André Rangel Macedo
PhD candidate in Art Science and Technology, Portuguese Catholic University, 2009

Audible and Visible Spectres - proposal for correspondence

Abstract:

Presentation of a proposal for correspondence between Colour and Music. The proposal is exemplified materially through a new hyper-instrument that gives users control over a multi-sensory algorithmic composition generated in real time. The methodology and mathematical model used are also presented in some detail, which are intended to be material and reference for future developments in the field of multi-sensory composition.

Keywords:

Visible spectrum, audible spectrum, synesthesia, multi-sensory composition, real time, colour, music, interactive composition, algorithmic composition, generative art, hyper-instrument, interface, meta-design.

Introduction

The senses of hearing and sight have always coexisted in human beings. According to researchers, newborns understand all their sensory impressions as a whole, they do not differentiate between light, sound, taste or smell (Campen 2008), and it is only around four months of age, with neuronal and social development, that the senses begin to modulate. Paul Hertz (Hertz 1999) considers works that merge two or more senses to be Synesthetic Art. Three decades earlier, Dick Higgins (Higgins 1965) had already coined the term Intermedia Art to describe multisensory composition processes that cross or merge the boundaries between different media, creating shared structures.
Correspondences between media are usually arbitrary, conditioned only by our cultural practices and psychological preferences. There have been several proposals for correspondences between colour and music over the last three centuries, but almost always, the systems created were based on the Western musical scale of twelve semitones.
This is possibly because in Western culture, the musical scale consists of seven musical notes, and seven is also commonly considered to be the number of colours in the rainbow.

This study proposes a relationship and a system of correspondence between Light (Colour) and Sound (Music) by juxtaposing the spectrum of audible frequencies and the spectrum of visible frequencies through mathematical modelling. To this end, wave frequency values from 28 Hz to 4 kHz (approximately the spectrum of fundamental frequencies of a piano's tessitura) were converted to wavelength values from 400 nm to 700 nm. By synchronising sound (musical) and visual events, the aim is to enhance and motivate design processes oriented simultaneously towards at least two senses: hearing and sight. To demonstrate this correspondence, a hyper-instrument was designed and produced that allows any user to complete an interactive algorithmic composition process.

Intermedia (between media), multisensory composition, which combines systematic knowledge of the musical and visual arts with scientific knowledge in the areas of sound and light physics, contributes to the understanding of emerging transformations and interactions between the arts, sciences and technologies. Today, the media can be described by mathematical abstractions and represented in digital formats, so the syntax of intermedia composition can be constructed by a programming language. "By implementing highly complex compositional structures between media, computers offer the possibility of controlling and synchronising different media." (Hertz 1999).

The following text is structured in five sections. First, representations of sound and light in the spatial and temporal domains are compared. This is followed by a presentation of elementary concepts of algorithmics associated with musical composition. We then present the core of this article, which is the proposal for a correspondence between colour and music. In the following section

, we describe the hyper-instrument designed to demonstrate our proposed correspondence, and present some details of the methodologies used in its materialisation. The last section presents the relationship between users/viewers and the multi-sensory composition, framing this work in the field of meta-design.

Audible spectrum and visible spectrum

Sound and light events are energy transport phenomena studied simultaneously by physics. Both propagate through waves, longitudinal mechanical waves in the case of sound and transverse electromagnetic waves in the case of light [1]. Sound waves require a material medium to propagate, but electromagnetic waves such as light can propagate in a vacuum. Both require a time lag between their emission and reception. In air, sound propagates at a speed of 344 m/s and light at a speed of 300,000,000 m/s. Sound waves perceptible to the human ear oscillate between approximately 20 Hz and 20 KHz with wavelengths between 17.15 and 0.0172 m, while electromagnetic waves perceptible to the human eye oscillate between 430 THZ and 750 THz with wavelengths between 740 and 380 nm. Despite the enormous differences in magnitude and speed, both sound waves and electromagnetic waves are represented by wavelength and frequency. It is intriguing that the sound spectrum is almost always represented in the frequency domain and the visible spectrum in the wavelength domain, given that frequency and wavelength are inversely proportional quantities.

