Protoson, Acoustic-Digital Interface Computerization of Strings Vibrational Energy

ABSTRACT

String vibration is a fundamental wave related with length, and it is the primordial one-dimensional object of Reality. This paper explores the development process of an acoustic-digital interface for musical expression using the vibrational energy of the string like a proto-sonic material, the Protoson.

The instrument considers the string like a sensor device that transduces the energy of the human body into an acoustic event. A second sensor transduces the acoustic event of the string into 1-dimensional electric signal that is digitalized in the form of numbers that a computer uses for digital processing of the information.

The interface is a physical grid, a 2-dimensional matrix of 10 equal-Strings with 20 frets. This structure gives the musician 200 positions of 2 x 1 cm each of them. It is thought to be played in standup position using 8-fingers "tapping" techniques, similarly to a typical electric guitar, but the instrument remains in a stand.

Playing technique is considered a key aspect of the instrument, and is linked with the harmonies in the relational topologies in the 2-D matrix surface, the possible movements. Actions.

Author Keywords

Stringed Instrument, Digital Processing, Microsound, Numbers

CCS Concepts

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

1. INTRODUCTION

Vibrations or oscillations are the fundamental aspect of existence, and the String is the most basic model that defines the vibration. Frequency and wavelength are the intrinsic properties of the string vibration. Frequencies are the material that forms Music. The Monochord (one-string) is the instrument used in the ancient Greece in order to study the harmonics and music theory. The Khitara, a seven strings lyre with resonant box used for public concerts of virtuoso, is the origin of the word "guitar". The term "chord" also has its origin in string. Thousands of different stringed musical instruments were developed during centuries around the world, and during the 14th century, the development of mechanisms based on keyboards were applied to stringed instruments, like the clavichord and harpsichord. Some centuries later, the stringed instrument controlled by keyboard adopts the form of the actual Piano, and the keyboard remains like the perfect paradigm of interface for pitch control in a musical synthesis device. It works perfectly well; it is possible to control the exact moment and intensity for a musical note. In addition, that is what we have in a musical score. However, keyboard came with a price; we lose the physical contact with the vibrating string. An electronic keyboard controller generates commands, there are not vibrating strings anymore. The purpose of the development of the Protoson is the return to the real string vibration for the genesis of sound, but with a strong digital computerization of the information.

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2. THE NATURE OF SOUND

2.1 Linear Scale vs Logarithmic Scale

Sound is a wave of vibrations that travels through the matter. Like any other wave, the main properties of sound are the frequency and wavelength. Frequency is the number of cycles per second, and it is measured in Hertzs. The nature of frequency is logarithmic (or exponential) because it is the nature of the repetition or cloning with the factor 2. This is the mathematical definition of the term octave, and the origin of the term came from the music. Music, sound, and frequency are logarithmic. Nature is logarithmic. However, our perception it's not. In fact, we perceive frequencies linearly. The cochlea transforms the logarithmic scale into a linear scale in the brain.

The nature of the frequency or pitch of a string is related with the length, tension and thickness, and it's logarithmic. In order to change one octave the pitch, it's needed to multiply (or divide) by 2 the length, or the movement displacement of the finger. With the invention of the keyboard, it was possible to linearize the control of the musical instrument, and the displacement is linear like our perception. This is an advanced characteristic. Then, it was decided to design the interface with linear displacements in x and y, with 1 cm of separation between strings, and 2 cm of separation between frets. Simplicity and ergonomy.

2.2 Frequency-Time Period

Frequency, the cycles per second, is the inverse relation with time period, the time needed to complete a cycle. Cycle is the effect of vibration. The interface needs to analyze the signal of the string in order to identify the x-y position, and the time period determines the latency of the analysis. It was selected a window size for analysis of 512 samples of the string signal, and maintain the latency in the range of 10 ms.

3. GUITAR ELECTR(ON)IFICATION

3.1 Electromagnetic Pickup and Amplifier

Electric Guitar is the origin of the interface Protoson, which in essence is a modified electric guitar. In the middle of 20th century, the development of solid-body electric guitars establishes the electromagnetic pickup with the main function of the instrument: an electric signal proportional to the strings vibration capturing the musicians physical playing in the form of movement of electrons. Mechanical Energy is transduced into Electric Energy, (Figure 1).

