The Sophtar: a networkable feedback string instrument with embedded machine learning

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ABSTRACT

The Sophtar is a tabletop string instrument with an embedded system for digital signal processing, networking, and machine learning. It features a pressure-sensitive fretted neck, two sound boxes, and controlled feedback capabilities by means of bespoke interface elements. The design of the instrument is informed by my practice with hyperorgan interaction in networked music performance. I discuss the motivations behind the development of the instrument and describe its structure, interface elements, and the hyperorgan and sound synthesis interactions approaches it implements. Finally, I reflect on the affordances of the Sophtar and the differences and similarities with other instruments and outline future developments and uses.

Author Keywords

augmented instruments, novel instruments, hyperorgans, feedback, embedded systems

CCS Concepts

•**Applied computing** → **Sound and music computing; Performing arts;**

1. INTRODUCTION

The Sophtar is a new electroacoustic string instrument featuring an embedded system for digital signal processing (DSP), networking, and machine learning. It is meant to lie on a table or horizontal stand to be played, similarly to a keyboard or steel guitar. The instrument is shown in Figure 1. Structurally, it bears resemblance to an electric guitar, albeit with some notable differences. It features two wooden sound boxes: a larger one corresponding to the body (Figure 3) of the instrument, and a second, smaller

Figure 1: A Sophtar built in 2023-24.

one in place of the headstock on the other end of the neck (Figure 2). The former houses a set of single-string pickups (see section 3.2), while the sound of the latter is captured by a built-in piezoelectric contact microphone, making it possible to amplify the sound from both sides of the fretted string.

A salient feature of the instrument is a large fretboard divided in long strips, one for each of the eight strings. Each fretboard strip is pressure-sensitive. This allows the instrument to sense the pressure exerted on each string separately while fretting. The mechanism is comparable to the polyphonic aftertouch feature found on some keyboards. This allows for sound processing techniques designed to affect the sound of each string after it is fretted or tapped by means of pressure. This enables playing techniques that borrow from the affordances of both fretted string instruments and keyboards.

Another notable feature of the instrument is a pressure-sensitive, spring-mounted button on the body of the instrument. The button can be assigned to different functions, but is mainly used to control the amount of audio signal sent from the pickups to a transducer housed inside the head sound box. The vibrations produced by the transducer resonate through the strings and the neck of the instrument, generating audio feedback that can be used to make sustained, droning sounds. The more the button is pressed, the higher the amplitude of the audio signal sent to the transducer. This way feedback can be controlled subtly by the same hand used to pluck the strings.

Finally, a third distinctive feature of the Sophtar is an embedded computer housed inside the body of the instrument. This allows to run machine learning models and DSP algorithms on board and to network the instrument to other instruments and performers in networked music performance scenarios.

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Figure 2: Detail of the head sound box.

Figure 3: Detail of the body.

1.1 Background and Motivation

I[1] designed the Sophtar to address some needs that arose following my engagement with various research and artistic topics. I am a member of TCP/Indeterminate Place (TCP/IP), a quartet whose practice is focused on networked performance with remotely controlled hyperorgans [4]. Hyperorgans are pipe organs that can be played via protocols such as MIDI and Open Sound Control [32], thereby enabling interactions beyond the conventional manuals and pedals found in organ consoles. TCP/IP is part of a larger network of musicians and scholars that looks at the creative opportunities offered by networking multiple pipe organs for real-time, geographically distant performance [8]. In my performances with TCP/IP, I experimented with various ways of interacting with hyperorgans, including the use of gestural controllers and artificial agents [4, 8], as well as pressure sensitive controllers and music information retrieval (MIR) techniques on live electric guitar feedback sounds to generate MIDI notes.[2]

As my work with TCP/IP continued, I increasingly felt the need to consolidate what I had learnt through experimenting with ever-changing setups into a single, self-contained instrument. One of the reasons behind this is that such an instrument would allow me to focus on practicing and refining the techniques that proved more rewarding in previous performances and experiments without the instrumental setup becoming too cumbersome or complicated. Further, I expect (and hope) that bringing these techniques together within the boundaries of a single instrument would lead to the emergence of new instrumental techniques that previous setups could not afford. Thus, in light of my practice with TCP/IP – itself partly informed by my previous work using feedback guitar in sound interaction design [29] and interactive machine learning [30] – I attempted to list a few requirements that the instrument should fulfil:

- Connectivity for networked performance
- Additional interface elements to perform with machine learning models
- Affordances of table-top guitar played with extended techniques
- Feedback capabilities
- On-board DSP for interacting with hyperorgans

For developing the Sophtar I worked closely with the instrument builder and musician Sukandar Kartadinata. His long-time background in embedded hardware design and software development for NIMEs [14, 15], his skill as a luthier, and his aesthetic sensitivity as a musician have all been crucial for finding solutions and exploring possibilities while designing and building the Sophtar.

