Demonstration of a proposal of correspondence between Light and Sound

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Abstract: Demonstration of a proposal of correspondence between Light and Sound. This proposal was materially exemplified by means of a new hyperinstrument, which gives its users the control over a multi-sensorial algorithmic composition generated in real-time. In this paper we present the origin and motivation of our correspondence proposal. We describe with some detail, the designed methodology to convert sound frequency to colour wavelength and the designed strategy to present the visual results on RGB systems. Audiovisual documentation of the demonstration available at http://3kta.net/solu

Resumen: Demostración de una propuesta de correspondencia entre Luz y Sonido. Esta propuesta fue ejemplificada materialmente por medio de un nuevo hiperinstrumento, que da a sus usuarios el control sobre una composición algorítmica multi-sensorial generada en tiempo real. En este escrito se presenta la origen y la motivación de nuestra propuesta de correspondencia. Se describe con cierto detalle, la metodología diseñada para convertir la frecuencia del sonido en la longitud de onda del color y la estrategia diseñada para presentar los resultados visuales en sistemas RGB. Documentación audiovisual de la demostración disponible en http://3kta.net/solu

Keywords: Hyperinstrument, Color, Sound, Synaesthesia, Music.

1. ORIGIN AND MOTIVATION

Two hyperinstruments, ColMus[1] and SoLu[2], were born from the necessity to modulate and integrate audio and visual materials as a whole, the need to homogenize the audiovisual design and production processes as well as to demonstrate a theoretical proposal of correspondence between light and sound. After the development of several experiments and projects that aimed to synchronize audio and visual events, concordant or discordant, we found that this type of work can be framed in the field of synaesthetic art, synaesthesic, or multisensory. Reading the book *'Hidden Sense'* from Crétier Van Campen, aimed to clarify and understand the state of the art in the field of synaesthesia. His book was also fundamental to the development of our projects and made clear three aspects: first, synaesthetic experience is personal and individual; second, humans in their first months of life "do not distinguish between" the senses, they just begin to modularize the senses with some months old; third, the most common type of synaesthesia is the experience of feeling a chromatic experience caused by the experience of a sound sensation.
Studies about the various synaesthesia manifestations point precisely to a psychological, mental and individual origin, which makes very complex to create a matching matrix or pattern between sensory stimuli of one of the five senses and the sensory responses in another of the same five senses. Given the complexity and mystery of the human mind, we chose to develop a scientific approach of physical

[1] ColMus was the first hyperinstrument we designed to demonstrate de correspondence proposal referred in this paper. Online documentation http://3kta.net/colmus
[2] SoLu is a redesign and improved version of ColMus. It was presented at EVA conferences in London and Berlin and TEI conference in funchal. Online documentation: http://3kta.net/solu and http://vimeo.com/14466295

nature that allowed to sustain our matching proposal. In order to simplify and objectify our study, we focused the relation of sound with only one of the visual language elements, the colour. This study resulted in a new proposal of correspondence between visible and audible spectra and it has been demonstrated and materialized in the form of two hyperinstruments. Visual perception as audible perception both depend on physical phenomena of energy transport, respectively electromagnetic and mechanical. These phenomena are studied and described by the scientific knowledge of physics with high level of 'objectivity' and quantification. It was this level of 'objectivity' that formed the basis and triggered our matching proposal. Basically this proposal made correspond to each audible frequency a visible wavelength that means it established a direct correspondence between the audible and visible spectra. Before publishing and grounding this proposal, we did a survey of previous documented and published proposals.

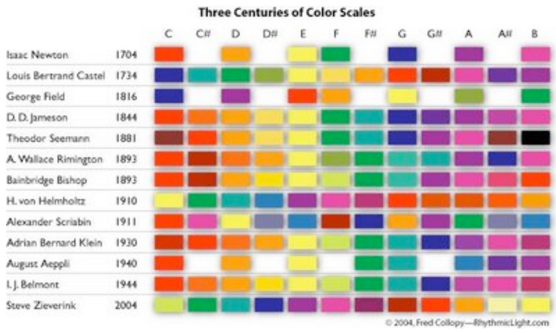

Figure 1. '*Three Centuries of Color Scales'*, was a reference to visualize the most importance correspondence proposal in the last three hundred years. Image from: http://rhythmiclight.com/