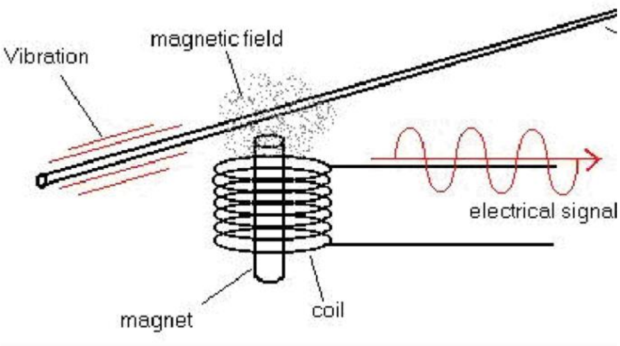

Figure 1. Electric Signal proportional to Vibration.

Together with the electronic circuits of amplifiers, a complete revolution in popular music begins, with electronic audio processing effects, manipulation of signal, and extreme amplification, until the process reach the point when Jimi Hendrix puts the electric guitar "on fire" with electronic sounds never heard before. New playing techniques in order to deal with the sounds that came out from the loudspeakers, including feedbacks that were creating pure electronic oscillations, were developed without rest. Some years later, Metallica and others were able to produce Thrash Metal sounds, with the technique "Palm Mute" creating perception of sounds completely detached with the original vibration of the strings, but extremely connected with the physical body/mind energy. Electronic signal processing is part of the instrument, Figure 2 shows an example of the amount of electronic processing in a Live setup of guitarist Steve Vai.

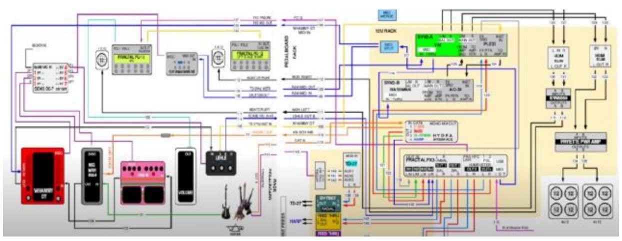

Figure 2. Steve Vai Live Guitar Rig 2022.

It's unclear the reason why the terms "electric" and "electronic", referenced like analog and synthetic sounds respectively, when the nature of both terms is exactly the same. The metaphorical power of metallic string electric signal processing is represented perfectly well in Figure 3, lyrics of Barón Rojo spanish rock band.

"....Thunder Storm without Light,
you're Symbol of Liberty,
I Could Never Live,
without Touching your
Strings of Steel....."

Figure 3. Lyrics "Cuerdas de Acero", 1985. Barón Rojo

3.2 Real-Time Digital Post-Processing

The term "real-time" has a special relevance when we talk about music and sound processing, Music and Time can be seen like synonyms from a philosophical perspective. Real-Time is related with the term "Latency", however real-time is not a fixed amount of time. Real-time processing was from the beginning of Computer Music a key goal, and this is exemplified perfectly with these words extracted from Miller Puckette, answering the first question received related with his early digital audio works , by someone from MIT Experimental Music Studio: "…Yeah, Can I plug my guitar into that?" (The first question and we want to plug the guitar, it's the constant leitmotiv of guitarists…). The answer is revelatory of the problematics of real-time systems: "No. You can't do that just yet". (Laughs) "I'm working on that!". Forty years later we continue working on that.

Computer-aided digital processing of the electric signal generated by the electromagnetic pickup is not an easy task. We need an analog-digital converter first, then we need to send the digital signal to the computer, the software needs to access the information, to do some operations, maybe also some analysis, and all these tasks … in real-time. There is some consensus about 10 milliseconds and the related haptic feedback after action, and 10 ms is also the time that a soundwave needs in order to cross a 3 meters room and reach our ears from a loudspeaker. However, real-time concept is also a musical decision, if someone wants to present a copy of the incoming sound in some moment of the actual future (a delay effect) the window of the real-time period is opened, and that (long) period of time could be used for real-time processing.

During the late 90's , computer music related with what happens at a millisecond level of a signal, or less, like microscopic sounds, has reached one breaking point in album Vrioon (2002), with the collaboration between Alva Noto and Ryuichi Sakamoto, mixing real piano sounds (vibrating strings) with digital post-processed versions of these sounds. Digital processing of the electric signal proportional in 1-dimension with the acoustic event of the vibratory energy of the string breaks the walls of the limits at that point.