2. RELATED WORK

Since 2007, Echo Ho has been examining and reinventing Guqin performance through the SlowQin [10], an electroacoustic string instrument made of plexiglas that resembles the Guqin but also acts as an interface to sound synthesis software.

Stapleton's Volatile Assemblage also known as VOLA [26] combines "a metal resonator with strings and contact microphone, belt-driven turntable with modified vinyl records, upcycled HHD drive controller with a LattePanda Alpha embedded computer running Arduino and Max/MSP patches, and two Bugbrand Postcard Weevils all connected via a mini-mixer to an amplified array of transducers, along with an assortment of actuators" [25].

The Electro Steel by Snyder et al. [24] uses interface elements of the pedal steel guitar to control an embedded digital sound synthesis engine.

There is a renewed focus on harnessing audio feedback for musical expression [20], with instruments such as Halldór Úlfarsson's halldorophone [28] and Adam Pultz Melbye's FAAB (feedback-actuated augmented bass) [22].

SEMILLA AI is a project by Moisés Horta Valenzuela that explores ways of interacting with sound synthesis models based on deep learning through custom-designed instruments. Particularly, Horta Valenzuela uses "the techno-poetics of Mesoamerican divination through "maiz throwing" and positions it as an interface for uncovering and exploring the "latent space" or hyperdimensional data distri-

[1]I am deliberately adopting a first-person point of view in writing this article as my own perspective and experience as a practitioner and researcher was central in the development of the Sophtar. I will try to avoid the passive voice and other impersonal forms as much as possible. When using the plural pronoun "we" I mostly refer to work done in collaboration with Sukandar Kartadinata.

[2]Examples of using MIR on electric guitar feedback can be seen in this video: `https://www.youtube.com/watch?v=tnUg_fe40Ig`. A full networked performance involving feedback and other electric guitar extended techniques can be seen here: `https://www.youtube.com/watch?v=fegi23aaruY`

bution within a generative neural network for audio synthesis" [11].

Several controller keyboards and surfaces allow for continuous, polyphonic manipulation of sound. David Wessel and collaborators developed the Slabs, an array of force-sensitive touchpads, itself inspired by Wessel's practice with the Thunder controller designed by Don Buchla [31]. Other examples include the Soundplane[3], the Continuum Fingerboard[4], the Seaboard[5], and the Osmose[6]. Some of these were analysed by Jensenius [13].

There is a long tradition of unconventional electroacoustic string instrument practice outside of academia. Keith Rowe has been playing tabletop prepared guitar for several decades, with the AMM free improvisation group and others [2]. Rowe's tabletop guitar playing has been compared to John Cage's prepared piano as well as Jackson Pollock's painting techniques.[7] In 2006, after a series of prototypes, guitarist Xabier Iriondo builds the first Mahai Metak: a 10-string tabletop electroacoustic chordophone with built-in sound processing capabilities [12]. Amplifying sound from both sides of fretted strings has also been used extensively by musicians such as Glenn Branca (who built a guitar with a second body in place of the headstock), Hans Reichel [7], and Fred Frith among others [6]. Musician and instrument builder Yuri Landman also experimented extensively with multiple bridges, preparations, and tabletop setups [16].

In the 1960's, a few musical instrument makers built electric guitars that were capable of triggering notes on electronic organs through a sort of proto- fret scanning mechanism.[8] They were very heavy and awkward to play,[9] and very few were made.[10]

3. FEATURES OF THE SOPHTAR

As I described in section 1, the Sophtar blends acoustic, electro-mechanical, and digital audio techniques. In this section I will look at these elements and their interplay more in detail.

3.1 Interface elements

The sound boxes and the neck of the Sophtar are made of amaranth tonewood, also known as purpleheart. The instrument has 8 strings, tuned low to high to D1, A1, D2, G2, D3, G3, D4, D4 (the top two strings are tuned to the same note). The scale length is 73 cm, or approximately 29 inches. The string spacing is 11.5 mm and is the same at both ends of the neck, making the strings parallel.

