Determining the Chromatic Index of Music

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Abstract
Musical diachrony and synchrony have revealed an incredible variation in musical scales, many of which are implied, lurking in traditional patterns and not adequately transcribed in their projection to the dominant Western music predicates. From antiquity the term “chromatic” was used to determine the coordinates of diversification in terms of psychoacoustic perception of music, and it yielded relatively recently the chromatic scale as a fine-tuning aberration of Western music to acoustic polymorphism. In a globalized environment of musical distribution the proposed chromatic index serves as a classification norm for musical genus alternation.

1. Introduction
An important attribute of a musical composition is its “chroma”, defined first in Ancient Greek Music [1]. Apart from the separation in “chromatic”, “harmonic”, “melodic” and “diatonic” entities, as defined in Western music, additional musical phenomena have been detected in Oriental music, in Byzantine music and in prosodic vocal phenomena, which cannot be exactly categorized with these predicates for tonal distributions [2].

Likewise, the characterization of a musical hearing as chromatic or non-chromatic consists strongly in its association with psychoacoustic phenomena, e.g. one particular artist may “color” a musical piece using his voice, while other artists may not [3]. We can realize, while listening to a composition, that the stronger feelings this causes to us, the more chromatic it is. The inverse statement is also true.

For chromatic determination there is need to clarify:
- the musical elements that turn a musical piece “chromatic” during performance
- the way a computer music transcription may reveal these elements
- the factors that categorize a musical piece according to its chroma.

These questions are thoroughly examined through this paper, and an algorithm is developed to measure chromatic elements. Psychoacoustics theories are used for corresponding musical segments with colors in the results section.

2. In Search for chroma in music
“Chroma” (the Greek word for “color”), as is generally defined, is the aspect of any object that may be described in terms of hue, lightness, and saturation.

The term chroma is strongly associated with the arts of music. Whereas it is widely used, especially in comparative musicology, there is not yet a clear definition for “musical chroma”. There is a great deal of many considerations and approaches from many different points of view. For instance, in the expression “European chroma, Oriental or Greek chroma” the differentiation is associated with cultures, uses of sounds and feelings.

From a scientific point of view, chroma is one of the attributes of sound. The rest of them are: tonal height, density, direction and mass. In contemporary literature, chroma is not to be confused with timbre (=sound color) [4]. Shepard has defined with chroma the note’s position within the octave and has created a nonlogarithmic pitch helix, the chroma circle, that clearly depicts octave equivalence [5]. Sundberg has added emotional coloring using tone categorization [3] while Juslin has mapped musical expression cues of basic emotions [6].

However, the purpose of this paper is not to measure musical emotion but to provide the web of ethnomusicology with an index of background acoustic variability, using chroma in its original context as a musical genus discriminator [1][7].

2.1. Chromaticism
Chromaticism in music is the use of notes foreign to the mode or diatonic scale upon which a composition is based, applied in order to intensify or color the melodic line or harmonic texture [8]. In Ancient Greek music, the term referred to the tetrachord, or four-note series, that contained two intervals like semitones. It is remarkable that not all ancient or medieval music had a compass as wide as an octave [1]. Later, in European music, the term “chromatic” was applied to optional notes supplementing the diatonic (seven-note) scales and modes, because these notes produced half-tone steps that were extraneous to the basic scale or mode. A full set of chromatic tones added
to any diatonic scale produces a chromatic scale, an octave of 12 semitones.

2.2. Theoretical approaches to chroma

Based on the previous sections, and taking also into account Oriental scales, it is essential to sub-divide the spaces between notes in a more accurate way than the 12-tone subdivision. This subdivision exists in the aforementioned modes and one can impulsively perceive, listening to relative scales, chroma, comparing them to Western modes. From this observation, we come to the conclusion that the essence of chroma is associated with the intervals between notes, and more specifically with the several intervals unequal to the tone (half – tone, 3-half-tone, quarter-tone etc).