4. MUSICAL GRID INTERFACE

4.1 Percussion Instruments

Percussive instruments made with stones, Litophones, maybe are the first contact with organized sounds in prehistoric times, together with flutes. Figure 4 shows a very imaginative recreation. Piano(forte) is the final evolution of strings percussion, and the "tapping" technique used mainly in electric guitars is an example of use of fingers hitting directly the strings in order to produce sound.

Figure 4. Litophone in Garden of Science, Israel (2009)

Early efforts during the past decades trying to capture the pressure in points of a 2-D surface, like the SoundPlane by Madrona Labs Figure 5, or the Continuum FingerBoard by Haken Audio Figure 6, are good examples of excellent quality matrix interfaces.

Figure 5. SoundPlane by Madrona Labs (2011)

Figure 6. Continuum Fingerboard by Haken Audio (1999)

Today, percussive devices presented with a grid format, a 2-D Matrix surface, seems to be the standard for interaction with music software. Figure 7 and [1].

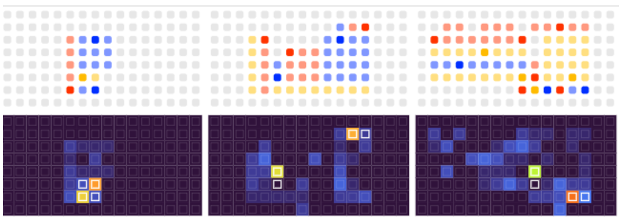

Figure 7. Musical Grid Interface (2022)

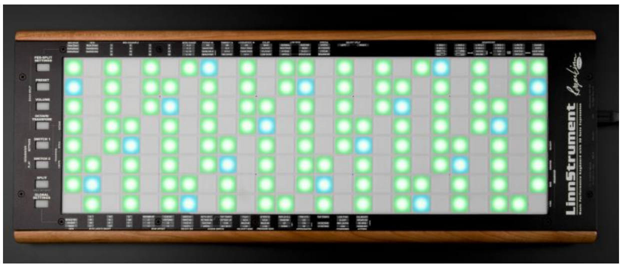

Figure 8. LinnStrument (2016)

Figure 8 shows the LinnStrument, another example of Grid Interface

Figure 9 shows the 2-D Matrix design of the Protoson, in which the strings are conceived like “sensing”devices, capturing the x,y coordinate of the tap pulsation.

Figure 9. Instrument Protoson (2023)

5. STRING VIBRATION PICKUP

5.1 MonoString (Monochord, Psalmodikon)

In the scandinavian countries, during S.XIX, many congregations could not afford Organs, and it was developed a variant of the monochord without a moving bridge, adding frets. Figure 10.

Figure 10. Psalmodikon. A monochord with frets (S. XIX)

Figure 11. ContinuuMini by Haken Audio (2019)

Figure 11 shows the similarities in the conceptual physical design of the ContnuuMini and the Psalmodikon.

Like the Psalmodikon, a very cheap alternative to Organ, the concept behind Protoson is the development of a simple module with one string and one pickup, and width of 1 cm (and 2 cm between frets), that can be easily expanded n-times. The cost of this module could be reduced to a few dollars, and because the analysis is done with available free software, we can obtain in real-time (in the range of 5 milliseconds if we use 256 samples) the audio data from more than 20 positions in independent digital audio channels, enabling the possibility of synthesis by processing of every pressed note/pitch/vibration. Figure 12.

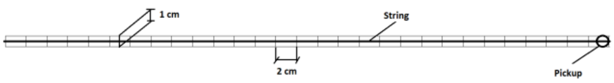

Figure 12. Basic 1-String module design of Protoson instrument

Figure 13 shows the concept of vertical channelization after analysis based on Equal Temperament 12-TET (horizontal white/grey lines) made on Melodyne software by Celemony, enabling the individual processing of every acoustic event (Pitch change or any other).

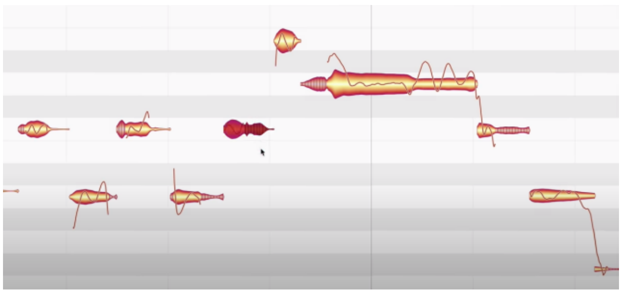

Figure 13. Example of channeling based on pitch detection in Melodyne by Celemony.