In brief, we concluded that the existing proposals related colour with music in a very unbalanced and simplistic way. On one hand are used colours from almost all longitudes of the visible spectrum, on the other hand are used only 7 or 12 'notes' of diatonic musical scale, which itself is a cultural aesthetic convention. Our dissatisfaction with these proposals is resumed as follows: the C note on the left most octave of a piano keyboard is much more 'bass' than the c note on the right most octave of the same keyboard, but according to the proposals listed in the table presented in Figure 1, to all C notes of piano corresponds the same colour because the mapping was constrained to just one octave. Besides this constraint, already in the stage production of the second hyperinstrument, we noticed that the colours chosen on the last three centuries proposals were very often aligned according to their order in the visible spectrum being that to which one of those colours corresponds a specific wavelength. However, for each musical note, because it is not specified which is the instrument that produces it, corresponds, considering the spectral composition of the sound, a range of frequencies - the harmonics. Hence in the assertation of our proposal, we use the so-called 'pure tone' - sine waves generated by synthetic processes so that, theoretically, harmonics were eliminated.

Following the review of previous proposals, we decided to produce a correspondence proposal based on physical quantities of light and sound phenomena, not considering the randomness and diversity of matches found/ imagined by human beings who experience the psychological phenomenon of synaesthesia. At this early stage, our intuition pointed to a correspondence proposal in which the bass (sounds) match the bluer colours and the treble (sounds) match reder, but the proposal based on physical quantities (sound and light) presented as the exactly reverse: bass corresponding to the red and high-pitched sounds to blue. This proposal will be described in more detail in the following section of this text.

2. METHODOLOGY

2.1 Hertz to nanometers

Light and sound phenomena are similar in many aspects. Both are energy transport phenomena studied simultaneously by physics. Both propagate through waves, longitudinal mechanical waves in the case of sound and electromagnetic transversal waves in the case of light[3]. Both require a period of time between their emission and reception. The physical characteristics of these two phenomena are also distinguishable. Electromagnetic waves, like light, can propagate in a vacuum but sound waves require a medium to propagate. In the air, light propagates at a speed of 300,000,000 m / s and sound propagates at 344 m / s. Electromagnetic waves perceivable by the human eye range between 430 and 750 THz with wavelengths between 740 and 380 nm, sound waves perceivable by the human ear range roughly from 20 Hz to 20 KHz with wavelengths between the 17.15 and 0.0172 m. Despite the enormous differences of size and speed, both electromagnetic waves and sound waves can be represented by their wavelength and frequency.

Almost all light and almost all sounds have a spectral composition because they are composed of a complex mixture of vibrations of different frequencies. Almost all light is polychromatic, so it can be described by several different frequencies as do the sounds that we hear that commonly result as well from a mixture of several frequencies. However there are exceptions, monochromatic light is described by only one frequency or wavelength, and the sounds said 'pure tones' are also composed of a single frequency. Both, monochromatic light and 'pure tones' are not common in nature but can be synthesized, examples are the

[3] Although in modern physics light or electromagnetic radiation can be described by two complementary ways: as a wave in an electromagnetic field or as a flux of particles named photons. Though both are acceptable as light descriptions, the description of light as a wave is more appropriate to the purposes of our work.

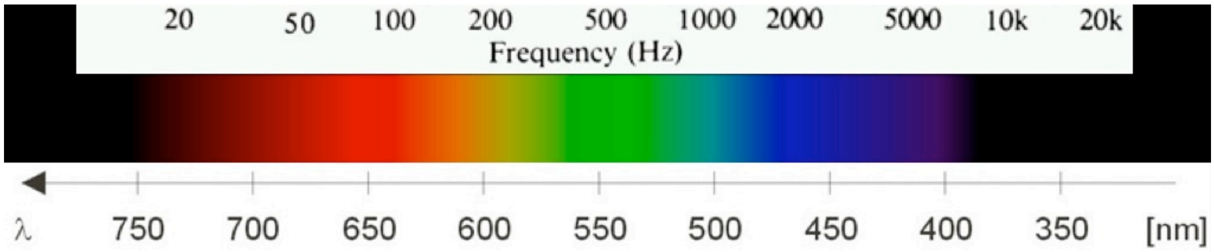

Figure 2. Ilustration of our correspondence proposal, note the exponential spacing in sound frequency domain in Hz vs the linear spacing in light wavelength domain in nm.

light said coherent emitted by laser devices or the sound produced by frequency synthesizers.

