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Visible and Audible Spectrums - a proposal of correspondence

Abstract:

Presentation of a proposal of correspondence between Colour and Music. This proposal is materially exemplified by means of a new hyper-instrument, which gives its users the control over a multi-sensorial algorithmic composition generated in real-time. The employed methodology and mathematical model are also presented with some detail, insofar as they pretend to be matter and reference for future developments in the field of multi-sensorial composition.

Keywords:

Visible spectrum, audible spectrum, synaesthesia, multi-sensorial composition, real-time, colour, music, interactive composition, algorithmic composition, generative art, hyper-instrument, interface, meta-conception.

Introduction

The senses of audition and of vision have always coexisted in human beings. According to researchers, new-borns understand all of their sensorial impressions as a whole, they do not differentiate light from sound from taste from smell (Campen, 2008), and it is only around four months of age, with neuronal and social development, that babies begin to modularize the senses. Paul Hertz considers works who merge two or more senses as Synaesthesic Art (Hertz, 1999), and three decades before that, Dick Higgins had already coined the term Intermedia Art to describe processes of multi-sensorial compositions which cross or merge the boundaries between different media, thus creating shared structures (Higgins, 1965).
Correspondences between media are usually arbitrary, conditioned only by our cultural practices and psychological preferences. There have been several proposals of correspondence between colour and music in the last three centuries but, almost always, the proposed systems had their ground on the western musical scale of twelve half tones. Possibly because in western culture the musical scale is composed of seven musical notes and seven is also ordinarily conceived as the total number of colours of the rainbow.

This study proposes a correspondence relation and system between Light (Colour) and Sound (Music) by juxtaposing the spectrum of audible frequencies and the spectrum of visible frequencies by means of a mathematical modelation. To do that, the values of the wave frequency from 28 Hz to 4 KHz (nearly the spectrum of fundamental frequencies from the texture of a piano) have been converted to values of wavelength from 400 nm to 700 nm. By synchronizing sound (musical) and visual happenings we pretend to empower and motivate processes of conception simultaneously oriented to at least two senses: audition and vision. In order to demonstrate this correspondence we have designed and produced a hyper-instrument that allows any user to finalize a process of interactive algorithmic composition.

Multi-sensorial, intermedia composition (between media), which combines systematized knowledge of Musical and Visual Arts together with scientific knowledge from the fields of sound and light physics, contributes to an understanding of the emergent transformations and interaction between Arts, Sciences and Technologies. Today, media can be described by mathematical abstractions and represented in digital formats; and so the syntax of intermedia composition can be built into a programming language. "Implementing compositional structures highly complex between media, computers offer the possibility of controlling and synchronizing different media" (Hertz, 1999).

The following paper is structured in five sections. Firstly, sound and light representations in the spatial and temporal fields are compared. It then follows the presentation of elementary concepts of algorithmic associated with musical composition. We immediately present then the core of this paper, which is the proposed correspondence between colour and music. In the next section, we describe the hyper-instrument designed to demonstrate our proposed correspondence, and present some details of the methodologies employed in its materialization. The final section presents the relation of the users/spectators with multi-sensorial composition framing this work in the field of meta-conception.

Audible spectrum and Visible spectrum

Sound and light occurrences are phenomena of energy transport studied simultaneously by physics. They both propagate through waves, longitudinal mechanics in the case of sound, and transversal electromagnetic in the case of light [1]. Sound waves need a material medium in order to propagate, but electromagnetic waves as the light can propagate in the void. They both need a time interval between their emission and their reception. In the 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 human ear oscillate approximately between 20 Hz and 20 Khz, with wave lengths between 17.15 and 0.0172 m; electromagnetic waves perceptible to human eye oscillate between 430 THz and 750 THz, with wave lengths between 740 and 380 nm. In spite of big differences in greatness and speed, both sound waves and electromagnetic waves are represented by the wavelength and frequency. It is an intriguing fact that we almost always represent sound spectrum in the frequencies domain and the visible spectrum in the wavelengths domain, seen that frequency and wavelength are inversely proportional greatnesses.