5.2 Nu Capsule. Single-String PickUp

Figure14 shows the Nu capsule used in Protoson. It's a sensor (transducer) build with low impedances coils and integrated preamplifier, that gives a flat response proportional to the vibration of the string Figure 15.

Figure 14. Nu Capsule self-contained active pickup

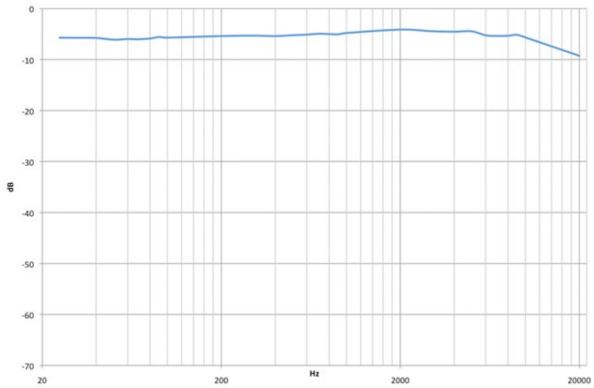

Figure 15. Flat response.

Figure 16 shows the actual implantation in an independent module, the ten pickups necessary in the Protoson.

Figure 16. A group of 10 Pickups in Protoson

6. INFORMATION THEORY

6.1 Entropy and Time. Syntropy.

The electric signals originated in the pickup are carriers of information. The origin of this information is the physical action of the body transferring some mechanical energy to the strings. It's possible to affirm that part of the information of the body/mind, including feelings, is embedded in the electric signal, however that information is not possible to decode completely, because is a subconscious process, and we really don't know nothing about how to code in a first place that process. We can define this information in relation with the "uncertainty" and "surprise", the entropy of the signal, and by definition, Music has an infinite entropy continuously, because is the Time-Space itself, and it's not possible to know with infinitesimal precision the instant (it's not "reproducible"). A period of Time can be infinitesimally small. However, we don't live there, our music, our present time, is more than one second (maybe two seconds?). Then, it's better to look from the opposite perspective, the Negative Entropy (always positive, casually), and we can start from 0, not from infinite. This concept is called the "Syntropy" of the signal. We can make an subjective analysis of the syntropy contained in our digital signals, and we can see that everything is happening mainly in the first 50 milliseconds after touching the string (after all, the main conscious musical action is only to touch or not to touch). This part of the signal is known with the term "attack". In that period of time, the syntropy starts a process of "change" from zero, increasing until reaches some asymptotic value that correlates with a certain periodicity of the wave (a classic MIDI based synthesis system starts directly from this high state of the syntropy, like a switch, it's not taken in account the process of change from zero). This time contains essential musical information like it was experimentally confirmed by Pierre Schaeffer in the 60's with his studies of the "Anamorphosis" of "Objets Musicaux" with his observations of strong changes on the perception after attack manipulation (at that time physical manipulation with scissors of magnetic tape with recorded sounds). The analysis for information retrieval, parallel and serial processing of how is "the process of change" of these small portions of sounds, the Proto-Sounds, is the main focus of this project, the quantum of sound, the Protoson.

Figure17 shows the difference between the spectrogram of a middle C tap on nickel string and cobalt string, with the exponential decay of the energy of the partials. It shows clearly that the information is concentrated in the first 50 milliseconds. This exponential change shows what happens with the syntropy, starting form one state of zero, the absolute chaotic "action"of touching the string, in a complex evolution of the vibration until is stabilized in a quasi-periodic state. We can see the unique "process of change" of the syntropy like a meta-container of the expression of the physical action, the communication process of energy in the form of musical act.

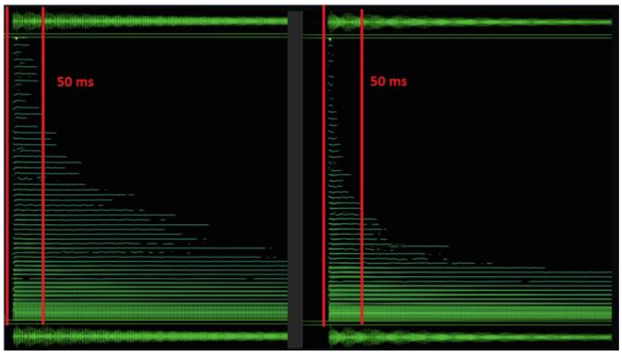

Figure 17. Difference between the first 50 ms in Nickel String and Cobalt String

7. THE PROTOSON

7.1 Materials

The instrument (Figure 18) is made with aluminum rods of 6, 8 and 10 mm diameter. The specification is that needs to be maintained a perfect flat surface of 60cm x 10cm, in order to have a clean string vibration when is pressed.