Algorithmic composition

Algorithms originate in mathematics, in the process of solving a problem: "it is a step-by-step recipe for achieving a specific goal" (Cope 2007). A classic example is the Euclidean algorithm – a process used to find the greatest common denominator of two numbers. The result is the same whether the process is performed by a computer or a person. Thus, an algorithm consists of rules, operations, memory, and usually computers, inputs, and outputs. Operations transform the values of memories, inputs, and outputs. Rules define which operations to perform, depending on the conditions in the values of inputs and memories. Algorithms are fundamentally deterministic, finite, and do not know or make random choices. But randomness can be simulated, or the programme can branch out to external reality in order to introduce randomness into the algorithm.

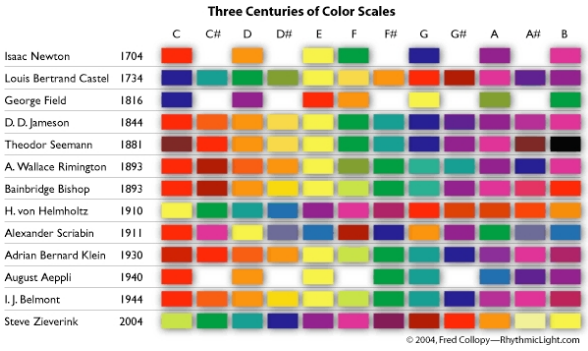
The power of computers has eliminated the tedious work of executing certain algorithms, leaving humans free to focus on the creative part of the work, namely the process that is the algorithm. If we can exhaustively describe a system on a sheet of paper, that system can be incorporated and implemented on a computer. Algorithms can be written in any language, but to be understood by a computer, they must be expressed in a computational language. The computer has become a very effective and convenient means of implementing algorithms very quickly. A computer connected to the appropriate machines can execute instructions to play music, draw, etc. Today, audiovisual artists have the technology to compose algorithmic works. Algorithmic artists, also known as algorists, are those who introduce and control original algorithms in their creative work (Verstko 1999).

Algorithmic processes that generate artistic forms have a long and venerable tradition. Examples include the composer's score, the architect's plan, and the dance choreographer's notes. When considering the most important composers in the history of algorithmic music, David Cope refers to Guillaume Machaut in the 14th century, J. S. Bach, F. J. Haydn,
W. A. Mozart in the 18th century, and A. Webern, P. Boulez, and J. Cage in the 20th century. Alpern (Alpern 1995) considers algorithmic composition to be automated composition and highlights Lejaren Hiller, Leonard Isaacson, Robert Baker, and Iannis Xenakis as pioneers of computer-assisted algorithmic composition. From the past to the present, there are three main approaches to computerised algorithmic composition: algorithms for sound synthesis; algorithms for compositional structure; and algorithms for correlating sound synthesis with compositional structure. At the procedural and methodological level, Burns (Burns 1996) identifies five types of algorithms: stochastic, chaotic, rule-based, grammatical, and artificial intelligence. The interactive algorithmic composition made possible by the hyper-instrument we now present simultaneously integrates stochastic and rule-based methodologies, as will be explained later in this text.

Music and Colour

Throughout history, there have been various models and devices aimed at real-time performance of visual and sound events. According to Golan Levin (Levin 2000), the synchronisation of images and sounds is variously known as ocular music, visual music, colour music or music for the eyes. In his master's thesis, Levin analyses and lists some of the most relevant attempts throughout history to relate sound and image, beginning with Bertrand Castel's (1688–1757) "Ocular Harpischord," considered the oldest device for the performance of visual music.

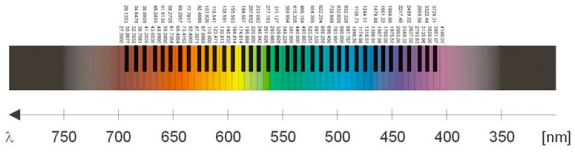
Figure 1 - Correspondences between colour and music.



