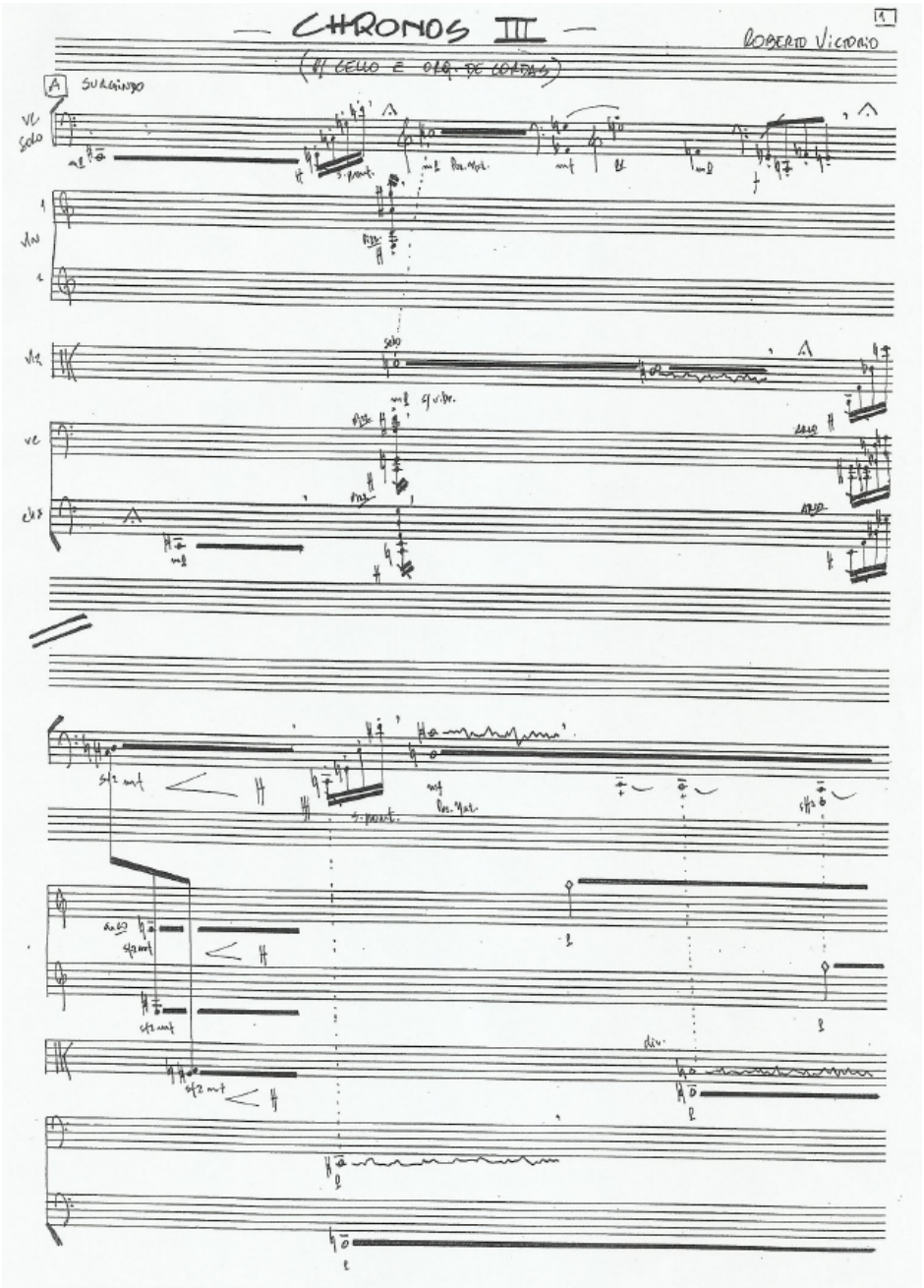


Source: Composer's Manuscript
Image description: 3 lines of the score with the two kinds of materials.

1 Conclusions drawn from a performance of the first author as the soloist with the Campinas University Orchestra in 2022, conducted by Cinthia Alireti. A video of the performance is available in: https://www.youtube.com/watch?v=XyUK7Yz8M6w

The orchestral version maintains the same connection between materials and their role in influencing the flow of energy, where long notes layer the steady texture in a cumulative process, interrupted from time to time with attacks of entire sections shortly diphase from the cello:

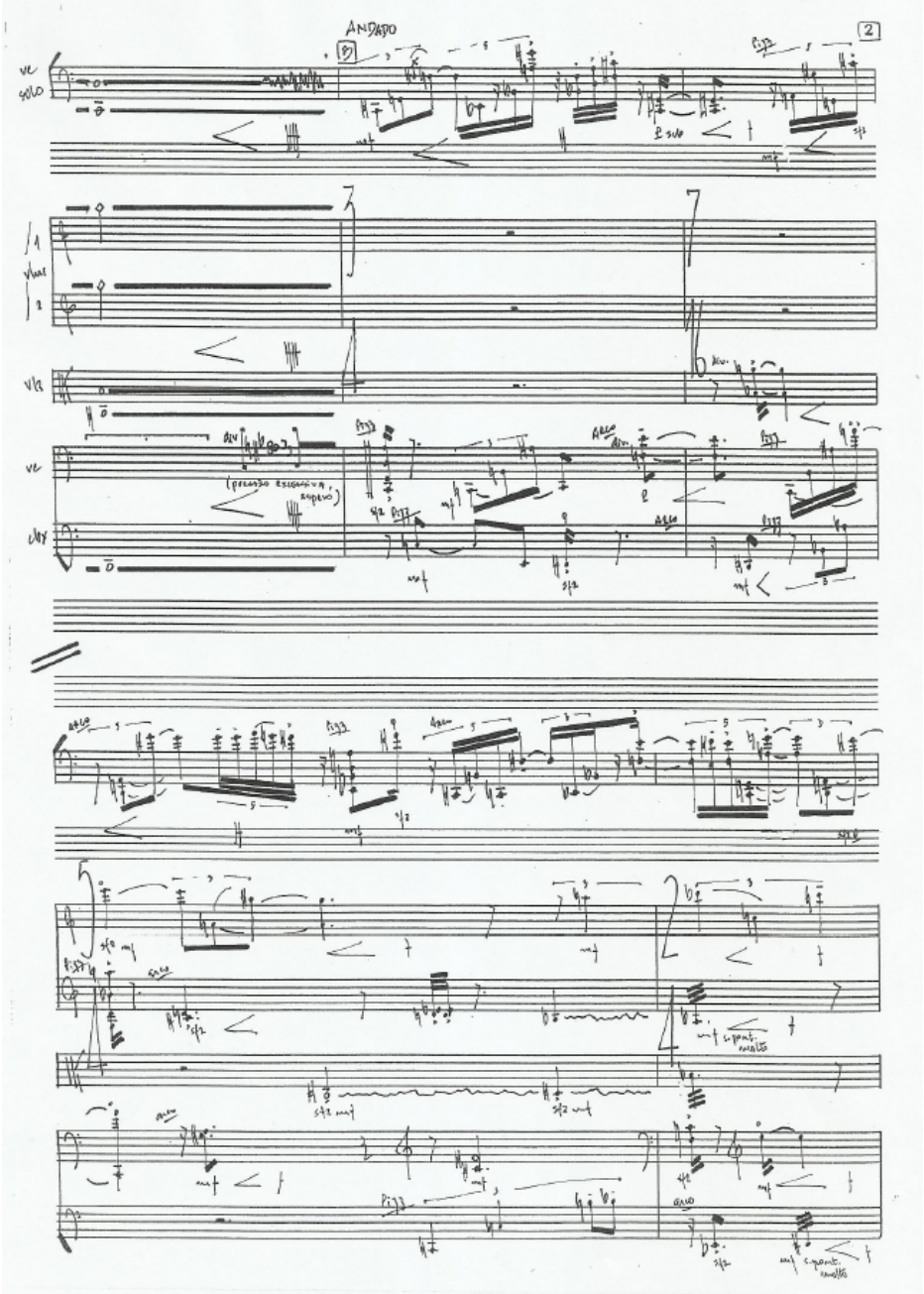
Example 4 – *Chronos IIIb*, page 1



Source: Composer's Manuscript
Image description: First page of the orchestral version.