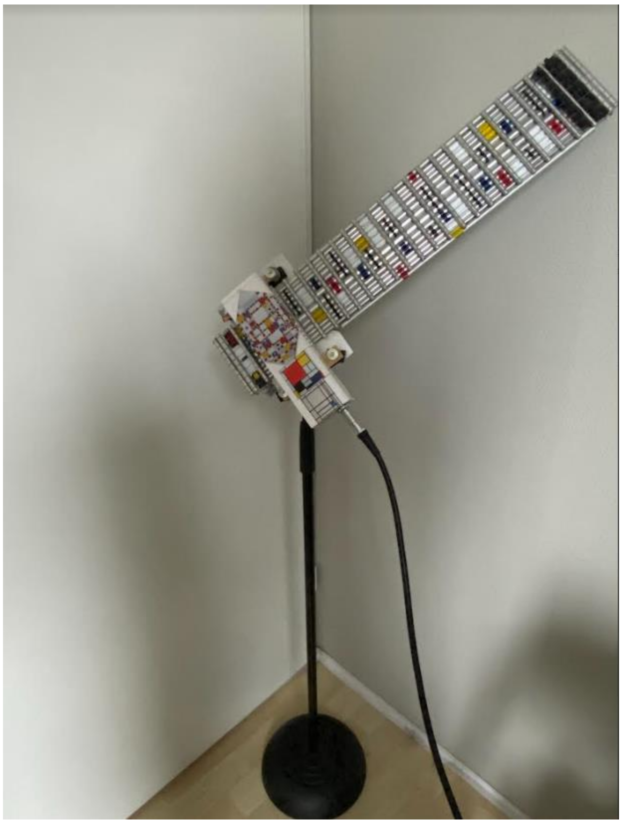

Figure 18. The Protoson

7.2 Processing. Analysis and Synthesis.

7.2.1 Audio signal driven sound synthesis [2]

The realization of the instrument with 10 strings gives the structure a 2-D Matrix surface, and the purpose is to obtain the digital audio data that corresponds to every coordinate in order to be processed independently. The algorithm for pitch detection and assignment of coordinates was done using a sigmund object [3], but it can be used any of the available algorithms. Figure 19

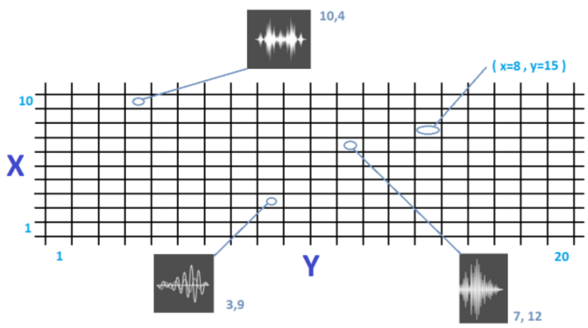

Figure 19. Coordinates x,y for every Audio Data

In digital domain, we can access to the audio data of these acoustic events, and we can apply different kind of analysis and synthesis. This action is a "process". Figure 20 shows two examples, one with the pitch tracking and envelope information, the synthesis of an oscillator, the other one with a generalization of the analysis and the generation of parameters n-times that maps the synthesis algorithm. Every sound synthesis system developed in the past could be used at this point, including physical modelling, with the only limitation imposed by the computational power. [2]

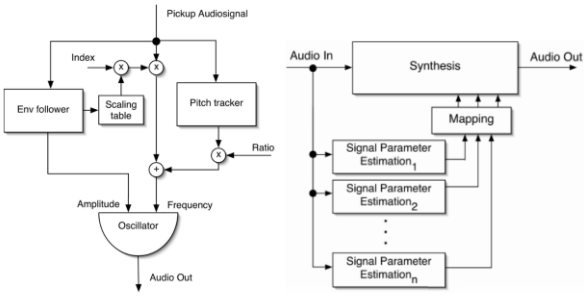

Figure 20. Examples extracted from Audio Signal Driven Sound Synthesis [2]