Of all the possible correspondences between music and colour, the mapping of musical notes or pitches to colour tones has been the most common proposal over the last 300 years. Looking at the colour scale table (figure 1), we see that proposals often match colours from the visible spectrum to the twelve semitones that make up an octave of the diatonic scale. Newton, through a speculative approach in 1704, aligns the spectrum by a diatonic scale (Collins, 2007). In 1734, Louis-Bertrand Castel clearly undertook a more random and symmetrical alignment than Newton's between the notes C and G. Castel kept yellow for E and exchanged red and blue for C and G, adding intermediate chromatic values to obtain a 12-level chromatic-musical scale. Field, in opposition to Newton (Silvestrini, Fischer 1999), based his proposal on Moses Harris' studies on the discoveries of Jacques Christophe Le Blon, who observed that it was possible to represent "all" colours by mixing the pigment colours blue, red and yellow. Field also related the brightness of light to yellow, darkness to blue and an intermediate state with red. In the chromo-musical scale he proposed, in addition to blue, red and yellow, he used three more secondary colours resulting from mixing pairs of the first three.
The chromo-musical scales proposed between 1844 and 1893 again aligned the spectrum with a diatonic scale, with slight variations. Helmholtz and Scriabin broke with this trend once again. Helmholtz aligned the colours he considered primary in additive colour synthesis (red, green and blue-violet) with the notes of the A major chord, and Scriabin proposed a scale considered to be the result of the influence of his synesthesia. At the end of the 20th century, another key figure in the study of possible associations between colour and music was Jorge Antunes (1982), who proposed a "chromophonic" table that corresponds musical notes to frequencies in the visible spectrum in great detail (see Appendix 3).

Considering that the piano is the instrument traditionally used in the composition process and that, furthermore, it is the one that produces the widest spectrum of musical pitches of all the elements of the classical orchestra, it was decided to take it as a reference in this demonstration. The correspondence between colour and sound frequency that we propose was obtained using the mathematical model that best suited the conversion of the exponential spacing of the intervals between the fundamental frequencies of the notes comprising the tessitura of a piano into linear spacing of the wavelengths of the visible electromagnetic spectrum. Figure 2 graphically illustrates this correspondence.

Figure 2 - Correspondence proposed in this study.



The Hyperinstrument

Tod Machover (Machover 1992) proposes the term hyper-instrument to define tools, resulting from technological research in the field of the arts, that transcend the traditional limits of amplification of human gestures. As systems, stimulators and facilitators of the creative process, they combine the traditional roles of performer and composer with the

computational power of the machine. Tod considered them to be the musical instruments of the future which, aiming at increased expressiveness, will redefine musical expression itself.

Figure 3 - The Colmus hyper-instrument.



To demonstrate the correspondence we propose, the Colmus hyper-instrument (Figure 3) was designed and produced as the result of a multisensory composition process that aims to simultaneously involve the senses of hearing, sight and touch of users/performers. This composition thrives on contrasts: it simultaneously integrates digital and analogue media; commercial *hardware* and *customised hardware*; it merges *low-tech* mechanical technologies and *high-tech* digital and electronic technologies; it combines simple materials such as wood and iron with *software* in the form of a fully *customised* original application.

The first step in programming the application was to implement the algorithm that allows "RGB" values (a standardised dimension for almost all electronic image display devices) to be matched to each wavelength value in the visible spectrum. As an exact match is not physically possible, an approximation based on current scientific knowledge was implemented. The methodology involves two distinct steps: first, conversion of electromagnetic wavelength values to values of the CIE XYZ three-dimensional colour model (Gernot 2000) using the conversion table available in Annex 2; second, conversion of CIE XYZ values to RGB values using the conversion formula available in Annex 3.
Once this first phase of programming has been implemented
and using the mathematical model we developed (see Annex 4) to convert values between 27.5 Hz and 4,186.01 Hz to values between 700 nm and 400 nm, the application made it possible to match the fundamental frequency of each note in the piano's tessitura to the corresponding RGB values.