Musical instruments, like the classical piano, can execute a particular melody with limited (little) chroma. This extracts from the fact that the piano can only produce discrete frequencies of sound (12 frequencies per octave), so the chromaticity of the piano is specified only in terms of unrelated to the specific scale notes. Consequently, in this case the concept of chroma coincides with the terminology of Western music.

What happens, however, in the case of the violin or the great “instrument” of human voice? Things here are much more complicated, since the violin or human voice can produce continuous sound frequencies without limitations. Moreover, the intervals between notes can be of any distance, not just multiples of the half-tone, as with the piano. These special intervals give more chroma to the sound (see Fig. 1).

In general, we define as “chromatic” any sound with frequency irrelevant to the discrete frequencies of the scale. In proportion to the distance of the interval, that this sound creates with its “neighbors” (previous and next sound), we can estimate, how much chromatic this sound is.

3. Alphabet

The notation in the current paper is the proper staff notation of Western music with the addition of the half-flat sign ♭ and the half-sharp sign # from the Arabic music. The half-flat sign (♭) represents some frequency between one note and its flattened one, while the half-sharp sign (#) represents some frequency between one note and its sharp one. Using these extra symbols, the minimum spaces are the quarter- tones (see Fig. 2).

This symbolism is an approach to recording variant musical hearings in the Western music notation. Greater subdivisions could be used in lots of cases, because of the peculiarities in notation of Western and Oriental music,

![Figure 1. The musical human computer interface of chroma in staff notation, in haptics, and its fundamental frequency perception.](image1)

![Figure 2. The notation for microtonal staff symbolism.](image2)

3.1. Fuzzy frequencies correspondence

In Oriental music, a maqam is a sequence of notes with rules that define its general melodic development. The nearest equivalent in Western classical music would be a mode (e.g. Major, Minor, etc).

Many maqams include notes that can be approximated with quarter tones (using the half-flat sign ♭ or the half-sharp sign #), although they are rarely precise quarters falling exactly halfway between two semitones. Even notes depicted as semitones may include microtonal subtleties depending on the maqam in which they are used. For this reason, when writing for instance Arabic music using the Western notation system, there is an understanding that the exact tuning of each note might vary from each maqam and must be acquired by ear.

For computer music predicates, there is need to precisely match notes with accurate frequencies. The most frequently used formula for calculating the frequency of a given note is:
\[ f = f_0 \cdot 2^{(\frac{c}{1200})} \]  

where \( f \) is the frequency we are after, \( f_0 \) is the reference frequency, and \( c \) is the pitch shift in cents. 100 cents are a semitone and 1200 cents are an octave. Therefore, it follows that doubling the frequency of a note puts it up an octave and halving the frequency of a note puts it down an octave.

In order to find the frequencies of quarter-tones we set \( c=50 \). A handy reference chart follows (according to the international equal tempered scale, where \( A_4 \) is tuned to be at exactly 435 Hz) in Table I:

<table>
<thead>
<tr>
<th>Note</th>
<th>( C_4 )</th>
<th>( C#_4 )</th>
<th>( D_4 )</th>
<th>( D#_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq(Hz)</td>
<td>258.65</td>
<td>266.228</td>
<td>274.03</td>
<td>282.059</td>
</tr>
<tr>
<td>Note</td>
<td>( D_4 )</td>
<td>( D#_4 )</td>
<td>( E_4 )</td>
<td>( E#_4 )</td>
</tr>
<tr>
<td>Freq(Hz)</td>
<td>298.837</td>
<td>307.59</td>
<td>316.602</td>
<td>325.88</td>
</tr>
</tbody>
</table>

Table II. Oriental scales microtonal spectrum thresholds.