Figure 21 (Left) shows another example of use of pitch tracking algorithm in order to obtain the harmonic content of the incoming signal with bandpass filters (this diagram was implemented in a Pure Data patch, with 720 Band Pass Filters in parallel). Figure 21 (Right) shows a concept, "Patch for Guitar", for processing without pitch tracking, comparing the classical approach to synthesis with oscillators and the access to similar information directly from the mathematical representation of the periodicity of the incoming signal.[4]

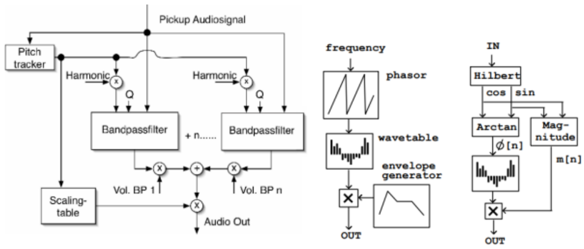

Figure 21. Example of synthesis by processing [2] and [4]

The barriers between audio processing and audio synthesis are not there anymore.

7.2.2 Pitch Shift and Feedback Loop

It was developed one patch in MAX/MSP, using multichannel objects functionalities, applying one pitch shift process for every audio data, using in real time the data of the pitch tracker, in order to create continuously the shift that matches to equal temperament 12-TET, with 1 semitone change for y and 5 semitones change for x. Any temperament can be used, or any mapping configuration. The output of the pitch shift modules are of very low quality, but the pitch shift is correct. Then, the new low quality sounds are sent to a "Feedback Loop" Figure 22, the most simple process that one can imagine in digital processing (just a copy of the actual sound added to the sound of the future, continuously). The results were very promising, without "ghosts" or strange sounds generated. In this case, the limitation was related with minimum duration of the incoming sounds, it was observed that with less than 100 milliseconds of duration, however, no optimization was developed and the computational power limit of the system was reached with this implementation.

7.2.3 Feedback Loop alone

The pitched sound obtained from the infinite loop does not need the incoming sound to be pitch shifted first. And the parametrization with envelopes of the, incoming sound and feedback, gives good results easily without limitations in the duration, and it's possible to reach 20 notes per second, if the technical physical execution is gained.

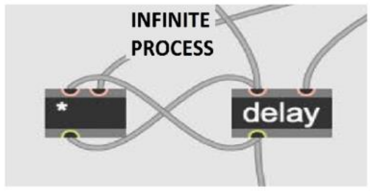

Figure 22. Infinite Process

7.2.4 Mixing with Oscillators and Noise

Different implementations mixing the incoming sound with oscillators and noise generates unlimited possibilities, controlling with specific envelopes mainly the firsts 50 milliseconds of the incoming signal.

To process a signal can be extended ad infinitum in realtime, it's a matter of computing power, and there are two axioms:

- It's always possible to obtain a Sound B like a result of processing a Sound A.
- It's always possible to obtain a mix of the Sound B with a Sound C, and Sound C can be a Sound B' (another process result of Sound A) or not.

These axioms generalize the concept of serial and parallel processing, any sound could be seen like an output of a process, and at the same time is an input.

8. TOPOLOGIES OF THE MATRIX.

8.1 Numbers

Movements (physical actions) are functions of Time, and they correlate in some degree with music/sound. There is an energy interchange between themselves. Harmony is a relation between frequencies (numbers), and the finger movements in the system of coordinates x,y of the matrix follows the same principle. The set can be reduced to 3 elements and the reflection of these 3 from one "Reference" point, the zero Fig. 23. This is a consequence of the cyclic nature of vibration, the octaves (being 3 and -3 the same principle, one octave apart). The topologies of the matrix surface is equivalent to harmony, however the execution of movements responds to a different neurological mechanism, and the repetition and practice is necessary in order to store the capabilities. It's not a conscient mechanism. There is an intimate connection between storage of these capabilities and the generative process of music.

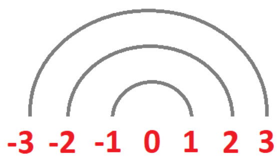

Figure 23. Harmony

The marks (black, white, red, blue and yellow) in the Protoson are relations between numbers, distances, intervals… vibrations. It's present in the capture device of the strings, a cross metaphorical reference to "Broadway Boogie-Woogie", the painting of 1943 of Mondrian about the music, and here capturing the vibrations and channeling to the digital world.