The next step focused essentially on designing a simple algorithm that generates and calculates the structure of the composition in real time. This algorithm was implemented using both stochastic and rule-based methodologies in order to introduce contrast into the composition. Contrast and repetition are, according to Roy Bennett, the two basic ingredients of musical form and design (Bennett 1982). The existence of some degree of repetition in all music is one of its global properties (Leach and Fitch 1995), so the performance of this generative composition takes place in a loop, repeating at the end of every 10 bars. The intervals between the notes that make up the chords of a perfect cadence are also repeated, but in real time, they are transposed individually through the random addition or subtraction of 12 semitones. Another rule in this composition is the occurrence of rhythmic variations

during its performance. For example, at the beginning of the first bar, between 1 and 16 semiquavers are chosen at random, occupying random positions in time during the first three bars, creating distinct and unexpected rhythms.

Interactivity and Metaconception

In contemporary music, there is a growing interest in interactive and multi-modular works (Campos, Traldi, Oliveira and Manzoli 2007). The power of modern computers and their processing capacity offer new possibilities for interactive musical, visual and multi-sensory composition. The art of the present is real-time art, live art where what counts is its instantaneity (Virilio 2005). The hyper-instrument created for this demonstration is therefore current because it calculates the audiovisual composition in real time. As a hyper-instrument, the central objective of its meta-design was its easy and intuitive use by human beings. Meta-design corresponds to the design of tools, parameters and operating conditions that allow the end user to take responsibility for the final design. In a truly interactive context, the advantages of meta-design are transferred to the end user. Users/viewers can interact with the composition, drawing its melodic line and controlling the number of beats per minute through an interface that does not require literacy. By giving users/viewers control of the application, they become the performers of the artistic work. According to Kerckhove (1997), the first law of interactivity stipulates that the user forms or provides the content. The fact that the viewer creates or forms the content themselves transforms them from a receiver of communication into the main provider.

Conclusion

The implemented algorithm, which allows for the correspondence between sound frequency and light colour frequency, will certainly be integrated into future multisensory compositions, as we are considering its reuse and improvement. With regard to the practical functionality of the project, there is currently no representative sample of results and opinions, as the proposed correspondence and the hyper-instrument that demonstrates it have not yet been presented publicly.

The hyper-instrument prototype we present allows people with little or no skills as audiovisual users and creators to participate in a generative algorithmic composition process. This work therefore deserves further continuation and analysis, to be developed after public implementation.
I conclude that the correspondence between light colour frequency and sound frequency associated with the design of multi-sensory interactive systems is fertile ground for future research.

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Notes

[1] - Although in modern physics, light or electromagnetic radiation can be described in one of two complementary ways: as a wave in an electromagnetic field or as a stream of particles called photons. Although both are acceptable descriptions of light, the description of light as a wave is the one that best suits the purposes of the study in question.

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André Rangela@3kta.net
Colmus: http://3kta.net/colmus

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Appendix 1

Chromophonic correspondence table proposed by Jorge Antunes

E E 43 - 362,394,032,514,969.60 c/sec - Infrared F F 43 - 383,949,460,419,379.20 c/sec - Infrared F# Fá# 43 - 406,731,331,346,897.92 c/sec - Red
SOL Sol 43 - 431,008,558,088,192.00 with interest - Red
SOL# Sol# 43 - 456,693,149,713,039.36 with interest - Red
LÁ Lá 43 - 483,785,116,221,440.00 c/sec - Red
LA# La# 43 - 512,460,379,374,838.08 c/sec - Orange-red SI Si 43 - 543,070,783,191,121.92 c/sec - Yellow-green DÓ Dó 44 - 575,264,483,652,443.20 c/sec - Green
C# C# 44 - 609,393,324,558,570.24 c/sec - Cyanotic blue D#
D# 44 - 645,633,227,830,107.20 c/sec - Blue
D# D# 44 - 683,984,193,406,894.08 c/sec - Blue-violet E E
44 - 724,798,065,029,939.20 c/sec - Violet-blue FÁ Fá 44 - 767,898,920,838,758.40 with interest - Violet
F# F# 44 - 813,462,662,693,795.84 with interest - Ultraviolet SOL Sol 44 - 862,017,116,176,384.00 with interest – Ultraviolet