In the excerpt that follows (Ex. 5), the proportional notation of the cello part demands the addition of time signatures. A strict polyphony builds up here with independent trajectories of each orchestra's section, while the cello section, despite the dislocated attacks and subdivisions, is set close to the soloist in the timbral aspect:

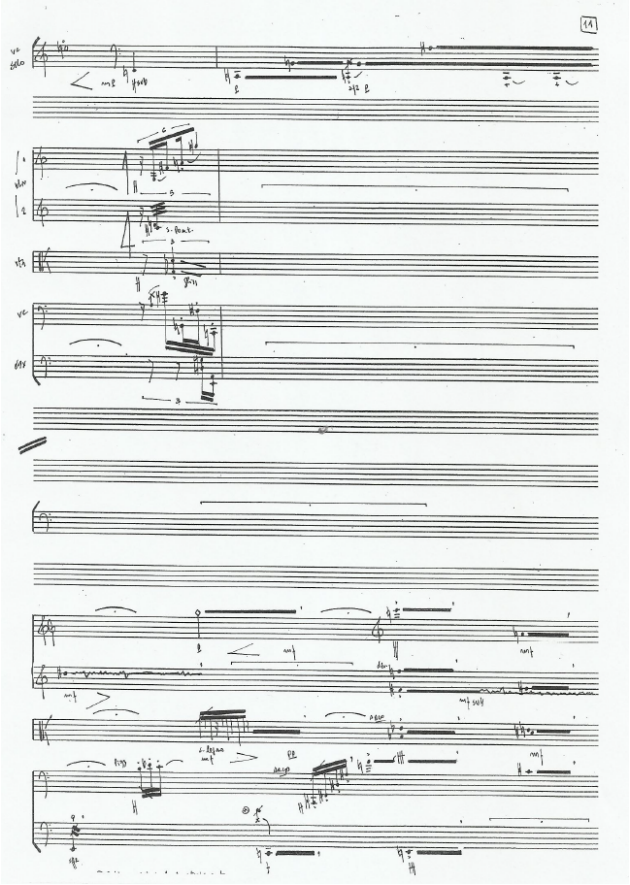
Example 5 – *Chronos IIIb,* page 2



Source: Composer's Manuscript
Image description: Second page of the orchestral version.

The first two pages of *Chronos IIIb* illustrate the general procedure applied in its entirety: the extraction of materials and relations between materials from the solo part, for further amplifying and, in many parts, actualizing connections that were only virtual or quite discrete in the original. In other words, the orchestra plays like a gestural resonator, not only sustaining or accompanying but developing different expressive paths from directions already contained in the solo cello piece. This involves pitches that were not present in the original cello part, leading to harmonic expansions. Also, each part has its particular expressive interest with such a plurality that they are connected only by their temporal profile, in the sense proposed by the composer. Even orchestral interludes (Ex. 6) keep developing materials just played by the solo cello, resulting in new dialogical settings for the same ideas from before:

Example 6 – *Chronos IIIb,* page 11.



Source: Composer's Manuscript
Image description: Eleventh page of Chronos IIIb, including an orchestral interlude.

In sum, the expansion formula adopted by Roberto Victório breathes new expressive life into his pieces, dealing not only with the original material as pitch settings to be harmonized but also considering their gestural forces. It seeks ways to reconfigure these gestures according to the physical constitution of a different instrumental variation as an ensemble of soloists, resulting in a diversity of forms for the same gestural setting. To systematize this compositional procedure, our best effort may be to identify the modes of interaction between the original part and the expanded part. We propose this in the table, adopting the composer's rehearsal letters as a method of sectioning the piece:

Table 1 – Analysis of modes of interaction between the solo cello and the orchestra in *Chronos IIIb*

Section	Gestural features of solo cello	Modes of Interaction
A	Long and steady notes cut by short-note gesture	Long notes are replicated by the orchestra; short gestures are equally repeated with a short delay
B	Tuplets and quintuplets with a strict pulse and fast alternation of modes of attack	Polyphonic layers rhythmically displaced in relation to solo cello; cello section follows the soloist modes of attack
C	Long note followed by the proliferation of the short-note gestures in a sequence of fast notes	Long notes are sustained as a harmonic accompaniment to the soloist's fast passage
D	Short notes with fast alternation of modes of attack, including percussive and singing sounds	Short delayed gestures following the soloist's modes of attack
E	*Col legno* attacks interrupted by Bartók pizzicato; low string pedal and melody; fast alternation of mode of attack with preponderance of harmonic sounds	Attacks simultaneous to Bartók pizz.; resonance of *col legno* attacks; long notes are sparsely played, and the section ends with an accumulation of long notes
F	*Col legno* chords interrupted by Bartók pizz.; harmonic and long notes are occasionally interrupted by grainy sounds (pizzicato and percussive sounds)	Long notes are sustained with occasional short notes
G	Material similar to section B	Polyphony as Section B

H	Short-note gestures with fast alternation of modes of attacks; addition of layers of pizzicato while singing	Pause (silence)
I	Most complex gestures of the piece with very fast alternation between modes of attack, percussive sounds and singing	Polyphony of short notes
J	Long notes in *piano* are increasingly interrupted by sounds in *forte*, both pitched and percussive	Imitation of the soloist's modes of attack
K	Short notes with shifts of modes of attack; ends with a three-strings texture (open string, dissonant interval, and left hand pizz.)	Sparse short notes; pause during three-strings melody
L	Long notes until *forte subito*; three-strings melody	Long notes and fast gesture in *forte subito*; pause during three-strings melody; interlude short-notes material from previous sections
M	Long notes until *forte subito*; sequence in pizz.	Long notes and pause during *forte subito*; grainy sounds during soloist's pizz.
N	Rhythmic fast passage	Polyphony as Section B and interlude with long notes accumulation texture.
O	Long notes in harmonic and low note with percussive sound	Harmonics and low-register cluster in the end
P	Fast gestures with alternation of modes of attack	Sparse pizz. in low strings sections
Q	Long notes	Long notes
R	Reprise of Section E	As Section E
S	Fast tremolo passage	Accumulation of long notes and final chord
T	Alternation of long high notes with short gestures	Sparse high notes and short gestures
U	Long notes and final short gestures	Polyphony with preponderance of high notes
V	Three-strings melody; pizz chords; three-strings melody until it fades out	Increasingly sparse long notes

Source: Authors
Table description: Rows to the piece's sections and columns to its gestural features and main modes of interaction.

In organizing the piece's materials and the ways the composer expanded them for orchestral forces, this table points to an economy of means, relying on the independence of each part to provide the same liberty intended in the solo version, also in the orchestral version. Of course, grouping many musicians demands adjustments in the score, but the temporal duality that features in the piece remains effective. In conclusion, this formula can be replicated in other settings by considering the proper gestural force of a new set of agents.

2. 3. The *Chronos IIIc* Project

Still, in the second semester of 2010, Roberto Victório was touring to release the album *Chronos*, containing the integral recording of the ten pieces, including *Chronos III*, performed by Dimos Goudaroulis. After a launch concert at São Paulo State University, the same program would be performed at the *Bienal de Música Contemporânea* in Cuiabá. However, the Greek cellist would not be available to play. Victório was prepared to play the cello but desired something different for this concert, so he decided that a version for cello and electronics could bring the novelty that the piece needed (Victório, 2023a, 29'45").