The theoretical proposal of correspondence between light and sound that we primarily developed, aimed to match the lowest frequency from the electromagnetic visible spectrum to the lowest audible sound frequency and the higher frequency from the visible electromagnetic spectrum to the highest audible sound frequency. In the first approach, the linear mapping (commonly scaling) of a series of numbers (the frequency of electromagnetic waves in the visible spectrum) in to another series of numbers (the frequency of sound waves in the audible spectrum), did not work because our auditory perception of sound frequency is exponential.[4] The result was that for a big part of the audible spectrum, the lower frequencies zone, the variation of the chromatic feeling was minimal and for a very small part of the audible spectrum, in the area of higher frequencies, the variation of the chromatic feeling was huge. In order to create a more 'coherent' match, we searched for a mathematical model or formula to convert the exponential spacing interval between the frequencies sensed by the basilar membrane, to the linear spacing of the wavelengths of the visible electromagnetic spectrum. We began by contacting two experienced mathematicians, after we presented this challenge, they considered that no mathematical function solves this challenge with complete accuracy. One of the mathematicians, Professor Antonio Leite, suggested to find a mathematical model close to the intended one. In this regard we researched possible formulas that could be adapted and found the following (n = 12 * (log (f/220) / log (2)) + 57) to convert the fundamental frequency of each note from the piano 'tessiture' to linear midi values. With support from the pianist and architect Anne-Kathrin Siegel, we adapted the previous formula and transformed it into the following (n = 700 - (12 * (log (f/220) / log (2)) +36) * 3.44827586207) which allowed us to convert frequencies of an exponential scale to wavelengths of a linear scale - in this case the wavelengths of electromagnetic vibrations included in the visible spectrum.

During this research, intrigued us the fact that commonly sound spectrum is represent the in the frequency domain and the vibrations in the visible spectrum are represented in wavelength domain since frequency and wavelength are inversely proportional quantities. It seemed to us that there is a certain inconsistency in the scientific approach to the measurement of light and sound phenomena. We formulate the question:

Light and sound are, as stated above, energy transport phenomena, respectively electromagnetic and mechanical. Both phenomena can be studied as waves, and as such, their wavelengths and frequencies can be measured. But most times, by convention, the luminous phenomena perceptible by humans are measured in nanometers (on the wavelength domains) and sound phenomena are measured in hertz (on the frequency domain). Why this two phenomena are not measured consistently, using the same unit of measure? We speculate on the reason for this 'inconsistency', and concluded that perhaps there was a practical issue of facility of calculation with one or another unit of measure respectively, or in fact these phenomena were studied in a hermetically separate way for a long time. It is not our aim to investigate and clarify the reason for this "separation" but we see and record this fact.

2.1 Nanometers to RGB

After we found the mathematical model, described in the previous section, our aim was to demonstrate it in an art work, in this case, an audiovisual hyperinstrument. At first sight, the most evident form to demonstrate the proposed theoretical correspondence, would be to use an oscillator to generate an audible 'pure tone' and a 'coherent' light source. But the coherent light (laser) sources available for civilian use do not allow wavelength variation of the emitted electromagnetic vibration, therefore, the above demonstration was not possible. Given this impossibility we chose to use an RGB additive system, which, besides being the standard of the majority of current display devices from monitors to projection systems, would make much more accessible the feasibility of the demonstration. However, the RGB colour space does not allow to produce all the visible electromagnetic vibrations (colours) present in the visible electromagnetic spectrum. Adding to this impossibility, we know that all chromatic sensations depend: on the spectral composition of incident light on the object or surface that is observed, on the spectral reflectance or

[4] According to Georg von Békésy, *The basilar membrane possesses exponentially graded stiffness, so that the base is some 100-fold stiffer than the apex*. (von Békésy 1960)

transmittance of the same object or surface, and also on the spectral response of the observer. So we assumed these limitations as a starting point and accepted that the demonstration of the correspondence proposal would be an approximation considering the technological and physical constraints that we just outlined.