We made the composite pressure-sensitive fretboard by fixing eight separate force sensing resistor (FSR) strips to the neck, covering its entire length (see top of Figure 4). The fretboard itself is made up by eight separate fretted strips, which are mounted on top of the FSRs and attached to the body through screws at both ends (see bottom of Figure 4).

We made the bottom section of the fretboard, below the lowest string, larger in order for it to work as a thumb rest. This edge of the fretboard is fitted with a silver touch-sensitive strip, which can be seen in Figures 1 and 3. This sensor can track the position of the thumb resting on it, allowing for an additional control dimension to be used to interact with machine learning models as I will describe further in section 3.4.

The body of the instrument includes a custom tremolo bridge and various interface elements that we arranged in order for them to be easily reachable with the right hand when plucking the strings using a thumb pick (see Figure 5. All controls are mapped via software, so they could potentially be assigned to control any parameter, but we arranged them with specific functions in mind that I will describe below.

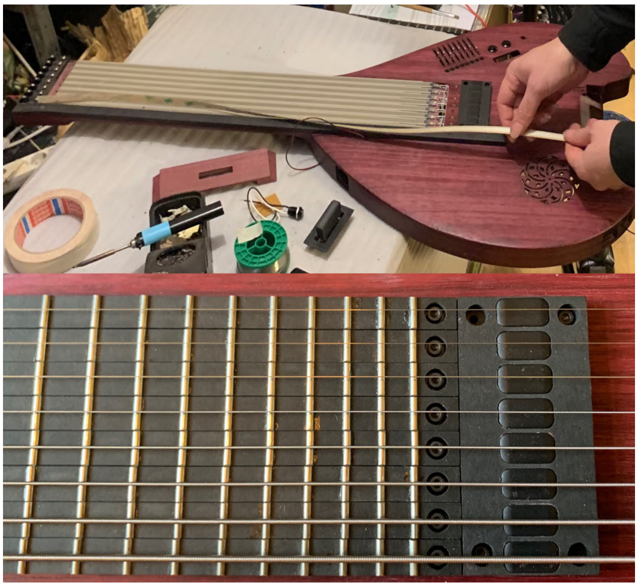

Figure 4: The Sophtar with the fretboard removed, showing the pressure-sensitive strips (top); a detail of the composite fretboard attached to the body of the instrument and the multichannel pickup system.

Figure 5: The interface elements on the Sophtar body with a transparent overlay of a hand to better illustrate the ergonomics.

The rectangular button placed under the index and ring fingers is a custom spring-mounted, pressure-sensitive expression block. We designed it taking the *touche d'intensité*

[3] https://www.madronalabs.com/soundplane
[4] https://www.hakenaudio.com/continuum-fingerboard
[5] https://roli.com/products/seaboard/rise2
[6] https://www.expressivee.com/2-osmose
[7] https://en.wikipedia.org/wiki/Prepared_guitar
[8] https://en.wikipedia.org/wiki/Guitorgan
[9] https://en.wikipedia.org/wiki/Vox_(company)#GuitarOrgan
[10] https://reverb.com/item/5227224-1966-vox-guitorgan-v251-guitar-organ

found on the Ondes Martenot as inspiration. It is made of two 3D-printed elements, the button and a box mounted inside the body. The box houses two springs pushing against the button and two distance sensors placed longitudinally. Differently from the *touche d'intensité*, the expression block of the Sophtar can be tilted left and right (see Figure 6) and the amount of tilting is sensed by calculating the difference between the outputs of the two sensors. The main function of the expression block is to adjust the intensity of the signal sent to the head transducer and therefore modulate the overall amount of feedback. Tilting the block left or right increases the feedback intensity of the low or the high strings respectively. Thus, the expression block allows to subtly and continuously vary the amount of feedback generated by the instrument and at the same time change the spectrum of the feedback within the same instrumental gesture.

Figure 6: The tilt action of the expression block.

The two buttons above the expression block can be used for various purposes. The left one allows to latch the gain values set using the expression block, thereby freeing the right hand without loosing the feedback. Pressing the right one releases the gain latch. Pressing both buttons together allows to interact with reinforcement learning algorithms by temporarily assigning feedback functions to the buttons (see section 3.4). Further to the right there is a third button placed so that it can be reached with the pinky finger while pushing the expression block with index and ring fingers. This works as a "kill switch" that mutes the headstock transducer audio output entirely when pressed. This can be used to let the feedback decay quickly and let the instrument resonate, or perform staccati and other effects.