Victório is not a computer music designer, so he joined forces with composer Cristina Dignart, relying on her assistance to expand *Chronos III* into a new version with electronics, entitled *Chronos IIIc*. The composer had a general idea rather than a clear plan of how the piece could sound. In rehearsal with Cristina, they decided section by section how they could apply the available means to get a result approved by him. Cristina Dignart reports how the piece was made in the premiere:

> We did the entire process in real time and there is no fixed part. Before the concert we rehearsed with Roberto, where he indicated the use of effects he liked (Delays, phasers, etc.) and these were triggered on a guitar pedalboard in real time. (...) A guitar pedalboard was used that already

> had its effects on it, as well as a Max patch with a ring modulator, which was made by my husband [the composer Ticiano Rocha] (Dignart, 2021)

This situation motivated the present project as *Chronos IIIc* never took a final form with fixed material for performance. Its background of versions with wide openness provides a rich and clear field for electronics. However, its rhythmic complexity does not allow for an electronic resource as fixed media. Additionally, the heterogeneity of sounds and the intensely responsive interactions demanded by the expansion formula indicate the difficulty of designing real-time processing with live-electronics means.

In conclusion, the structure of the piece clearly demonstrates its potential to receive a live-electronics part, but its temporal demands, which constitute the main feature of the piece, make this realization a challenging one. Fortunately, as this project was stuck only as a nice idea, the Music Representations Team (REPMUS) at IRCAM released Somax2, a system designed for improvisation in real-time that is able to provide stylistically coherent musical structures while interacting with previously recorded collections of music materials, called corpus. Considering the stylistic continuity in Roberto Victório's catalogue and the distinctive results of his expansion formula, this appeared to be a productive approach to materialize *Chronos IIIc*.

3. Somax2

To understand how Somax2 met the creative demands of *Chronos IIIc*, we first need to explore how a computational agent can engage in dialogue with a human musician beyond predefined responses. We present the basic architecture of Artificial Intelligence to explore how they can offer unique elements for music-making, especially in improvisational settings. Next, we provide a brief introduction to the system's functioning, explaining how the Repmus Team achieved their research goals in Somax2, primarily through its modular structure adopted in our computer music design.

3. 1. Artificial Intelligence Systems Architecture

Artificial Intelligence is a general term given to virtual machines able to perform actions that we usually attribute to the necessity of a mind (Boden, 2018, p. 1). Generating wind through repetitive circular movement is not typically considered an activity that requires mental processing. Understanding the political forces implicit in the verses of a poem is not something most of us can grasp without considerable reflection. This principle seems clear when we consider the distance between a fan and discourse analysis; however, the line gets very blurred when we think of actions that require some kind of reasoning, either very instinctive or reductive. Therefore, just as diverse as human intelligences are, artificial intelligence can be.

Some basic attributes define intelligence in computational systems of this category: 1) capacity for problem solving; 2) learning from the environment; 3) development of cognitive structures; 4) goal orientation (Medeiros, 2018, p. 19). Since the definition of how humans perform these tasks also varies, the architecture of an Artificial Intelligence system changes based on the chosen concept of human intelligence as a model, resulting in a diversity of AI ontologies (Medeiros, 2018, p. 23). The fundamental dilemma, as in anthropological ontology, is how we can make sense of the connection between mind and body. Therefore, the project of AI agents must address how an algorithmic chain perceives the world—how it acquires and produces signals that manifest its decisions (Medeiros, 2018, p. 43).

Following these premises, we can first define the components of an agent: first, a *body*, which represents a way of perceiving and acting in an environment; second, a *controller* that receives percepts and decides how to act in relation to them. Finally, even though it is not explicitly considered a part of the "being," our anthropological exploration with Victório has provided us with the foundation to regard the *environment* itself as a third component of the agent.

This perspective considers that interactions, in line with Bakhtin (1982), propel human life rather than being a mere accident (Poole & Macworth, 2023, p. 54).

Assuming this artificial being is alive, it does not perceive and act in a vacuum of reasoning. It brings a given set of basic knowledge about its inner and outer world that influences all future learning it can add to this set, known as a *belief state*. This belief state also includes the memory it creates as it acts (Poole & Macworth, 2023, p. 55). Additionally, it is relevant to mention that as the body is known by its capacities for acting and perceiving in the environment, the controller can be known by its functions of transitioning from a former belief state to a new one after its engagement with a percept, and also by its function of commanding actions after the encounter of a belief state with a percept (Poole & Macworth, 2023, p. 57).

With the algorithmic structures that articulate these concepts into a real system, we have a finite set of unknowns to be replaced by any sort of data, including sounds. Between these data, there is a certain way of relating them, resulting in the interaction of all elements according to these pre definitions. Nonetheless, it is important to remember that as autonomous as these systems are intended to be, none of them is meant to exist in a world without humans. Therefore, all these paradigms are always situated in a hybrid environment where actual human intelligence is constantly interfering in the AI's design after one's emotions, preferences, and inclinations (Liu, 2023, p. 27). This environment of mutual learning and, in our case, of mutual listening, is probably the most important product of this new environment.

3. 2. Computational Musical Agents at IRCAM

Taking Artificial Intelligence architecture as a framework for understanding computational agents applied to music, we can observe a short history of the development process that resulted in the Somax system. Since its inception in 1992, the

Music Representation Team at IRCAM has been developing ways of modeling music practices into computational representations. Initially, these were compositional formal systems related to individual practices, such as the Messiaen, Xenakis, and Ligeti libraries for PatchWork (Assayag, Rueda, 1993). In 1997, the group introduced the OpenMusic application, which allowed visual programming of creative flows for sound synthesis applied to music-making, expanding the possibilities of compositional modeling (Bresson, Agon, Assayag, 2011).

In 2006, a new system named OMax was released to extend the capabilities of modeling music-making beyond static compositional settings, venturing into the dynamics of improvisational contexts (Assayag, Bloch, Chemillier, Cont, Dubnov, 2006). This system implemented a hybrid use of OpenMusic (OM) and MaxMSP (hence the name OMax), enabling the combination of statistical models to improve the prediction of musical structures and the workflow of previous projects. The resulting body-controller architecture could function as a flexible computational agent capable of learning different styles in real time, marking a significant advancement over earlier computational systems for improvisation with closed algorithmic schemes (Ibid., p. 3).

Relating the AI architecture to OMax's architecture, the Max component serves as the system's body, perceiving signals from a human performer and generating audio signals. The translation between body and controller is facilitated through either OSC or MIDI protocols, providing information for analysis after statistical operations performed in the OpenMusic domain. An important stage in processing the signal involved slicing the data, with segmentation following preset definitions that prioritize specific sound components (Ibid., p. 5).

Stil in 2006, OMax was enhanced with the OFON system, which improved the body's capacities to act by using the sound quality of the environment as a source that embodied raw messages received from the OpenMusic controller. This extension aimed to

create a clone of the sound emission from the human performer, resulting in a homogeneous interaction in the timbral aspect (Assayag, Bloch, Chemillier, 2006).

Following these developments, the Repmus team embarked on creating various applications to improve processes and results for improvisational contexts. ImproteK, released in 2012, emphasized the role of tradition in a computational musical agent's belief state. It sought to add the idiomatic domain of musical language as a dominant factor in the controller's decisions, allowing memory to interfere not only in short-term choices but also in long-term decisions related to formal structures associated with musical genres. Later, this led to the DJazz version, which improved the system's ability to perceive rhythmic structures on a large scale (Chemillier, 2018).

While ImproteK and DJazz focused more on musical genres, OMax took a more immanent approach and evolved into the Somax system in 2012. Somax increased its capabilities in dealing with real-time information with less influence from predetermined musical structures. A major step was the addition of an offline stage in the preparation of a musical setting, involving the creation of a sound corpus—a pre-recorded sound file segmented according to user preferences. These segments are then concatenated based on the controller's analysis of the sound played by the human agent during improvisation. This introduced significant improvements in the temporal dimension, emphasizing rhythmic patterns detected from the human agent's onsets in influencing the computational agent's coherent flow. Another improvement was the real-time signal analysis as a chromagram, detecting pitch with higher energy and using the others as factors to influence the matching with the corpus (Bonnasse-Gahot, 2014). To facilitate the new corpus-based logic, in 2012 Somax was implemented with a domain in MATLAB, later updated to a Python domain in 2016, running parallel to the Max patch and replacing OpenMusic as the controller (Romeu-Santos, 2016).