<table>
<thead>
<tr>
<th>Note</th>
<th>Low threshold</th>
<th>High threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_4 )</td>
<td>254.94</td>
<td>262.412</td>
</tr>
<tr>
<td>( C#_4 )</td>
<td>262.412</td>
<td>270.1</td>
</tr>
<tr>
<td>( D_4 )</td>
<td>270.1</td>
<td>278.016</td>
</tr>
<tr>
<td>( D#_4 )</td>
<td>278.016</td>
<td>286.16</td>
</tr>
<tr>
<td>( D#_4 )</td>
<td>286.16</td>
<td>294.55</td>
</tr>
</tbody>
</table>

4. Problem formulation

The procedure followed for the ascription of colors for a piece of music has 5 steps, depicted in Fig. 3.

Step 1 aims to isolate melodic motives in a piece of music so as to search for chromatic elements in it. MIDI and audio files (WAVE, MP3) were used and processed in different ways. In step 2, the isolated melody corresponds to a specific scale or mode, recorded in a “Scale Bank”, using a simple algorithm. Every scale in this database bears an initial real number \( \chi \), which determines the chroma of this scale. In step 3, melody is separated in segments, in order to process it piece by piece. In step 4, elements that add chroma to the given melody are found and analyzed, resulting in some real values. These numbers, correlated with \( \chi \), affect the

4.1. Input management

In step 1, .wav, .mp3 and .mid files were used. It is obvious that the procedure for melody isolation is non-identical for MIDI and audio files.

4.1.1. MIDI files. In MIDI files it is very simple for the melody to be isolated, since in a well orchestrated MIDI composition, melody can be usually found in some track, which often bears the label “melody”. We have used Cakewalk Music Creator 2003 and easily extracted melodies from several MIDI files. In some cases, greater effort was needed in order to recognize and isolate the melody, e.g. in some 1-track piano pieces. Nevertheless, no special difficulties were encountered at this part of the project.

4.1.2. Audio files. Things were not that clear as when analyzing audio files, since scores could not be directly extracted from the musical piece. Analyzing the sonograms, using Sonic Foundry’s SoundForge 6 and MatLab 6.5, in recordings where melody (or singer’s voice) surpassed accompaniment, we managed to get (in a very good approach) the frequency sequence of melody. The analysis proved to be easier in recordings with little (or without) accompaniment, while in “tough” orchestrations we encountered difficulties in configuring
loudness and display range settings on the FFT sonogram. A detailed description of those settings configuration disqualifies as necessary at this paper. For instance (Charles Aznavour: “La Bohème”) we configured the spectrum settings as follows: FFT size: 8192, FFT overlap: 75%, Smoothing window: triangular, Sonogram resolution: 100 samplings, Freq. Min: 0, Max: 380 Hz, Ceiling: 0, Floor: -43 DB.

The results of step 1 analysis for one MIDI and one audio file are shown in Table III containing the frequencies sequence for the first 9 events of each melody.

<table>
<thead>
<tr>
<th>MIDI</th>
<th>AUDIO</th>
<th>Event No.</th>
<th>Note</th>
<th>Frequency</th>
<th>Note</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>E\textsubscript{b}</td>
<td>5</td>
<td>615.18</td>
<td>D\textsubscript{3}</td>
<td>147</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>E\textsubscript{b}</td>
<td>5</td>
<td>615.18</td>
<td>D\textsubscript{b}</td>
<td>148</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>F\textsubscript{5}</td>
<td>3</td>
<td>690.52</td>
<td>E\textsubscript{b}</td>
<td>154</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>E\textsubscript{b}</td>
<td>5</td>
<td>615.18</td>
<td>D\textsubscript{b}</td>
<td>177</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>F\textsubscript{5}</td>
<td>3</td>
<td>690.52</td>
<td>G\textsubscript{b}</td>
<td>199</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>G\textsubscript{b}</td>
<td>5</td>
<td>731.58</td>
<td>F\textsubscript{b}</td>
<td>184</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>G\textsubscript{b}</td>
<td>5</td>
<td>731.58</td>
<td>G\textsubscript{b}</td>
<td>187</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>G\textsubscript{b}</td>
<td>5</td>
<td>731.58</td>
<td>G\textsubscript{b}</td>
<td>183</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>A\textsubscript{b}</td>
<td>5</td>
<td>821.17</td>
<td>A\textsubscript{3}</td>
<td>229</td>
</tr>
</tbody>
</table>

4.2. Matching a scale to the melody

The scale, at which a musical piece is written, is strongly associated with the piece’s chroma. Hence, our interest is focused on matching a musical hearing with a scale and finding a value that corresponds to the chroma of that scale. This value is its chromatic index.