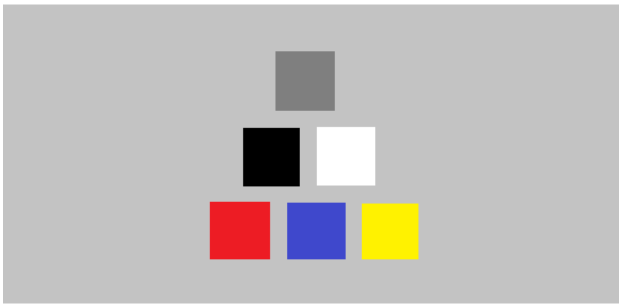

Figure 25. Mondrian and number 3.

9. FUTURE DEVELOPMENTS

9.1 Luthiering

Protoson is by definition a digital musical instrument, but it has an acoustic part also. The design of the prototype of the concept of the instrument was done without any specific knowledge and experience in Luthiering. The design and implementation of the instrument needs to be done by a Luthier, with specific selection of materials and maintaining the simplicity.

9.2 Musical Instruments Digital Audio Transmission Protocol

Protoson has in digital domain the virtual channels corresponding to the (x,y) audio event and the metadata of analysis. It is proposed a protocol for digital audio transmission of 16 concurrent digital audio channels, multiplexing by demand all the virtual digital audio channels (20 frets x 10 string = 200), with the label of the coordinate (x,y), in order to be demultiplexed in another processor. Transmission between processors needs to be done in less than 1 millisecond, following the standard AES67. The purpose of the protocol is to maintain in the digital domain the audio data information linked with the action of the instrumentalist, like an extension of MIDI 2.0. More than one communication protocol between synthesizers, It's proposed a communication protocol between processors (instruments) with real audio data. The technology for this purpose is not simple, because real-time here needs to be maintained in the range of the microseconds, but the actual technologies of digital data communication systems are more than enough to reduce the cost of this implementation.

9.3 Convolutional process in parallel.

Another technological emergence is the generalization of GPU's for audio processing Figure 25. The amount of computational power that can be applied to one single musical instrument is incredibly high.

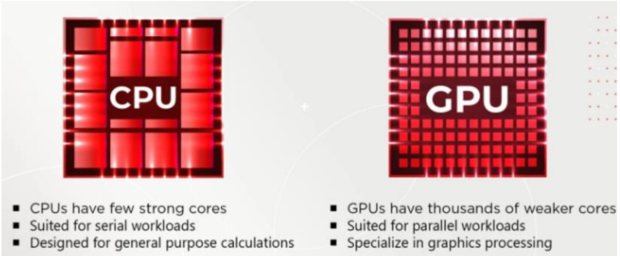

Figure 25. Difference between CPU and GPU cores

One can imagine one instrument like Protoson, with 200 positions x,y with independent audio data, and apply one independent convolution with an specific impulse response, in parallel, in real-time. For example, an impulse response of every resonant pipe of an organ applied to the proto-sounds, and we can get the graphical recreation of Figure 26.

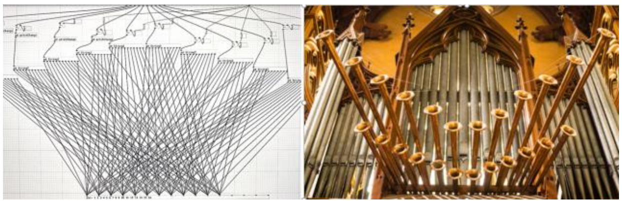

Figure 26. Pure (Digital) Data Patch of Protoson/Pure (Physical) Resonant Pipes of Organ

10. CONCLUSION

The results are more than satisfactory. The playability of the instrument is complete, without intrinsic defects. The development of the digital processing part of the instrument is fully functional; however, this part of the instrument is by definition an endless process in continuous "change".

11. ACKNOWLEDGMENTS

Our thanks to Internet, all the knowledge present there is a representation of the necessary efforts of too many. Without that, this paper would not be possible.

In addition, a special acknowledgment needs to be recognized because everything was different after one "Midnight".

12. ETHICAL STANDARDS[1]

There are no observed conflicts of interest. The software is used under License, or is public domain.

13. REFERENCES

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