In 2017, both streams of computational musical agents, aimed at different aesthetic directions, were combined into a single system called DYCI2—Creative Dynamics of Improvised Interaction (Nika, Déguernel, Romeu-Santos, Vincent, Assayag, 2017). DYCI2 provided the human agent with a balance between more reactive playing and a scenario-based, culturally influenced output from the computational agent. Retrieving improvements from its predecessors, DYCI2 incorporated Max objects allowing a combination of offline stylistically predefined parameters and real-time signals, outputting either MIDI data or audio segments as introduced by the Somax system.

This historical overview presents the technical and aesthetic paths of relevant projects that have become essential to a new project, Somax2. Projects like DJazz and DYCI2 continue to improve, each catering to their unique potentialities, perhaps more suitable for structured improvisation in the former and a kind of hybrid improvisation in the latter, including compositional frameworks. Understanding how each materializes the structure of a computational agent helps comprehend how the modular structure of Somax2 embodies these functions while maintaining freedom from tradition-guided improvisation, a distinction of what the other projects are evolving to address.

3. 3. Somax2 and Its Modular Front-End

In 2019, the Repmus Team unveiled Somax2, marking the third evolution of the system that originated with the OMax and later Somax. Incorporating insights from other computational musical agents for improvisation developed by the group, Somax2 introduces a fresh set of parameters aimed at enhancing responsiveness to human input and refining the matching process with the corpus. Its versatile design enables the integration of multiple human and computational players, resulting in a interconnected environment with varying degrees of interaction – from a self-guided flow independent of human influence to highly reactive modes capable of producing outputs as dynamic as those

generated by the human agent (Borg, Assayag, Malt, 2022; Assayag, Bonasse-Gahot, Borg, 2024).

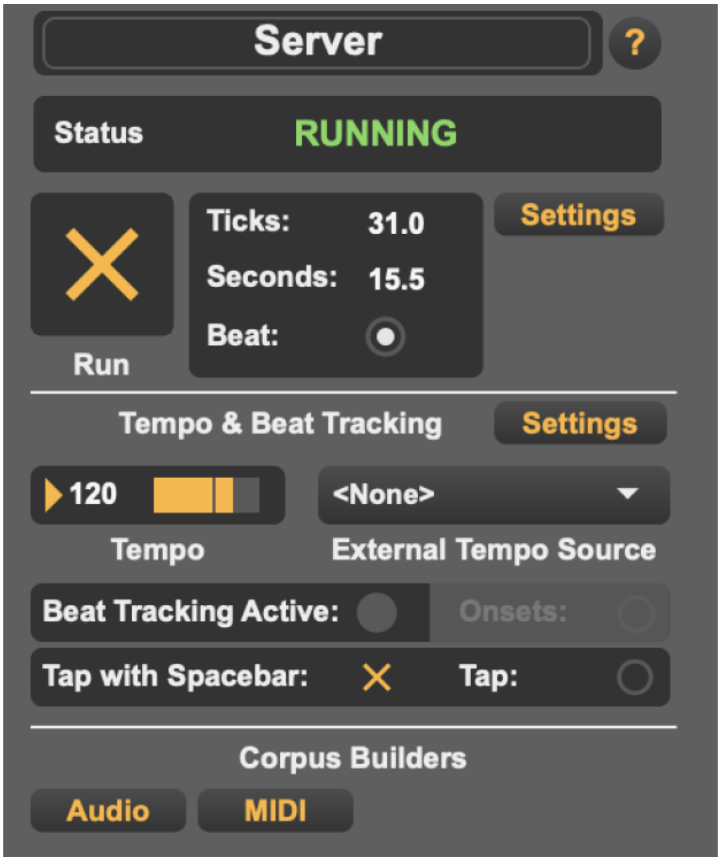
Once again, Somax2 entrusts the corpus with the role of a belief state, expanding its capabilities in offline segmentation to prepare audio or MIDI files as the memory that the system will draw upon for materials during improvisation. The matching process not only analyzes relations of similarity but can also be preconfigured to seek groups with corresponding chromas, ensuring that the result aligns stylistically with the structures played by the human agent. The system's body, implemented in a Max patch, reacts to the human agent's sound by associating segments with its onsets (using bonk algorithm) or its pitches (using yin algorithm), offering the flexibility to switch listening modes during performance. As reported in its last version, Somax2 advances further with a generative model implemented as a Python back-end responsible for managing corpus building, matching influences and generating output results, communicating with the Max front-end patch through the OSC protocol (Borg, 2019).

The system's body is implemented in the Max environment with a modular approach. A more detailed introduction to this front end is warranted as it plays a crucial role in presenting the later computer music design of *Chronos IIIc*. In particular, in the following sections, we will focus solely on the .app version of each module. These are Max abstractions specifically designed to provide a detailed user interface, and behave as wrappers around the more low-level core objects, providing also features for wireless and dynamic patching (see Section 3 of the Somax User's Guide for a detailed dissertation).

3. 3. 1. Server

The foundation of the modules in Somax2 is its Server (Ex. 7). This Server holds the responsibility of communication with the Python back-end, which operates in a parallel terminal and serves as a backbone for the Players. It is also in charge of managing the temporal relations between the corpus and the Players through the system's scheduler. As a result, the initial procedure for utilizing Somax2 involves initializing the Server:

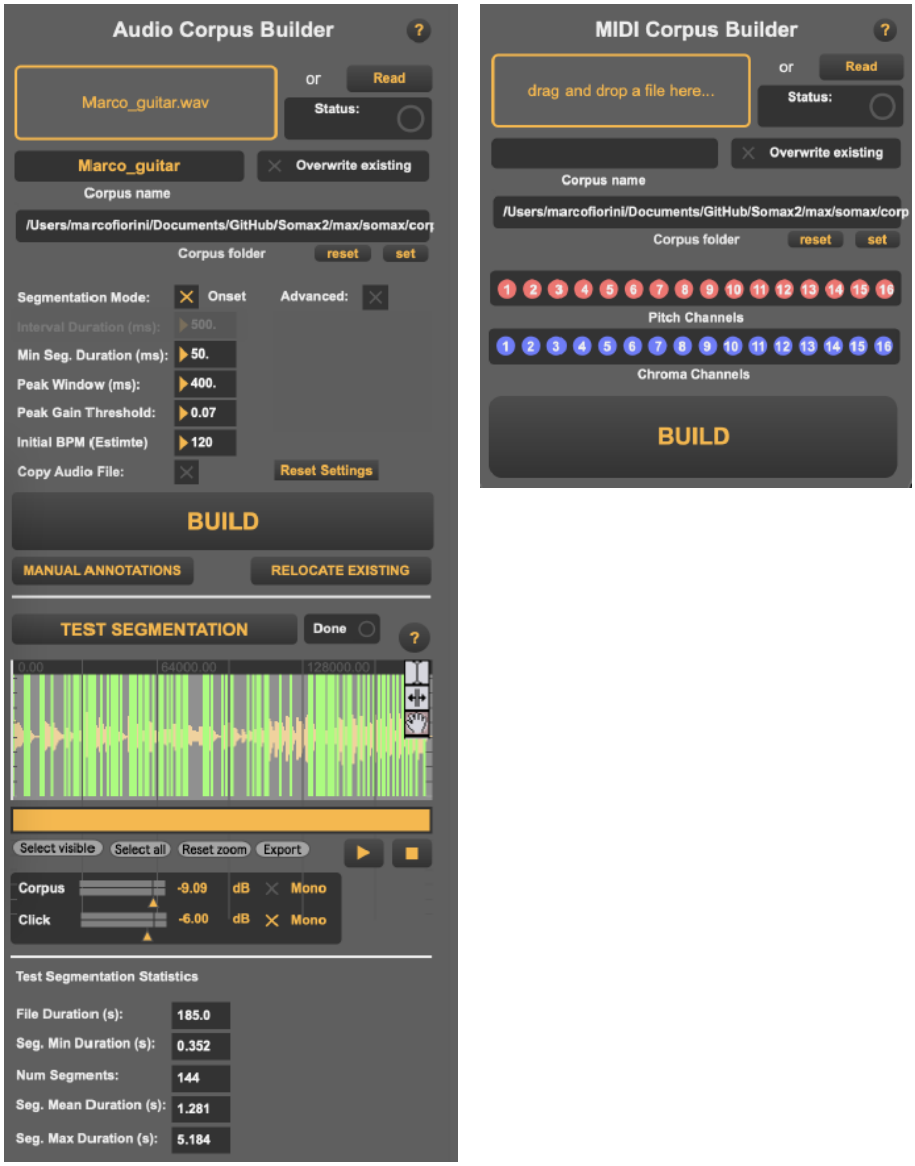
Example 7 – Somax2's Server module



Source: Fiorini, 2013, p. 14.
Image description: A Max module that functions as Somax2's server

As observed, the somax.server.app also incorporates specific audio and MIDI corpus building modules. The corpus builder is typically utilized during an offline stage to prepare a corpus, derived from either an audio or a midi file, thus supplying both modules (Ex. 8). This preparation involves initially uploading a file to its corresponding module, followed by defining the parameters for its segmentation. The segmentation produces slices that are subsequently recalled and played after a matching processing during the performance. Once a corpus is built—comprising the already segmented audio or midi file—it is saved as a .pickle file and is then available for selection by the players later on.

Example 8 – Somax2's Audio (left) and Midi (right) Corpus Builders



Source: Fiorini, 2013, pp. 23, 25.
Image description: 2 Max modules that functions as Corpus Builder after Audio (left) and Midi (right) files

3. 3. 2. Influencers

Once the server is running and a prepared corpus is available, the user needs to define the parameters of the influencers. The influencers are modules in charge of the machine listening part of the system. They can listen both to audio and MIDI live streams, such as musicians, or files, and are responsible for converting these

streams of musical information into a symbolic domain, sending them as influences to other modules of the system (specifically, the players).. As previously noted, Somax2 influencers are versatile and capable of dealing with both audio signals and MIDI, resulting in two corresponding modules (Ex. 9). Additionally, each influencer can directly output their audio or MIDI stream into selected audio or MIDI channels, functioning as an output monitoring for the user who chooses to exclusively imply Somax2 modules for performance. The influencer modules also display the real-time detection of incoming onsets, pitches, and chromas, analyzing and sending them to a player for later matching with a corpus.

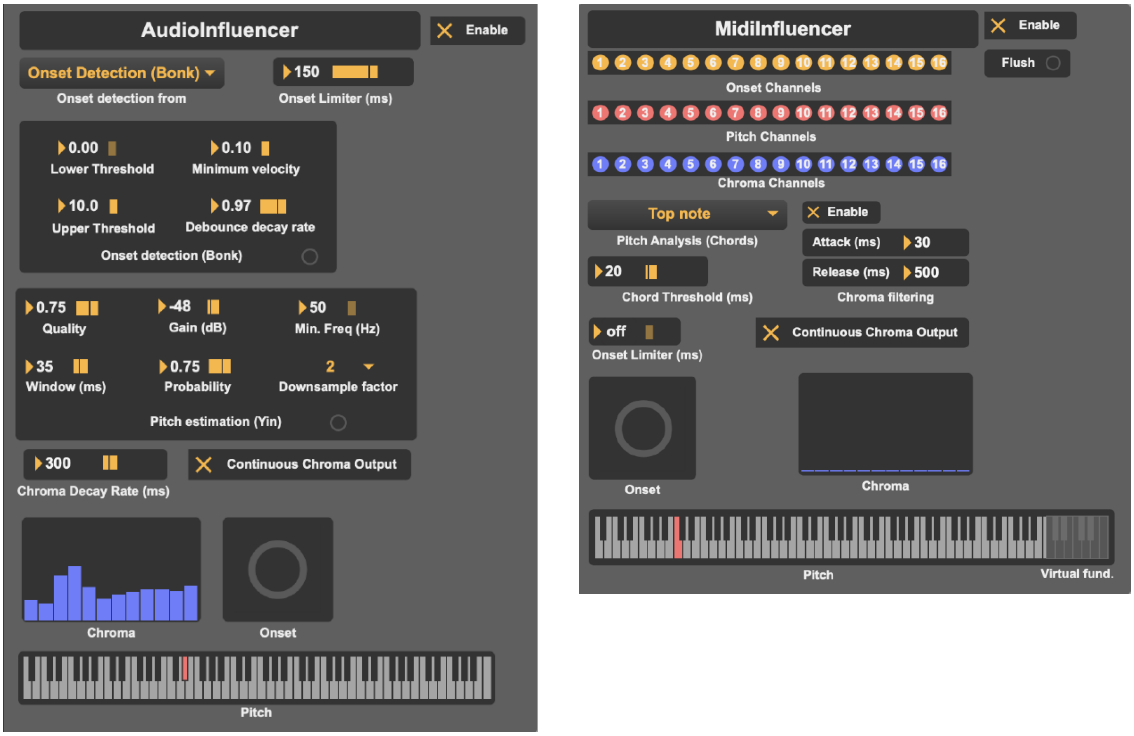
Example 9 – Somax2's Audio (left) and Midi (right) Influencers

Source: Fiorini, 2013, pp. 19, 21.
Image description: 2 Max modules that functions as Influencers after Audio (left) and Midi (right) files

The Influencer also includes a setting panel to manipulate the parameters related to its sensitivity to the signal it is 'listening to'. Both the audio and MIDI versions have parameters for onset detection, allowing the user to define the peak limit preferred for the detection. The audio module features a crucial 'Onset detection from' field that determines whether the influencer is triggered by

envelope attack or changing pitches, resulting in distinct signals to the player. On the other hand, the MIDI module can choose the main note to be analyzed from the top note, the bottom note, or the virtual fundamental, calculated from the harmonicity of the components being played (Terhardt, 1979).

Example 10 – Somax2's Audio (left) and Midi (right) Influencers' Settings



Source: Fiorini, 2013, pp. 20-21.
Image description: 2 Max modules that set the parameters for the Audio (left) and Midi (right) Influencers

Once configured, the Influencer can send the signal chosen by the user to the Player, facilitating a dialogue with the slices of the corpus.

3. 3. 3. Player

The modules collectively form Somax2's virtual body, where the Influencer serves as its organ for perception, and correspondingly, the Player module (Ex. 11) acts as its organ for action. While it offers various parameters for defining how it recalls corpus slices after receiving the signal from the Influencer, it also performs complex tasks such as selecting multiple sources

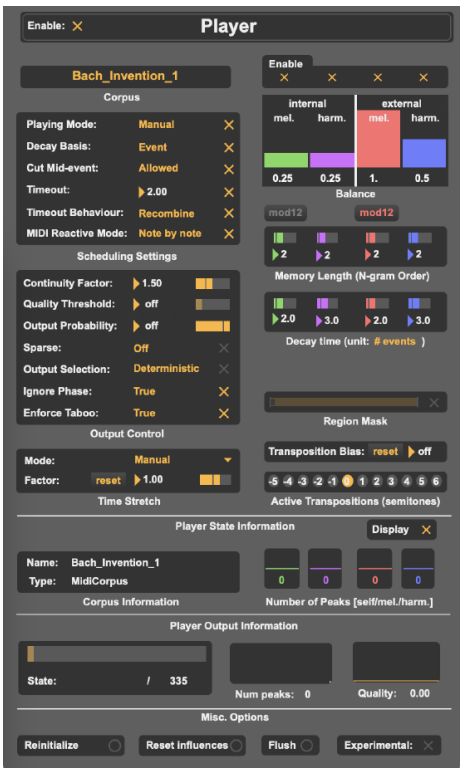
of influence. Additionally, a single patch can feature multiple players, allowing for mutual influence or different belief states, i.e., different corpora, resulting in a complex interactive environment. A significant addition to this project, introduced in the 2.5 version in 2023, is the Sparse mode, which introduces a threshold for the quality of the matches found between the incoming influences and the material stored in the corpus, enabling the player to exhibit a corresponding but less strict correspondence behavior. Finally, when exclusively using Somax2 modules for performance, the Player controls its output settings.