Appendix 2

Nm to CIE xyz conversion table

380, 2.689900e-003, 2.000000e-004, 1.226000e-002
385, 5.310500e-003, 3.955600e-004, 2.422200e-002
390, 1.078100e-002, 8.000000e-004, 4.925000e-002
395, 2.079200e-002, 1.545700e-003, 9.513500e-002
400, 3.798100e-002, 2.800000e-003, 1.740900e-001
405, 6.315700e-002, 4.656200e-003, 2.901300e-001
410, 9.994100e-002, 7.400000e-003, 4.605300e-001
415, 1.582400e-001, 1.177900e-002, 7.316600e-001
420, 2.294800e-001, 1.750000e-002, 1.065800e+000
425, 2.810800e-001, 2.267800e-002, 1.314600e+000
430, 3.109500e-001, 2.730000e-002, 1.467200e+000
435, 3.307200e-001, 3.258400e-002, 1.579600e+000
440, 3.333600e-001, 3.790000e-002, 1.616600e+000
445, 3.167200e-001, 4.239100e-002, 1.568200e+000
450, 2.888200e-001, 4.680000e-002, 1.471700e+000
455, 2.596900e-001, 5.212200e-002, 1.374000e+000
460, 2.327600e-001, 6.000000e-002, 1.291700e+000
465, 2.099900e-001, 7.294200e-002, 1.235600e+000
470, 1.747600e-001, 9.098000e-002, 1.113800e+000
475, 1.328700e-001, 1.128400e-001, 9.422000e-001
480, 9.194400e-002, 1.390200e-001, 7.559600e-001
485, 5.698500e-002, 1.698700e-001, 5.864000e-001
490, 3.173100e-002, 2.080200e-001, 4.466900e-001
495, 1.461300e-002, 2.580800e-001, 3.411600e-001
500, 4.849100e-003, 3.230000e-001, 2.643700e-001
505, 2.321500e-003, 4.054000e-001, 2.059400e-001
510, 9.289900e-003, 5.030000e-001, 1.544500e-001
515, 2.927800e-002, 6.081100e-001, 1.091800e-001