4.2.1. The chromatic index of a scale. The first basic factor for characterizing a musical piece as chromatic or non-chromatic is the scale, on which it is written. It is not incidental, that major scales in Western mode comprise an expression of happiness, livelihood, strength, cheerfulness etc, while, on the other hand, compositions in minor scales express grief, lamentation, weakness, melancholy, sorrow etc [6]. This verbal-conceptual approach of music joint with the observation that feelings like pain and grief are usually stronger and more stressful, extracts the conclusion that minor scales are more chromatic than major ones. This can also be noticed from the intervals of minor scales (1\(\frac{1}{2}\)-step, different accidentals while going up and down the scale). In the same manner, the Hijaz scale of Oriental music is more chromatic than Western music scales, since it contains 1\(\frac{1}{2}\) and \(\frac{3}{4}\)-steps.

A proposed algorithm for the metrics of the chromatic index for a specific scale is the following:

**Algorithm 1**

Let a tone correspond to 100 points. Points, opposed to cents, denote tonality in a metric system style. Table IV shows the points of each interval.

<table>
<thead>
<tr>
<th>Interval</th>
<th>p (points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tone</td>
<td>100</td>
</tr>
<tr>
<td>Half-tone</td>
<td>50</td>
</tr>
<tr>
<td>Quarter-tone</td>
<td>25</td>
</tr>
<tr>
<td>3/2 - tone</td>
<td>150</td>
</tr>
<tr>
<td>2 tones</td>
<td>200</td>
</tr>
</tbody>
</table>

- For each interval \(i\) in the scale calculate \(K_i\):
  \[
  a = \frac{p}{100} \quad p < 200 \\
  a = 1 + \left(\frac{p \mod 100}{100}\right) \quad p \geq 200 \\
  K_i = \frac{1}{a} \quad p \leq 100 \\
  K_i = 2a \quad p > 100
  \]
- The chromatic index of the scale is equal to
  \[
  \chi = \left(\sum_{i=1}^{n} K_i \right) + j / n
  \]

where
- \(n\): the number of whole tone steps in the scale (number of notes – 1 )
- \(j\): the amount of the extra accidentals on the scale notation, different from the accidentals at the key signature.

**Examples**

- **C major scale**

\[
\begin{align*}
\end{align*}
\]

for semitones: \(a = \frac{1}{2} \rightarrow K_i = 2\)
for tones: \(a = 1 \rightarrow K_i = 1\)

\(n = 7\)

Therefore, the chromatic index \(\chi\) for the major C scale is \(\chi = \frac{(1+1+2+1+1+1+2)}{7} = 1.286\)
Similarly, the chromatic index $\chi$ for the C minor melodic scale is $\chi = \frac{(18+4)}{14} = 1.571$ (4)

**Hijaz / Rast**

Hijaz on D  
Rast on G

for $\frac{1}{2}$ tones: $a = 3/2 \rightarrow K_{3/2} = 3$
for $\frac{3}{4}$ tones: $a = \frac{3}{4} \rightarrow K_{3/2} = 4/3$
$n = 7, j = 3$
Therefore the chromatic index $\chi$ for Hijaz / Rast is:
$\chi = \frac{[(2+3+2+1+4/3+4/3+1) + 3]}{7} = 2.096$ (5)

**Mode Plagal IV (8th)**

This mode is the most diatonic in Byzantine music. As seen in Fig. 4:
for 12 echomoria = 1 tone $a = 1 \rightarrow K_1 = 1$
for 10 echomoria: $a = 83.333 \rightarrow K_{10/72} = 1.2$
for 8 echomoria = $\frac{3}{2}$ tone $a = 66.666 \rightarrow K_{8/72} = 1.5$
$n = 7$
Therefore the chromatic index $\chi$ for Plagal IV is:
$\chi = \frac{(1+1.2+1.5+1+1.2+1.5)}{7} = 1.2$ (6)

It is obvious that the values of chroma, calculated by this algorithm, reflect the real chromatic difference among these 4 scales: a major scale is not very chromatic, while a minor melodic scale is more chromatic. An Oriental scale (like Hijaz / Rast) is much more chromatic than Western scales.