Example 11 – Somax2's Player module

Source: Fiorini, 2013, p. 16.
Image description: Somax2's Player module

The Player module also incorporates a settings window (Ex. 12), crucial for achieving specific outcomes. It manages the properties of the played corpus, determining how much of a segment will be played and whether the user wants segments to be interrupted before their completion. Other three crucial Scheduling Settings introduced in the 2.5 version, addressing the 'liberty of choice' of the player, are the Output probability, regulating the likelihood of the player initiating a new event upon receiving an influence from the Influencer, the Enforce Taboo button, reducing the chances of the same segment being repeated, and the Transposition Bias, which makes the matching area in the corpus wider for close but not equal pitches, eventually transposing a matching corpus event to the same pitch area of the incoming influence.

Example 12 – Somax2's Player settings module



Source: Fiorini, 2013, p. 17.
Image description: Somax2's Player settings module

Reflecting on the functioning of the system, a significant merit of Somax2 is undoubtedly its capacity to be trained by the corpus,

offering a generative feature as its concatenation is always open to different musical prompts from the human agent (Fiorini, Malt, 2023, p. 390). This behavior could be defined as genre-agnostic, meaning that compared with other purely generative systems that produce more standard structures, Somax2 works with specific materials on a navigation model that ensures variety with any kind of music material. Plus, its co-creative aspect requires a human counterpart to enhance the interaction and the results of the system, which is very similar to complex systems (where linear inputs give result to outputs full of unpredictability and unattended complex behaviors). Finally, a noteworthy consequence of the Somax2 corpus-based framework is its strong processing performance, ensuring stability for musical performance settings even when combined with other real-time processing in the same Max patch.

4. A Computer Music Design for *Chronos IIIc*

The distinguishing feature of Somax2 lies in its ability to analyze and retrieve a musical corpus, enabling it to be stylistically coherent with a belief state while interacting with another agent. This unique capability was a pivotal factor motivating its adoption in the computer design of Roberto Victório's *Chronos IIIc*. Victório's compositional approach exhibits a distinctive musical personality across his entire catalog, making it challenging to reproduce using alternative methods. Since Victório is not a computer music designer and the sounds of electronic music are not inherently associated with his work, using only real-time processing resources seemed inadequate. Standard effects wouldn't offer the interactive component embedded in his expansion formula.

The initial plan was to integrate Somax2 into live-electronics objects to introduce a new layer of sounds suitable for Victório's compositional style and provide a means to expand the live cello itself. Additionally, a fundamental premise of this computer music design was to create a stand-alone patch that the cellist could operate while performing the piece. The control mechanism involved a MIDI pedalboard, featuring a footswitch to navigate

through events and an expression pedal to manage volume levels. This approach aimed to enhance the live performance of *Chronos IIIc*, aligning with Victório's unique musical vision and providing an interactive and dynamic element to the composition.

Example 13 – Presentation mode of *Chronos IIIc's* Max patch

Source: Authors
Image description: Chronos IIIc's Max patch in presentation mode

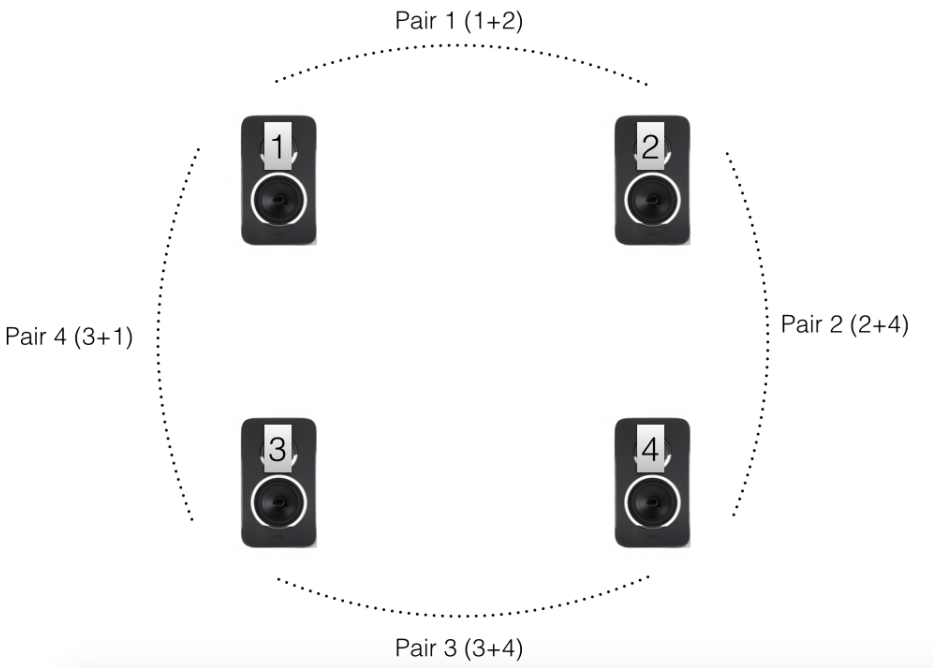
Before reporting the specific goals and procedures related to the design involving Somax2 modules, it is essential to outline some general aspects that informed other functions of the patch and influenced various decisions made during the design process.

4. 1. General Aspects

Although the desire to design *Chronos IIIc* had been present for quite some time, its actual realization was spurred by the convergence of two events: a residency by the primary author at IRCAM in October 2023 and the opportunity to perform a recital at the *Simpósio Musica Nova* in November 2023. These events imposed a beneficial time frame and provided necessary resources for the project, shaping several crucial decisions in its structure.

The residency at IRCAM, where the piece would be recorded for stereo reproduction, influenced the spatialization design. Additionally, the Simpósio Musica Nova in Curitiba offered a 4-channel system, prompting the adoption of a 4-channel logic. This choice had ripple effects on other aspects, such as determining the number of Players in Somax2. The spatial strategy involved conceptualizing the 4 loudspeakers as 4 pairs of stereo speakers (see Ex. 14), enhancing internal relations of movement. This approach aimed to create a compelling sonic experience given the limited number of speakers available for rotation.