André Rangela@3kta.net
Colmus: http://3kta.net/colmus

520, 6.379100e-002, 7.100000e-001, 7.658500e-002
525, 1.108100e-001, 7.951000e-001, 5.622700e-002
530, 1.669200e-001, 8.620000e-001, 4.136600e-002
535, 2.276800e-001, 9.150500e-001, 2.935300e-002
540, 2.926900e-001, 9.540000e-001, 2.004200e-002
545, 3.622500e-001, 9.800400e-001, 1.331200e-002
550, 4.363500e-001, 9.949500e-001, 8.782300e-003
555, 5.151300e-001, 1.000100e+000, 5.857300e-003
560, 5.974800e-001, 9.950000e-001, 4.049300e-003
565, 6.812100e-001, 9.787500e-001, 2.921700e-003
570, 7.642500e-001, 9.520000e-001, 2.277100e-003
575, 8.439400e-001, 9.155800e-001, 1.970600e-003
580, 9.163500e-001, 8.700000e-001, 1.806600e-003
585, 9.770300e-001, 8.162300e-001, 1.544900e-003
590, 1.023000e+000, 7.570000e-001, 1.234800e-003
595, 1.051300e+000, 6.948300e-001, 1.117700e-003
600, 1.055000e+000, 6.310000e-001, 9.056400e-004
605, 1.036200e+000, 5.665400e-001, 6.946700e-004
610, 9.923900e-001, 5.030000e-001, 4.288500e-004
615, 9.286100e-001, 4.417200e-001, 3.181700e-004
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625, 7.398300e-001, 3.205200e-001, 1.567900e-004
630, 6.328900e-001, 2.650000e-001, 9.769400e-005
635, 5.335100e-001, 2.170200e-001, 6.894400e-005
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650, 2.786200e-001, 1.070000e-001, 2.423800e-005
655, 2.148500e-001, 8.165200e-002, 1.691500e-005
660, 1.616100e-001, 6.100000e-002, 1.190600e-005
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675, 6.307700e-002, 2.345400e-002, 3.954400e-006
680, 4.583400e-002, 1.700000e-002, 2.791200e-006
685, 3.205700e-002, 1.187200e-002, 1.917600e-006
690, 2.218700e-002, 8.210000e-003, 1.313500e-006
695, 1.561200e-002, 5.772300e-003, 9.151900e-007
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720, 2.825300e-003, 1.047000e-003, 1.702600e-007
725, 1.994700e-003, 7.401500e-004, 1.220700e-007
730, 1.399400e-003, 5.200000e-004, 8.710700e-008
735, 9.698000e-004, 3.609300e-004, 6.145500e-008
740, 6.684700e-004, 2.492000e-004, 4.316200e-008
745, 4.614100e-004, 1.723100e-004, 3.037900e-008
750, 3.207300e-004, 1.200000e-004, 2.155400e-008
755, 2.257300e-004, 8.462000e-005, 1.549300e-008
760, 1.597300e-004, 6.000000e-005, 1.120400e-008
765, 1.127500e-004, 4.244600e-005, 8.087300e-009
770, 7.951300e-005, 3.000000e-005, 5.834000e-009
775, 5.608700e-005, 2.121000e-005, 4.211000e-009
780, 3.954100e-005, 1.498900e-005, 3.038300e-009
785, 2.785200e-005, 1.058400e-005, 2.190700e-009
790, 1.959700e-005, 7.465600e-006, 1.577800e-009
795, 1.377000e-005, 5.259200e-006, 1.134800e-009
800, 9.670000e-006, 3.702800e-006, 8.156500e-010
805, 6.791800e-006, 2.607600e-006, 5.862600e-010
810, 4.770600e-006, 1.836500e-006, 4.213800e-010
815, 3.355000e-006, 1.295000e-006, 3.031900e-010
820, 2.353400e-006, 9.109200e-007, 2.175300e-010
825, 1.637700e-006, 6.356400e-007, 1.547600e-010

http://cvrl.ioo.ucl.ac.uk/database/data/cmfs/ciexyzjv.txt

Appendix 3

Conversion from xyz to rgb:

```
var_R = var_X * 3.2406 + var_Y * -1.5372 +
var_Z * -0.4986
var_G = var_X * -0.9689 + var_Y * 1.8758 +
var_Z * 0.0415
var_B = var_X * 0.0557 + var_Y * -0.2040 +
var_Z * 1.0570

if ( var_R > 0.0031308 ) var_R = 1.055 * ( var_R
^ ( 1 / 2.4 ) ) - 0.055
else                 var_R = 12.92 * var_R
if ( var_G > 0.0031308 ) var_G = 1.055 * ( var_G
^ ( 1 / 2.4 ) ) - 0.055
else                 var_G = 12.92 * var_G
if ( var_B > 0.0031308 ) var_B = 1.055 * ( var_B
^ ( 1 / 2.4 ) ) - 0.055
else                 var_B = 12.92 * var_B

R = var_R * 255
G = var_G * 255
B = var_B * 255
```

http://www.easyrgb.com/index.php?
X=MATH&H=01#text1

Appendix 4

Mathematical model we developed to convert the fundamental frequency of the notes in a piano's range to wavelengths of colours in the visible spectrum:

```
n = 700 - (12*( log(f/220)/log(2))+36)*3.44827586207
```

The previous model was adapted from the following model.

```
n= 12*(log(f/220)/log(2)) + 57
```

Source:
http://www.music.mcgill.ca/~gary/306/week11/
mspfeatures.html

André Rangela@3kta.net
Colmus: http://3kta.net/colmus