4.3. The scale bank

“Scale Bank” is a database containing scales and modes, each of them expressed in terms of its individual attributes – with the value of chroma $\chi$ being one of them.

Table V. Scale chroma estimations.

<table>
<thead>
<tr>
<th>Name</th>
<th>Origin</th>
<th>tonal distribution (cents)</th>
<th>chroma $\chi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>Western</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Hijaz-Rast</td>
<td>Oriental</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>Plagal D</td>
<td>Byzantine</td>
<td>200</td>
<td>166.666</td>
</tr>
</tbody>
</table>

Table V shows the structure of the “Scale Bank”. The name of the scale or mode is written in the first column. The second column shows the origin of the scale. The third column denotes the frequency distribution of the notes in each scale, while in the last column the chromatic index for each scale is estimated. For comparison, it is assumed that a half tone corresponds to 100 cents. Likewise, an octave corresponds to 1200 cents. For example, if we consider the diatonic scale in Byzantine music (mode Plagal IV), where an octave is segregated in 72 echomoria, the note spaces are reduced in cents, as shown in Fig. 4.

The chroma value $\chi$ in Table V were estimated using (2). The values of $p$ arise by dividing each discrete step value of column 3 by 2. The “Scale Bank”, which we have created, consists of more than 70 scales and modes at the moment, taken from Western, Balkan, Arabic, Ancient Greek and Byzantine music. We intend to enhance the bank with modes from other cultures too (Indian, African etc).

4.4. Matching a scale to the melody

It is essential to know in which scale the musical piece being analyzed is written, because its chroma $\chi$ is used as a benchmark. A melody written in a particular scale fluctuates around value $\chi$ as a base, whereas $\chi$ is biased from other chromatic elements.
Usually in MIDI files the scale is declared, so there is no need to seek for it. Even if it cannot be detected or concluded from the key signature, due to bad file organization, the scale can be discovered using the following simple algorithm, which we always apply to audio files.

The algorithm is described here in brief. The algorithm scans the whole table, which has resulted from step 1 analysis, and records how many times each note of the melody was being played on an interval of an octave. From the notes most frequently played, it fetches the predominant intervals of the musical piece. Sliding their values in cents 6 times (one interval at a time) it creates 7 possible modes. If one of them matches perfectly with a mode of the “Scale Bank”, the melody automatically corresponds to that mode. If there is not an exact match, the closest mode to the interval sequence is considered.

4.5. Segmentation

There is a great deal of considerations and approaches about the question of melody segmentation. The segmentation of the melody is absolutely necessary in our research, in order to process each segment solely for finding chromatic elements. We used many segmentation suggestions with satisfactory results. The segmentation, that Cambouropoulos suggests [9], resulted in much a similar way, compared to our arbitrary segmentation, based on a sentient perception of the melody. Therefore, we used his approach for MIDI files. We also got very good results, using the “Auto Region” tool of SoundForge for audio files, changing the parameters of the tool on each case.

4.6. Extracting chromatic elements

Two elements influencing the perception of chroma in a melody are the progression of step intervals in the melody (as mentioned before) and also the rapidity when one note follows another. In our approach, we considered that the intervals result in a change in the main color, which depicts the music chroma, while rapidity affects the brightness of the color [10]. The initial value of chroma ($\chi^0$), around which the chromaticity of a musical piece wraps, is the chroma of the scale $\chi$. Depending on the evolution of the piece’s melodic line, chroma (expressed as a spot A) moves on a two-dimensional surface, where the musical intervals have an effect on the horizontal axis X, while rapidity affects the vertical axis Y. Moreover, the melodic line itself affects the chroma of the piece too. The initial chroma (that of the scale) is inlaid at position ($\chi^0$, 0) – the second coordinate denotes time.