Algorithmic composition

The algorithm has origin in mathematics: in the process of solving a problem, “it is a step to step receipt to achieve a specific goal” (Cope, 2007). A classical example is the Euclidean algorithm – the process employed to find the maxim common denominator of two numbers. The result is the same whether the process is executed by a computer or by a person. In this way, an algorithm consists in rules, operations, memory, and also, usually, computers, inputs and outputs. Operations transform the values of the memories, of the inputs and of the outputs. Rules define which operations to execute, depending on the conditions in the values of the inputs and memories. Algorithms are fundamentally deterministic, finite, and they do not know nor make random choices. But randomness can be simulated, or the program may have a ramification oriented towards external reality in such a way as to introduce randomness into the algorithm.

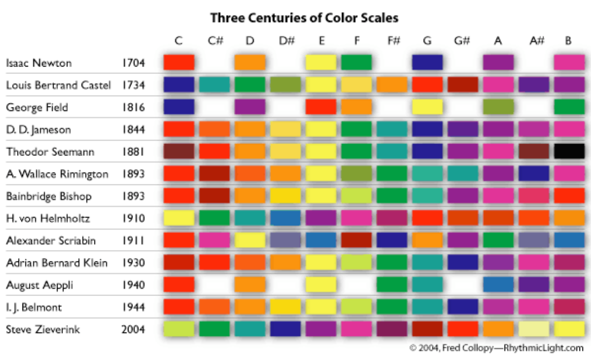
The power of computers has eliminated the harsh execution work of certain algorithms, leaving humans free to focus on the creative part of the work, namely in the process which is the algorithm. If we can exhaustively describe a system on a sheet of paper, then that system can be incorporated and implemented in a computer. Algorithms can be written in any language; in order to be understood by a computer, they have to be expressed in a computational language. Computer has become a quite effective and convenient mean to implement algorithms at a great speed. A computer switched to the appropriate machines can execute instructions to play music, draw, etc. Nowadays, audiovisual artists have the technology to compose algorithmic works. Algorithmic artists, also known as algorists, are those that introduce and control original algorithms in their creative work (Vertsko, 1999).

Algorithmic processes that generate artistic forms enjoy a long and venerable tradition. Examples include the composer’s partition, the architect’s plan, and the dance choreographer’s notations. Considering the most important composers in the history of algorithmic music, David Cope refers to Guillaume Machaud, in the fourteenth century, J. S. Bach, F. J. Haydn, and W. A. Mozart in the eighteenth century, and A. Webern, P. Boulez, and J. Cage in the twentieth-century. Alpern considers algorithmic composition as automatized composition (Alpern, 1995) and emphasizes as pioneers of computer’s assisted algorithmic composition Lejaren Hiller, Leonard Isaacson, Robert Baker and Iannis Xenakis.
Since the past until present days, there have been three main approaches to computerized algorithmic composition: algorithms for sound synthesis; algorithms for compositional structure; and algorithms for the correlation of the sound synthesis with the compositional structure. On the processual and methodological level, Burns identifies five types of algorithms (Burns, 1996): stochastic, chaotic, rule-based, grammatical, and artificial intelligence. The interactive algorithmic composition made possible by the hyperinstrument that we now present integrates simultaneously stochastic and rule-based methodologies, as will be shown ahead in this paper.

Music and Color

Along the times there have been several models and devices that aimed the real-time performance of visual and sound events. According to Golan Levin, synchronism between images and sounds is variably known as ocular music, visual music, colorful music or music-to-the-eyes (Levin, 2000). In his master thesis, Levin analyses and lists some of the most relevant attempts throughout history in the sense of relating sound and image, beginning with the “Ocular Harpsichord” from Bertrand Castel (1688-1757), considered to be the most ancient device for the performance of visual music.