Example 14 – Spatialization scheme of *Chronos IIIc*



Source: Authors
Image description: 4 speakers divided as 4 sets

Building on this foundation, the patch design was formulated with two distinct halves: the first encompassing the Somax2 dimension, and the second constituting the live-electronics dimension. The live-electronics components were situated predominantly in the front part of the performance space, whereas

Somax2 was positioned towards the rear, within the audience space. This spatial arrangement aimed to address the challenge posed by Somax2, which generates sounds from virtual instruments not physically present in the performance environment. Situating Somax2 towards the back, it was intended to mitigate the perceived absence of a visual reference for the sound emission. The overall spatial scheme for all sound sources in the electronics followed this general configuration:

Table 2 – Sound layers divided in the space

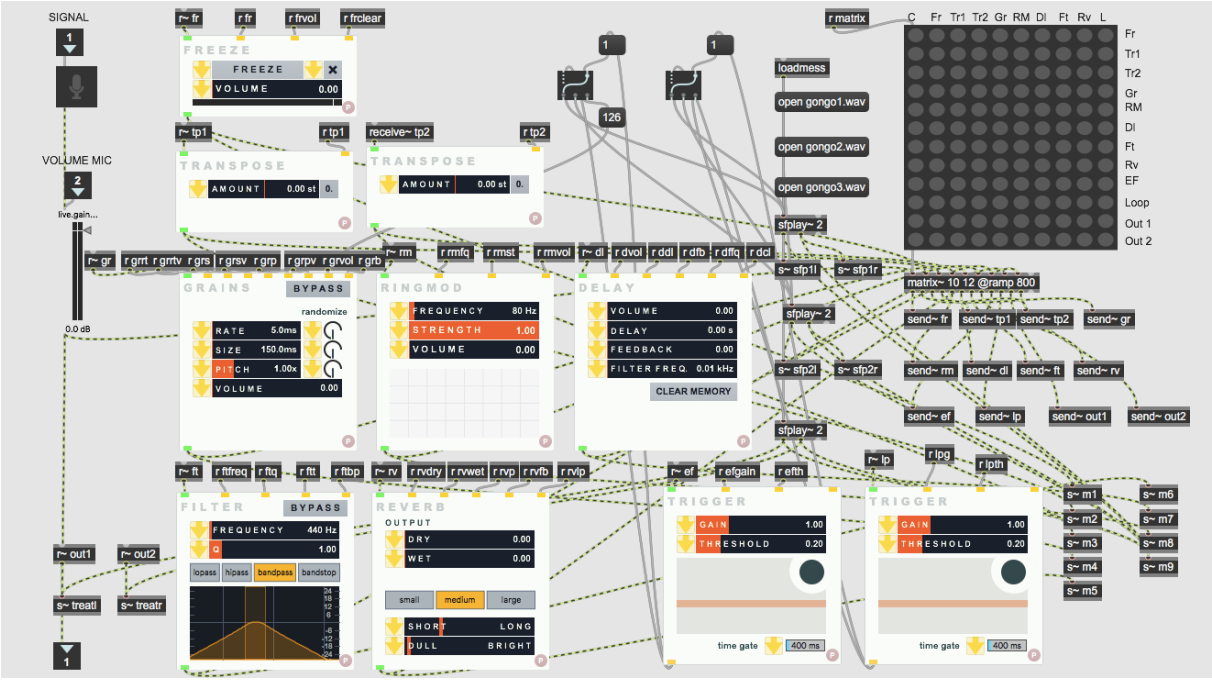
Pair	Live-Electronics	Somax2
1	Live treatment	none
2	Sound files 1	Player 1
3	none	Player 2
4	Sound files 2	Player 3

Source: Authors
Table description: Sound layers in the piece

On the other hand, the live-electronics dimension (Ex. 15) was tailored to accommodate real-time treatments, sound file triggering, and specific processing triggered by an amplitude detector. The majority of these processes were implemented using the 264 package, drawing on prior experience and guidance from composer Hans Tutschku, who collaborated with the package's developer, Chris Swithinbank, and also provided a modular front-end[2]. The signal routing across these modules was facilitated using the matrix~ object, proving to be valuable for subsequent presetting and offering the flexibility of multiple chains for a single sound source.

2 Documentation and download available in: https://github.com/mus264/264-tools

Example 15 – *Live-electronics* subpatch in *Chronos IIIc*



Source: Authors
Table description: Picture of the Max subpatch that controls the live-electronics in the piece.

With this context in mind, we can comprehend the operational adjustments made to the settings of the Somax2 modules and discern the overall framework of the electronic design for the piece.

4. 2. Somax2 as a Compositional Tool

As our previous overview highlighted, Somax2 was specifically developed to function as a computer music multi-agent system capable of real-time interaction with improvising players (including live musicians). All its components are tailored to address the demands of such an environment. However, the unique temporal demands of *Chronos IIIc*, characterized by its irregular tempo and heterogeneous musical materials, require an exploration of whether this improvisation tool can effectively serve a compositional context.

It is crucial to reiterate the aesthetic commitment to the composer's style, which guides the music design. This commitment emphasizes meticulous attention to craftsmanship at both the

material and interaction levels, as articulated in the expansion formula. Table 1 serves as a guiding reference for the project.

Firstly, the gestural features of the solo cello part were examined to extract their distinctive force, as emphasized by the composer. This analysis informs the decision on the materials that Somax2 would utilize as a belief state for interaction, i.e., to build a corpus. Opting for three Somax2 players allows the incorporation of up to three corpora at the same time, enabling simultaneous players on multiple sources. Furthermore, the Max object format of Somax2's modules allows them to receive messages to control their parameters at any time, offering flexibility, including the ability to instantaneously change the corpus that a player is using.

In the process of selecting materials, the decision was made to draw from Victório's cello compositions, with a specific focus on *Chronos IX*. This piece, recorded by the *Phronesis Cello Duo* for the *Simpósio* Música Nova 2021, was considered highly suitable due to its potential to provide gestures and flows aligned with the composer's style[3]. Being part of the *Chronos* series and composed for two cellos, it inherently offered harmonic structures in harmony with Victório's artistic expression.

During the offline corpus preparation stage, the audio file of Chronos IX was pre-segmented in Reaper. This involved carefully cutting gestures deemed essential for specific material categories in the various sections of *Chronos IIIc*. As a result, three pre-segmented audio files were created: *2cellos_long*, *2cellos_short*, and *2_cellos_mixed*.

Further exploration of the timbral texture led to the identification of a transposition opportunity. Sounds from Bororo rituals, specifically flutes and drums, were adapted to the cello as harmonics and percussions on the instrument's body. This transposition process was then reflected back to the electronic domain, giving rise to two additional corpora inspired by Victório's compositions: flutes and drums, based on the pieces *Aroe Enogware*, for Bororo sacred flutes, and *Letha*, for 2 percussionists, respectively.

3 Available in: https://youtu.be/wrTBhS59OX4?si=YDGk7kaltXobHnap

Recognizing the importance of the double bass in *Chronos IIIb* for enriching the low range of the sound spectrum, a corpus recorded by bassist Joëlle Léandre during her residence at IRCAM was incorporated into the Somax2 project. This corpus, named *Joelle*, featured a sound articulation that proved to be highly suitable for the desired nature of long notes. The Somax2 Audio Corpus Builder module efficiently carried out the segmentation of all these corpora, ensuring their effective integration into the project.

Secondly, the modes of interaction analyzed in Table 1 guided the decision on the number of players for each section and the corpus they would rely on. A meticulous process of parameterization, setting, and testing was undertaken for each section to achieve an interaction mode closely aligned with the composer's intentions. Summarily, this involved transposing the analysis of *Chronos IIIb* to *Chronos IIIc* (Table 3), illustrating how the piece can result in a closed structure with specific interaction modes while maintaining flexibility in the segments of the corpora and achieving the required mixture of rhythmical precision and flexibility.