Although foreign frequencies add chroma, some melodies may only use accepted notes and still cause a chromatic impression. The explanation to this is that the notes do not necessary follow the order of the scale. This means that if a musical phrase was just an ascending or a descending scale, then the chroma associated to the phrase would be that of the scale ($\chi^0$). But usually this is not the case! Consequently, an algorithm was developed in order to measure the chroma of the melodic line.

It is considered that the “clear” chroma $\chi$ of the scale incurs when the melodic line (only the accepted notes of the scale) is in an either purely increasing or purely decreasing form (ascending / descending scale). Every deviation of that form creates a more chromatic impression. In a graphical representation this impression is calculated from the area of the polygons, which are created between the melodic line and the (ascending or descending) line, which is gathered from the reordering of the notes in melodic line (see Fig. 5) according to algorithm 2.

**ALGORITHM 2**

- Create a graph representation of the melodic line of the segment.
- Reorder this line’s spots, in order to create a second (increasing or decreasing) line following the next rules:
  - IF the melodic line has a local maximum as the first note AND/OR a local minimum as the last note, THEN create a descending line using the notes of the melodic line.
  - IF the melodic line has a local minimum as the first note AND/OR a local maximum as the last note, THEN create an ascending line using the notes of the melodic line.
  - IF none of the previous rules stands, THEN detect a local minimum and a local maximum of this segment AND split the segment into more segments at these points AND follow the previous rules on each of the new segments.
• Calculate the area \( E_i \) of the polygons, which are created between the melodic line and the new line.
• RETURN this value (\( E_i \)).
• GOTO next segment.

4.7. Color mapping

Taking into account that greater value of \( \chi \) corresponds to greater chromaticity, it is essential to color the surface, on which spot A moves, based on the previous ranking. In this way, the chroma of the musical piece, which is being analyzed, is determined by the position of spot A on the surface. Thereby, colors are ordered in vertical stripes (with amplitude 0.1) from the left to the right side, as in Fig. 6.

![Figure 6. Visualizing the chroma of a melodic line.](image)

A musical piece starts with the color, which is defined by the position \((\chi,0)\) of x-axis, as its basic chroma. Since the variable \( x \) affects chroma, spot A moves either rightward on X-axis (more chromatic), or leftward on X-axis (less chromatic). Fig. 6 shows that if a melody moves higher on Y-axis at some color strip, the brightness of the color is increased, while if it moves lower on Y-axis, brightness is reduced. This happens because, since rapidity affects the Y-axis, the faster a musical piece is, the brighter feeling it provokes. In contrast, very slow music provokes darker feelings. (Imagine a cheerful song in very slow tempo!)

The choice of color on the final representation graph takes place per segment. All values of \( y \) in a segment produce the average \( \langle y \rangle \), which is the global y-coordinate of the segment. Similarly, all values of \( x \) produce the average \( \langle x \rangle \) of the segment. Value \( E \) of the segment acts upon \( \langle x \rangle \) and the global x-coordinate of the segment is \( E \langle x \rangle \). The color of the segment is finally defined by the position (\( E \langle x \rangle \), \( \langle y \rangle \)) on the surface.