On the left of the expression block there are eight sliders and on/off buttons, placed within reach of the index finger. The sliders allows to adjust the feedback gain of each string individually, similarly to other feedback instruments such as the halldorophone [28] and the FAAB [23]. The on/off buttons work instead as a mute buttons to selectively remove specific strings from the mix sent to the head transducer. On the opposite side of the body there is another group of eight sliders and buttons. These are used to adjust how much signal of each string is sent through the processing pipeline that generates MIDI and OSC to interact with hyperorgans.

Finally, the potentiometer at the top is used as a volume knob.

3.2 Embedded Hardware and Connectivity

The main processor of the Sophtar is a LattePanda 3 Delta[11] single board computer (SBC) housed inside the lower half of the body. LattePanda SBCs have been used in other NIMEs, such as the VOLA [26] and the Vodhrán [21]. We carved a rose on the body where the SBC is mounted, right above the cooling fan (see bottom of Figure 5). This way the opening acts as a sound hole and it also lets the heat produced by the microprocessor out. The design represents

[11] `https://www.lattepanda.com/lattepanda-3-delta`

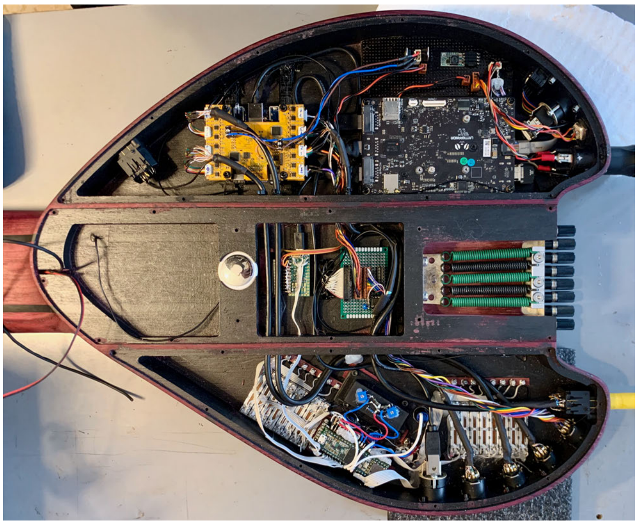

Figure 7: The electronics housed in the body of the Sophtar. The ADC/DAC board is on the top left (yellow), whilst the SBC is on the top right (black). The two Teensy microcontrollers are in the centre and bottom sections.

eight interlocked *ouroboroi* (i.e. snakes eating their tails) echoing the eight feed-backing strings. The SBC is connected to an ADC/DAC board designed by Sukandar Kartadinata. This acts as a multichannel (16 inputs and 16 outputs) audio interface for the Sophtar and is USB Class Compliant. The board converts the signals coming from the string pickups and the output of the software run on the SBC. We used eight Cycfi Nu Capsules[12] pickups to capture the sound of each string individually. The signals of the interface elements are handled by two microcontrollers: a Teensy 3.6[13] for the sliders, knob, and buttons; and a Teensy 4.0[14] for the fretboard FSRs and the thumbs touch strip. The embedded hardware housed in the Sophtar body is shown in Figure 7.

The Sophtar has ten ports distributed on both sides of the body (see Figure 8). The output of each port is listed below.

- Audio
  - 4-ch. audio in
  - 8-ch. unprocessed audio out (unbalanced signals from the pickups)
  - 4-ch. processed audio out (balanced, ch. 1-4)
  - 4-ch. processed audio out (balanced, ch. 5-8)
  - headphones stereo output (not shown in Figure 8)
  - unprocessed mono mix (to be used with conventional amps)
- Data
  - Ethernet
  - USB Type A
- Other
  - Power supply input
  - HDMI video output

[12] `https://www.cycfi.com/projects/nu-v2-capsule/`
[13] `https://www.pjrc.com/store/teensy36.html`
[14] `https://www.pjrc.com/store/teensy40.html`

We decided to include unprocessed outputs to make it possible to play the Sophtar even without the SBC. This way if the computer stops working one can use outboard gear to process the individual signals from the pickups or simply the mono output with an amplifier just like with an electric bass or guitar.