Figure 1 - Correspondences between music and color.

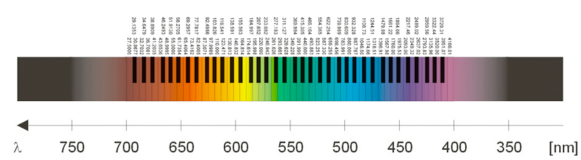


Of all the possible correspondences between music and color, the mapping of musical notes or heights to color tonalities was the most common proposal in the last 300 years. Observing the table of colors scales (fig. 1), we can see that the proposals often make correspond colors from the visible spectrum to the twelve half tones that constitute an eighth of the diatonic scale.
In 1704, Newton, through a speculative approach, aligns the spectrum by a diatonic scale (Collins, 2007). In 1734, Louis-Bertrand Castel clearly undertook a more random alignment, and symmetrical to Newton’s between Do and Sol notes. Castel maintains the yellow in Mi and exchanges the red and the blue from the Do and the Sol, adding the middle chromatic values to obtain a chromo-musical scale with 12 levels. Field, in opposition to Newton, based his proposal on Moses Harris’s studies upon the discoveries of Jacques Christophe le Bon, who first observed it was possible to represent “all” the colors beginning with a mixture of blue, red and yellow color pigments (Silverstini, Fischer, 1999). Field also related the shine of light with yellow, darkness with blue, and a middle state with red. In the chromo-musical scale he proposed, besides blue, red and yellow, he employed three more secondary colors, resultant from the pair mixture of the three first ones.

Between 1844 and 1893, the proposed chromo-musical scales again aligned, with small variations, the spectrum by a diatonic scale. Helmholtz and Scriabin again shatter this trend. Helmholtz, by aligning the colors which he considered to be primary colours in the additive synthesis of color (red, green and blue-violet) by the notes of major La chord, and Scriabin by proposing a scale considered as a resultant of the influence of his synaesthesia. In the end twentieth-century, another outstanding name in the study of the possible associations between color and light is Jorge Antunes (1982), who proposed the “chromophonic” table, which makes correspond to musical notes frequencies of the visible spectrum in a quite detailed way (see annex 3).

Considering that the piano is the most commonly used instrument in the process of composition, and is besides that, from all the elements of the classical orchestra, the one that produces the largest spectrum of musical heights, we have decided to take it as a reference in our demonstration. The correspondence between color and sound frequency that we propose was obtained by applying the mathematical model that was better adjusted to convert the exponential spacing of the intervals between the fundamental frequencies of the notes comprised in a piano’s texture into linear spacing from the wavelengths of the visible electromagnetic spectrum. Figure 2 graphically illustrates this correspondence.