4.8. The acoustic perception of chroma

A lot of theories have been deployed about the feelings that colors provoke [11][12]. At the same time, all these theories are absolutely subjective, and we cannot accept them uncritically. This extracts from the fact that color perception differs in proportion with the culture, the personality and the experiences of each individual. Nevertheless, we focused our efforts on modeling a color scale on 12 grades, corresponding one basic color to each one of them. It is generally accepted that the white color indicates the absence of color (lowest grade) and the black color implies the greatest chromaticity (highest grade). On the following Table VI colors are ranged in chromatical order, beginning from white and ending to black. While ascending this scale, colors provoke increasingly stronger feelings, resulting in a climax at the highest grade (black).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Color</th>
<th>Feelings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>White</td>
<td>(non-chromatic) seriousness</td>
</tr>
<tr>
<td>2</td>
<td>Sky Blue / Turqoise</td>
<td>gentleness, calm, peace</td>
</tr>
<tr>
<td>3</td>
<td>Green</td>
<td>harmony, brio</td>
</tr>
<tr>
<td>4</td>
<td>Yellow / Gold</td>
<td>happiness, shine, cheerfulness</td>
</tr>
<tr>
<td>5</td>
<td>Orange</td>
<td>playful</td>
</tr>
<tr>
<td>6</td>
<td>Red</td>
<td>passion, love</td>
</tr>
<tr>
<td>7</td>
<td>Pink</td>
<td>innocence, anxiety</td>
</tr>
<tr>
<td>8</td>
<td>Blue / Royal Blue</td>
<td>convulsion, intensity, roughness</td>
</tr>
<tr>
<td>9</td>
<td>Purple</td>
<td>depression, grief, melancholy, death, lamentation</td>
</tr>
<tr>
<td>10</td>
<td>Brown</td>
<td>trouble, indiscipline, punishment</td>
</tr>
<tr>
<td>11</td>
<td>Gray</td>
<td>failure, weakness, sadness, dubiety</td>
</tr>
<tr>
<td>12</td>
<td>Black</td>
<td>(colorful) melancholy, strongest feelings</td>
</tr>
</tbody>
</table>

5. Experimental results

More than 100 exemplar melodic pieces were examined, ranging from Western music to Oriental and from techno to Byzantine music. About 70 different scales were recorded. Fig. 7 shows exemplar chromatic graphs resulting from MIDI executions of Beethoven’s “Für Elise” and Madonna’s “Like a prayer”, and MP3 (converted to WAV) live performances of “La Bohème” (Charles Aznavour) in a concert with Liza Minnelli and Feyrouz’s “Ghannaitu Makkata”.
Pieces (a) and (b) in Fig. 7 are written in a minor melodic scale. Two colors predominate at the first piece. Several hues of green and red are alternated during the first 50 segments of the sample. The reason for that is that the music turns from minor to major scale and reversely, and this provokes different feelings. At the last segments, green becomes brighter and brighter because of the rapidity the melody moves.

Figure 7. The estimated chromatic indices for (a) Beethoven’s “Für Elise”, first 50 segments, (b) Aznavour’s “La Bohème”, first 9 segments, (c) Fayrouz’s “Ghannaitu Makkata”, first 10 segments, and (d) Madonna’s “Like a prayer”, first 10 segments.

It is obvious that the song “La Bohème” is much more chromatic than “Für Elise”. Colors are very dark and end to a black, which is the most chromatic grade. This shows that Charles Aznavour is very chromatic while singing. Using the alphabet, which was previously mentioned, we extracted many misquoted tones and intervals of quarter-tones, which are very chromatic.

Similarly, Fayrouz’s song is clearly chromatic and less rhythmic, with variations of its chromatic indices although it does not use hard chromatic scales, so common in oriental singing. On the other hand, Madonna’s extract is diatonic, cheerful and strongly rhythmic but rather invariable in its chromatic indices. However, it should be noted that this song was analyzed by its MIDI equivalent, without taking into account the value added to its chromatic index by the vocals of the singer. An important observation is that in MIDI files tones are equally tempered according to Western music notation, which does not allow greater subdivisions between frequencies. In contrast, a performer can sing or play in all possible frequencies, so in audio recordings chroma can be easily found and recognized.

6. Conclusions

The chromatic index of a musical piece serves as a musical genus identifier and provides an alternate description of its morphogenetic structure. A colorful strip can be associated with a musical piece serving as a signature and as a classifier as well.

The chromatic indices that accompany a melodic piece are metadata that can be utilized in a wide range of applications, from musical information retrieval to taxonomy for web delivering of music.

7. References