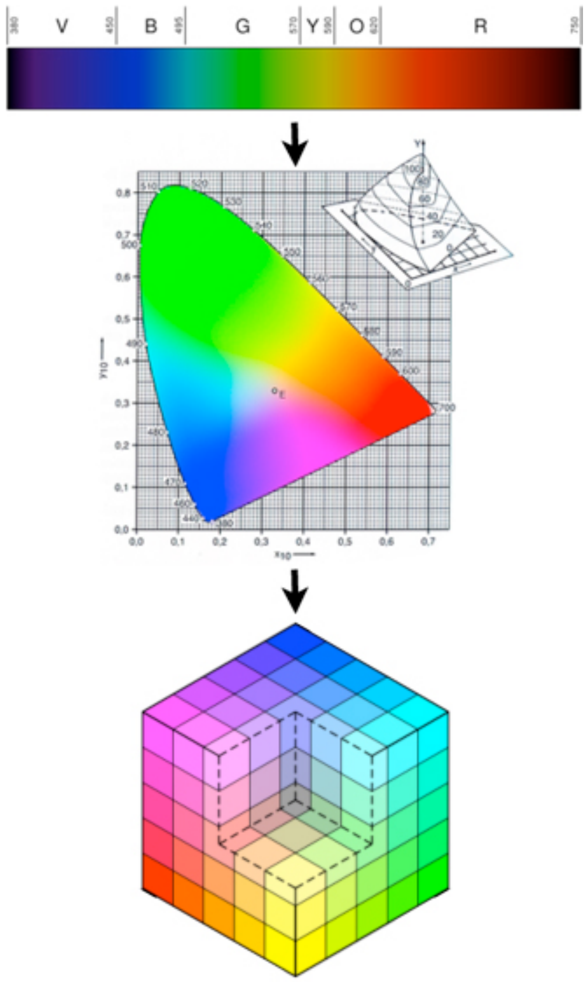

Figure 3. Method used to convert nm to RGB. Conversion from nm to CIE XYZ coordinates, followed by conversion from CIE XYZ coordinates to RGB coordinates.

The system we decided to design should therefore convert the number of Hz of a certain audible frequency in to three RGB coordinates to produce a chromatic sensation approximate to the one produced by the electromagnetic visible vibration with wavelength determined by the mathematical formula presented. We researched about different available models and formulas for converting wavelengths, in nanometers, to RGB coordinates, but given the diversity of models available and because we wanted this choice to be supervised by an expert, we contacted the photometry Master Stefan Grünsteidl, from the National Center Laser Applications, University of Galway in Ireland, that was in Portugal at that time, developing a patent for the company 'Multiwave Photonics, Inc.' specialized in optical fiber and laser. After we explained our challenge, Grünsteidl agreed to collaborate pointing us the solution for the conversion of nanometers to RGB coordinates. His efforts primarily directed us towards making a conversion of the wavelengths that compose the visible spectrum to the CIE[5] XYZ three-dimensional colour space. In this direction he provided us a translation table with 5 nanometers of resolution. In order to obtain bigger fluidity, we created a computer program integrating a custom designed algorithm, that is able to calculate the interpolation of the CIE table values provided by Grünsteidl. Thus, we obtained coordinates in CIE XYZ colour space for any wavelength of the electromagnetic spectrum. The conversion from CIE XYZ colour space to RGB colour space was obtained by integrating in our program an algorithm that implements a neutral programming function available on the website *'EasyRGB'*[6], specialized in information technology and services related to colour. This site is a reference resource with technical information about colour, colour science, programming techniques and compiles a series of links devoted to physics, psychology, physiology and colour technology. In short, although it is not physically or technically possible to produce with RGB systems all the electromagnetic vibrations that compose the visible spectrum, we implemented a system, that converts wavelengths to RGB coordinates, that produces chromatic sensations that come closest to the chromatic sensations caused by the electromagnetic vibrations present in the visible spectrum. This system, integrates custom designed and programmed software, that includes the mathematical formula presented in this text, allowing to make real-time conversion of a sound frequency to the correspondent chromatic sensation produced by an RGB system.

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[5] CIE stands for Comimission Internationale de L'Eclairage, online: http://www.cie.co.at/

[6] EasyRGB website: http://www.easyrgb.com/