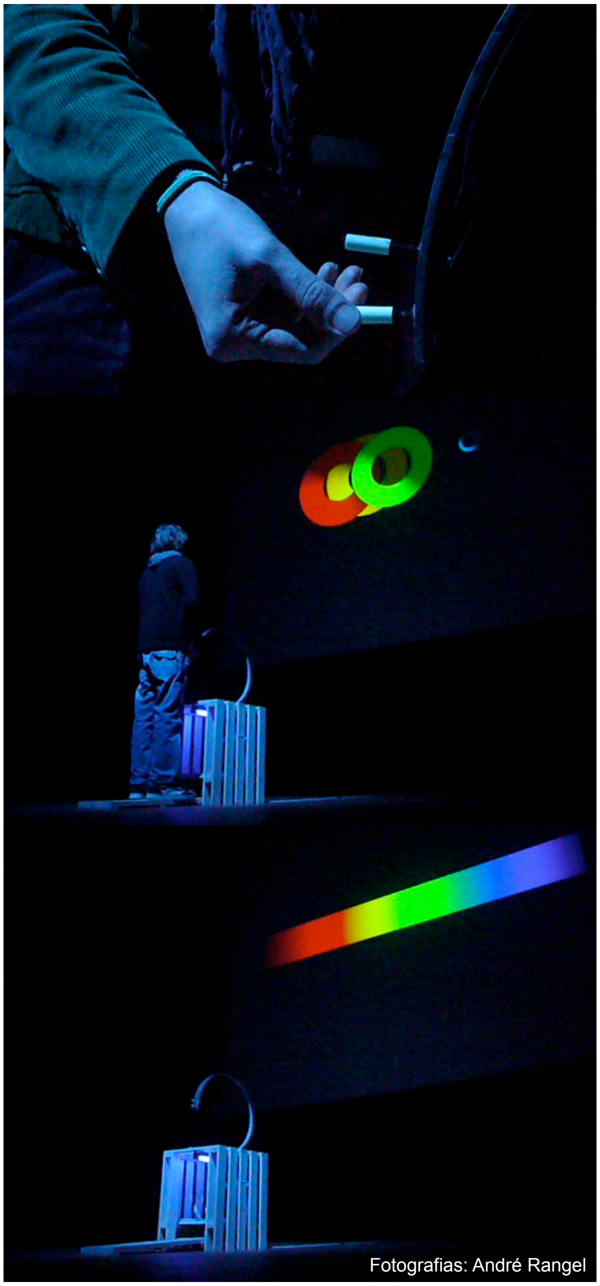
Figura 2 - Proposed correspondence in this study.



The Hyperinstrument

Tod Machover coins the term hyper-instrument (Machover, 1992) to define tools, resultant from technological research in the field of arts, which transcend the common amplification boundaries of human gestures. As systems, stimulators and facilitators of the creative process, they combine the traditional roles of the performer and the composer with the computational power of the machine. Tod has considered them to be the future musical instruments that, aiming a magnified expressibility, will redefine musical expression itself.

Figura 3 - The hyperinstrument Colmus.



In order to demonstrate our proposed correspondence, the Hyper-instrument Colmus was designed and produced (fig. 3), as a result of a process of multi-sensorial composition that intends to simultaneously implicate the senses of audition, vision and the tact of users/performers. This composition lives from contrasts: it simultaneously integrates digital and analogical media; commercial and customized hardware; it merges low-tech mechanical and high-tech digital and electronic technologies; it combines simple materials such as wood and iron with software in the form of an original application wholly customized.

The first step in the programming of the application was to implement the algorithm that allows making correspond "RGB" values (standardized dimension to almost all of the electronic devices of image presentation) to each wavelength value of the visible spectrum. An exact correspondence being physically impossible, we implemented an approximation based on present scientific knowledge. The methodology implies two different moments: first, conversion of the electromagnetic wavelength values into values of the three-dimensional color model CIE XYZ (Gernot, 2000), employing the conversion table available as annex 2; second, conversion of the CIE XYZ values into RGB values, employing the conversion formula available as annex 3.
After this first phase of the programming was implemented, and by using the mathematical model we developed (see annex 4) to convert the values between 27.5 Hz and 4,186.01 Hz to values between 700 and 400 nm, the application allowed making correspond to the fundamental frequency of each note of the piano's texture the corresponding RGB values.

The next step focused essentially on the design of the simple algorithm which generates and calculates in real-time the structure of the composition. Using simultaneously stochastic and based-rules methodologies, this algorithm was implemented so that contrast could also be introduced in the composition process. Contrast and repetition that are, according to Roy Bennett, the two basic ingredients of musical project and form (Bennett, 1982). The existence of some degree of repetition in all music is one of its general properties (Leach & Fitch, 1995); so, the performance of this generative composition happens in "loop", repeating itself at the end of every 10 bars. The intervals between the notes that compose the chords of a perfect cadence are also repeated, but in real-time, they are individually transposed through the random addition or subtraction of twelve half tones. Another of the rules in this composition is the occurrence of rhythmical variations during its performance, e.g., between 1 and 16 sixteenths are randomly chosen in the beginning of the first bar that occupy random positions in the time between the first three bars, thus creating distinct and unpredictable rhythms.