Figure 8: The ports on the sides of the Sophtar's body.

3.3 Interaction with Hyperorgans

One of the motivations behind the design of the Sophtar is to consolidate (and possibly enhance) some of the hyperorgan interaction techniques I experimented with in my research and practice with the TCP/IP quartet. In the example I referred to in section 1, I used spectral analysis of guitar feedback audio to generate MIDI notes. In that instance I particularly appreciated the textures and clusters the organ was producing as the analysis algorithm attempted to track the continuously changing pitch of the guitar strings being slowly bent using the whammy bar. The glitchy output of the analysis and the fact that the organ can hardly play a continuous glissando without intervening on the air pressure contributed in creating an interaction that I find interesting. This was one of the main reasons for including a tremolo bridge in the Sophtar design and deal with the challenges and costs that come with building a custom one. This hyperorgan interaction idea is pushed further with the Sophtar. Each string is analysed separately, extracting the pitch frequency and spectral energy of the ten loudest partials in the signal. This generates up to 80 MIDI notes at the same time. The eight sliders on the right side of the body can then be used to select how much each string contributes to generating the notes, making it possible to go from playing just a few organ notes when tapping on a specific string to generating a large amount of notes that result in massive blocks of sound.

Another interaction enabled by some hyperorgans is the possibility of quickly and continuously change stops via control data, resulting in ever-changing registrations and complex, evolving timbres. I find working with stops generally more stimulating than focusing on pitches, as the process tends to bring out the unique timbral character of each organ. The "general crescendo" pedal found in the console of the Sauer organ and Utopa Baroque Organ at the Orgelpark in Amsterdam is a "stop-crescendo device" [5] that makes it possible to progressively add stops to the registration while playing by means of an expression pedal. Inspired by this idea, I designed a hyperorgan interaction using the pressure-sensitive fretboard of the Sophtar. Increasing the pressure on the fret after playing a note progressively add stops to the registration. Conversely, reducing the pressure reduces stops. This way, a long note triggered by a sustained sound played on the Sophtar can be continuously modulated using a pressure-controlled stop-crescendo. Since pressure is sensed for each string, different stop-crescendo sequences can be programmed and activated independently for each string.

3.4 Interaction with Machine Learning Models

Currently, I am experimenting with embedding two sound interaction and synthesis approaches into the Sophtar. Firstly, I am trying to navigate the latent dimensions of models trained using RAVE [3] (a variational autoencoder for real-time audio synthesis). The feedback sound modulated via the expression block is used as audio input to the model, while the pressure on the fretboard and the thumb position on the touch strip as ways of continuously navigate the latent space of the models. So far, I have obtained interesting results with a model I have trained with recordings of traditional chants for the interactive installation project CORALS by artist Marco Barotti [1]. Secondly, I adapted the Assisted Interactive Machine Learning [30] approach based on reinforcement learning and corpus-based concatenative synthesis that I used in previous projects to be used with the Sophtar. Positive and negative feedbacks given to an artificial agent running on the SBC allow to explore different areas of a large sound corpus, which is activated through the sound of the Sophtar strings. The pressure on the fretboard controls the cutoff frequency of eight band-pass filters that process the sound synthesis output. This allows one to blend the sounds from the strings and the corpus-based synthesis engine continuously, for each individual string, through pressure.

4. EARLY REFLECTIONS

I was not interested in "hybridising" an electric string instrument with some kind of polyphonic aftertouch controller just for the sake of adding controls and complexity. What led me to it was primarily a reflection on the affordances of sound synthesis models and my dissatisfaction with how I was approaching performing with them. Both variational autoencoders like RAVE and corpus-based sound synthesis approaches rely on various ways of reducing dimensionality in order to offer a more compact representation of the timbre space of the model and make it more usable in performance and composition. Similarly, interacting with the sound concepts enshrined in a remotely controllable pipe organ is, for me, to explore its timbre dimensions through the affordances offered by its design. A pipe organ is a sound synthesis model. Adding pressure sensitivity to each string was a way for me to embed ways of exploring the latent space offered by such models within the familiar instrumental gestures of fretting and plucking a string. Throughout the design process, I intentionally constrained performance actions to the haptic and tactile domains. I purposely avoided adding any visual feedback such as built-in displays, backlit buttons, and LEDs. The only LED on the instrument is on the on/off button on the side, and the HDMI port is to connect a screen primarily for programming and debugging purposes. I am resisting displays and visual feedback not just for constraining instrumental interaction mostly to the aural and haptic domains, but also for avoid the temptation of reprogramming, or changing the constraints of the instrument, while playing. This is not to avoid the use of presets or similar solutions (which I find totally fine and acceptable) but is motivated by the desire of moving within a specific set of constraints consolidated in a single instrument. I find this particularly rewarding and inspiring in improvisation. I see my work with the Sophtar as a form of postdigital practice and I resonate very much with how Thor Magnusson defines its rationale: "the point is not to go back to pre-digital technologies [...] but to transcend the general digital computer to arrive at a more distinctive, limited, designed, and characterful musical instrument" [19].