Table 3 – Analysis of materials and modes of interaction adopted in *Chronos IIIc*

Section	Corpora (Player 1 = P1, etc)	Most Relevant Parameters of Interaction (including relevant live-electronics events)
A	2cellos_long (P1)	Sparse mode ON (P1); Continuity mode (P1); Probability OFF
B	2cellos_short (P2)	Reactive mode; Cut ON + live cello with short delay (for matching with cello section in *Chronos IIIb*)
C	2cellos_long (P1)	Reactive mode
D	2cellos_long (P1). 2cellos_short (P2)	Reactive mode (P1, P2); Cut ON (P2)
E	Joelle (P3)	(Starts with sound files triggered by the live cello) + Reactive mode with high continuity [1,5] (P3); Yin mode active
F	flutes (P1), 2cellos_ short (P2), Joelle (P3)	Reactive mode (all)
G	flutes (P1), 2cellos_ short (P2), Joelle (P3)	Continues from F and stops in H
H		(solo cello only)

I	2cellos_mixed (P1), 2cellos_short (P2), Joelle (P3)	Reactive mode (all), Cut on (P2)
J	2 cellos_long (P2)	Reactive mode, Sparse ON
K	2cellos_mixed (P1), 2cellos_long (P2), Joelle (P3)	Low quality [0,3] (P1, P2)
L	flutes (P1), 2cellos_ long (P2), Joelle (P3)	High continuity [1,5]
M	flutes (P1), 2cellos_ long (P2), Joelle (P3)	Continues from L
N	flutes (P1), 2cellos_ long (P2), Joelle (P3)	Continues from L
O	flutes (P1), 2cellos_ short (P2), flutes (P3)	Cut ON (P2), Sparse mode (P3)
P	Joelle (P3)	Bonk mode
Q	flutes (P1), 2cellos_ short (P2)	Low quality [0,3] (P1, P2)
R	drums (P1), 2cellos_ short (P2), flutes (P3)	(Starts with sound files triggered by the live cello) + Reactive mode with high continuity [1,5], Sparse mode (P3)
S	drums (P1), 2cellos_ short (P2), flutes (P3)	Continues from R
T	drums (P1), 2cellos_ short (P2), flutes (P3)	Yin mode
U	2cellos_short (P2), flutes (P3)	(adds Ring Modulator)
V	2cellos_long (P1), Joelle (P2)	stops before the end

Source: Authors
Table description: Rows to piece's sections and columns to its corpora and setting of parameters.

The parameters with significant musical roles include the Sparse mode, which controls the player's activity level; the quality threshold, which restricts or expands the range played from the corpus by focusing only on matches above that threshold; the continuity parameter, ensuring a player continues playing after the cello stops, particularly relevant in Section L for the "orchestral" interludes; the output probability parameter, employed to halt the player at the end of a section, allowing it to finish the segment it is

reproducing without interruption. Additionally, the transposition setting played a crucial role. Gradually increasing its values throughout the piece broadened the range of possible matches in the corpus, reducing the likelihood of repeating the same segment and contributing to the formal structure of the composition.

5. Conclusions

The discourse surrounding the Somax2 design for *Chronos IIIc* illuminates the role of computational agents in music composition. These systems, exemplified by Somax2, are crafted to engage with human performers, infusing a dynamic and responsive element into the creative process. The historical trajectory of computational music agents, progressing from OMax to Somax2, reveals a continuous evolution marked by advances in design and capabilities. The amalgamation of diverse modules and the integration of novel features underscore a steadfast commitment to augmenting the system's functionality over time.

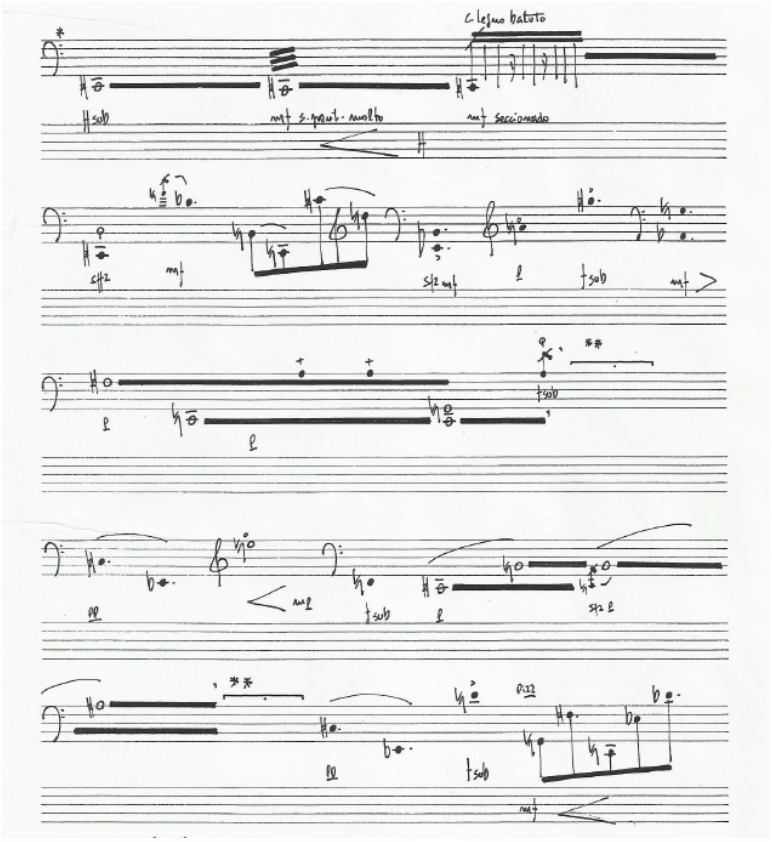
In unveiling the design ethos of *Chronos IIIc*, we witness a hybrid approach blending Somax2's computational processing with live-electronics. This approach aimed to honor the composer's distinctive style while introducing fresh layers of sounds and interactions to enrich the live performance. The incorporation of corpora from specific compositions, such as *Chronos IX* and pieces inspired by Bororo rituals, demonstrates the significance of corpus-based music generation in expanding Somax2 applicability across styles and cultural backgrounds. These corpora act as belief states, shaping the system's output and ensuring stylistic coherence with the composer's body of work.

As we delve into the intricate details of parameterization in Somax2, a crucial aspect in achieving precise musical expressions, the significance of settings becomes evident. Parameters like Sparse mode, quality threshold, continuity, output probability, and transposition, implemented in the 2.5 version, play pivotal roles in sculpting the system's output. Somax2's real-time interaction

capability aligns seamlessly with the demands of compositions like *Chronos IIIc*, which necessitate irregular tempo and heterogeneous musical materials. This versatility suggests that computational agents can serve as valuable tools for both improvisation and composed music.

Repeated performances of the piece provided an opportunity to observe the consistency of interaction modes, with Somax2 consistently selecting different segments. A notable occurrence transpires in the sections between pages 6 and 8 (Ex. 16, for instance), where the writing opens up, allowing for a nuanced exploration of cues to connect with Somax2. This creates a space for a form of improvisation even when adhering to the written score, occasionally resulting in a blend where the cello seemingly accompanies the Somax2 performance.

Example 16 – *Chronos III,* page 6, lines 2-6



Source: Composer's manuscript
Image description: 5 lines of the piece to exemplify its open notation in an excerpt of intense interaction with electronics

The incorporation of spatialization considerations in *Chronos IIIc*'s design underscores the profound impact of performance environments on creative decisions. Utilizing a 4-channel system and strategically arranging sound sources contributes to the overall aesthetic experience. The realization of *Chronos IIIc* was shaped by the authors' collaboration at IRCAM, emphasizing the importance of interdisciplinary cooperation and access to specialized resources in fostering innovative projects.

Throughout our discussions, there is a persistent emphasis on maintaining attention to aesthetic craftsmanship. Whether in the selection of corpora, parameter settings, or the integration of live-electronics, the verified potential lies in preserving and enhancing the composer's distinctive style, as affirmed by the composer's satisfaction with the final result.

When Young and Blackwell (2016, p. 507) pose the questions, "Can musicians and computers relate to each other as equivalent partners?" and "Can an audience recognize this relationship?" the affirmative response to the first question is evident from the reported experience. However, the answer to the second question remains less clear, especially in the context of a written piece like the one discussed. Audiences consistently respond with surprise upon learning that the electronics part is not fixed. Clarity might emerge if audiences hear the same piece multiple times, revealing the nuances of these distinctions. This ambiguity stands as a noteworthy merit of Somax2, showcasing a new creative path for the genre of live-electronics composition.

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Authorship contribution

Author 1 wrote the article, performed the musical piece reported in the text, and co-designed the patch. Author 2 wrote parts of the article, revised the text, designed the patch, and is part of the research team that developed the Somax2 system. Author 3 revised the text, recorded the musical performance, and is part of the research team that developed the Somax2 system. Author 4 is the head of the research project and oversaw the article writing, the computer music design, and the preparation for performance.

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