Interactivity and Meta-conception

There is in contemporary music a growing interest in interactive and multi-modular works (Campos, Traldi, Oliveira & Manzoli, 2007). The power of modern computers and its processing ability offer new possibilities to musical, visual, multi-sensorial interactive composition. The Art of today is real-time Art, live Art where what counts is its instantaneity (Virilio, 2005): the hyper-instrument created to this demonstration is therefore part of that present Art trend, for it calculates audio-visual composition in real-time. As a hyper-instrument, the main goal of its meta-conception was its easy and intuitive utilization by human beings. Meta-conception corresponds to the conception of tools, parameters and conditions of functioning, which allow the final user to hold responsibility of the ultimate conception. In a truly interactive context, the advantages of meta-conception are transferred to the final user. Users/spectators can interact with the composition designing its melodic line and controlling the number of beats by minute through an interface that doesn’t require alphabetization. By giving users/spectators the control of the application, these become the performers of the artistic work. According to Kerckhove (1997), the first law of interactivity stipulates that it is the user that forms or supplies the content. The fact that the spectator himself creates or forms the content transforms him, from a communication receptor in to main supplier.

Conclusion

The implemented algorithm, which allows the correspondence between sound frequency and color light frequency, will certainly integrate future multi-sensorial compositions, seen that we consider its reutilization and betterment. In respect to the functionality of the project at a practical level, we do not yet have a representative sample of results and opinions, given the fact that our proposed correspondence and the hyper-instrument that demonstrates it have not yet been publicly presented.
The hyper-instrument prototype that we present allow people with few or very few skills, while users and creators of audiovisual, to participate in a process of generative algorithmic composition. Therefore, we believe that this work is worth of continuation and deeper analysis, to develop after public implementation. I conclude that the correspondence between color light frequency and sound frequency associated to the conception of interactive multi-sensorial systems is fertile ground to future researches.

Translation

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Notes

[1] - 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.

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Annex 1

Table "*correspondência cromofônica*" proposed by Jorge Antunes

MI	Mi	43 - 362.394.032.514.969,60 c/seg - Infravermelho
FÁ	Fá	43 - 383.949.460.419.379,20 c/seg - Infravermelho
FÁ#	Fá#	43 - 406.731.331.346.897,92 c/seg - Vermelho
SOL	Sol	43 - 431.008.558.088.192,00 c/seg - Vermelho
SOL#		Sol# 43 - 456.693.149.713.039,36 c/seg - Vermelho
LÁ	Lá	43 - 483.785.116.221.440,00 c/seg - Vermelho
LÁ#	Lá#	43 - 512.460.379.374.838,08 c/seg - Laranja-avermelhado
SI	Si	43 - 543.070.783.191.121,92 c/seg - Amarelo-esverdeado
DÓ	Dó	44 - 575.264.483.652.443,20 c/seg - Verde
DÓ#	Dó#	44 - 609.393.324.558.570,24 c/seg - Azul-cianótico
RÉ	Ré	44 - 645.633.227.830.107,20 c/seg - Azul
RÉ#	Ré#	44 - 683.984.193.406.894,08 c/seg - Azul-violeta
MI	Mi	44 - 724.798.065.029.939,20 c/seg - Violeta-azul
FÁ	Fá	44 - 767.898.920.838.758,40 c/seg - Violeta
FÁ#	Fá#	44 - 813.462.662.693.795,84 c/seg - Ultravioleta
SOL	Sol	44 - 862.017.116.176.384,00 c/seg – Ultravioleta

Annex 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
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
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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
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630, 6.328900e-001, 2.650000e-001, 9.769400e-005
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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
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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

Annex 3

xyz to rgb color conversion formula:

```
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

Annex 4

Mathematical model developed to convert fundamental frequencie values of the piano notes to the color wavelengths of 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