The design of the Sophtar is still being explored, I expect to make changes to its software and hardware, but I also expect to progressively shift my focus from design to performance and consolidate how the instrument works. Working with Sukandar Kartadinata has brought about a dialogue between the two of us that productively forced me to make decisions on what the instrument could and could not do. Given the technical complexity of the instrument, I was relatively reluctant about adding features to the initial design. The idea of adding the touch strip to the thumb rest, which I have initially envisioned simply as a surface of bare wood, came from an exchange with Sukandar. While initially sceptical about adding such feature, I progressively changed my mind after mimicking how my hands would approach fretting the strings while moving my thumbs along the sensor strip. The idea was also in agreement with the concept of adding dimensions to string fretting and plucking actions to explore sound synthesis models, so I eventually opted for adding the touch strip to the thumb rest.

To submit this paper to NIME I had to choose one primary and up to three secondary subject areas. Among these are "Augmented, embedded and hyper instruments" and "Novel controllers, interfaces or instruments for musical expression". Having to make a decision, I asked myself whether the Sophtar is an augmented instrument, given its resemblance to an electric guitar, or an entirely new instrument, given its peculiar affordances and playing techniques. I suspect the line between the two categories is blurry. In their paper "When is a Guitar not a Guitar?", Harrison et al. ask: "which is more important to a performer's impression of an instrument, global form or input modality?" [9]. They suggest that there are complex interactions between a certain 'cultural load' of the guitar form and the input modalities of the instrument. At first sight, the Sophtar looks like a strangely shaped electric guitar. I expect the perception of the instrument might quickly evolve as it is used in performance, particularly for its instrumental gestures focused on subtle modulations of pressure on the neck and expression block, which brings it somewhat closer to instruments such as the Haken Continuum Fingerboard, the Ondes Martenot, and the Slabs. Perhaps at this stage trying to answer this question is not particularly useful beyond figuring out which box to tick in the NIME submission system. What will shape the identity of the Sophtar as an instrument is likely going to depend on how people will play it and what kind of music they will make with it. I look forward to going back to this and other questions after some Sophtar practice. There is only one Sophtar in existence at the time of writing. Thus, its ergodynamics [18] will likely be shaped by my own idiosyncrasies and biases as a performer and researcher, at least initially. Feedback from other musicians and co-performers will likely broaden my view on what the instrument could and should do. Whilst having other musicians pick up and learn how to play the Sophtar might take some time, I expect that working with composers might reveal latent articulations – or ergodynamics to once again use Thor Magnusson's clever term – relatively quickly.

5. FUTURE WORK

I am planning to enhance the Sophtar with a set of movable actuators that can be activated remotely to mechanically pluck the strings. I regularly perform with live coder and composer Mattias Petersson, who is also a member of TCP/IP. Having actuators on the Sophtar would open a window for him to send live-coded patterns to the instrument, creating potentially interesting interplays of shared agency between him live coding, myself moving the actuators, and the Sophtar interacting with hyperorgans.

Alongside RAVE and AIML, I am planing to try to run on the Sophtar some audio corpus manipulation patches based on the FluCoMa library [27].

The work on hyperorgan interaction design will continue with interfacing the Sophtar with the Sinua[15] system, a control protocol dedicated to pipe organs that allows for more sound shaping possibilities.

In conclusion, the aim of this contribution is mainly to introduce and describe the instrument. I expect that working with and within a single instrument might lead to vertical explorations that dig deeper on some instrument-specific aspects, as opposed to the more horizontal investigations that occur when changing setup often. Resonating with the thought that musical instruments are epistemic tools [17], I look forward to sharing what I will learn by playing the Sophtar.

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