A Color-based Visualization Approach to understand harmonic structures of Musical Compositions

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Abstract

Music expertise is the ability to understand the structural elements of music compositions by reading musical scores or even by simply listening to music performance. Although the most common way to learn music is through the study of musical scores, this approach is demanding in terms of learning ability, given the required implicit knowledge of music theoretical notations and concepts.

In this work we define a two-level color-based approach, that exploits graphical visualization techniques to represent data structures of classical music, and to perform harmonic analysis of musical compositions. Our main goal is to make easier and very quick the study of classical notations (recognized as a tedious and difficult task in the field), by providing individuals with a mechanism that clarifies complex relationships in music using visual clues. We performed a preliminary study to evaluate the effectiveness of our approach as well as participants' perceptions about its usefulness and pleasantness. The results of the study provided us with overall positive feedback about the effectiveness of our approach as well as further directions to explore.

1 Introduction

Every day we enjoy different types of music and sounds. Often they are nice, sometimes they are annoying. Music creates a remarkable atmosphere in which people can dream and evoke memories. The musical everyday listening is something special and strongly related with the mood of the people. No complex task or a special ability is needed. Users can sense the nature of music and what music want to evoke, without comprehending its underlying structure.

A very different situation arises when listen to music requires some consciousness, when musicians have to compose music, when students have to learn complex musical rules. Here, some efforts are required to understand the structure of musical compositions. In particular, a difficult field in this area is the study of classical music. Untrained people may only be able to feel the sound elements such as pitch, rhythm, volume, and speed. Conversely, the form of the music and the *harmonic*, *melodic*, and *rhythmic* structural aspects are usually known only by musicians who have received extensive training in music theory and music history. The corresponding learning curve is steep and makes classical music apparently sophisticated and of difficult comprehension.

Music expertise is the ability to understand the harmonic, melodic, and rhythmic structural elements of music compositions by reading musical scores or even by simply listening to music performance. Learning musical rules is hard, and as before mentioned, it is true especially for classical music, where the rigidity of its structures and styles require greater efforts in terms of both their understandability and applicability. The most common way to learn music is through the study of musical scores, which contain the objective notations of a music composition. However, the analysis of musical scores is demanding and beginners have to spend considerable amount of time to learn the basics of music theory before being able to understand the musical notations. It must be emphasized that the knowledge of music theory is essential to perform harmonic analysis of classical music.

Making this task accessible to everyone, even for those who do not have strong knowledge of music theory, is the main goal of our work. Therefore, we investigated whether Information Visualization techniques could be employed for our aims, by exploiting in some way our strong visual cognition ability (i.e., visual memory or visual attention). A secondary goal is to provide a mechanism that, by exploiting graphical elements, could help individuals to quickly understand complex theoretical rules. Furthermore, such a mechanism could be used by teachers to convey music theoretical concepts in a meaningful and pleasant way.

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Different attempts were made to visualize the structure of the music. A critical issue in this field is how to create informative and insightful visualization from which users, with a poor music background, are able to *see* the sound and, at the same time, are able to semantically understand underlying structure of music. The most important challenges to address when to visualize musical structures, lie in both the preprocessing of the input data (i.e., music elements) and the design of a reasonable (meaningful and intuitive) graphical representation for music.

In this work we define a two-level color-based graphical representation, that without involving preprocessing of musical data, allows users to understand the harmonic structure of musical compositions. We focus our attention on the harmonic analysis problem: given a musical composition, the objective is to find the harmonic structure, that is, the best harmonic succession of chords. We discuss the main features of our approach as well as its effectiveness through a preliminary evaluation study involving participants from both musicians and novices in the classical music field.

The rest of the paper is organized as follows. In Section 2 we present interesting works in the same field. In Section 3 we define the harmonic analysis problem while in Section 4 we discuss the characteristics of the proposed approach. In Section 5 we present the preliminary results about the user study we performed with people interested in music (without classical background) and classical musicians. Finally, in Section 6 we conclude with some final remarks and future directions.

2 Related Works

Different attempts have been made to visualize music. *Arc Diagrams* represents one of the first examples to visualize repetitions in music compositions using information visualization [13, 14].

The *Isochords* system [1] is a method for visualizing the chord structure, progression, and voicing of musical compositions represented in MIDI format. Taking advantage of a Tonnetz grid that emphasizes consonant intervals and chords, Isochords shows how harmony changes over time.

Other approaches use 3D views to visualize music components. Smith and Williams [12] discussed the possibility of visualizing MIDI in 3-dimensional space by using color to mark timbre. The *comp-i* system [9] shows the structure of music as a whole by using 3-dimensional piano roll visualization. Its main goal is to allow users to perform visual exploration of a given MIDI dataset in an immersive and intuitive manner.

Another MIDI-based system available in literature is *Music Animation Machine* [7]. It encompasses a number of visualizations including a basic 2-dimensional piano roll notation for visualizing structure. This visualization is additionally expanded with colors based on pitch classes using the circle of fifths. Colors based on a circle of fifths for visualization of tonal distributions and for understanding consonance and dissonance intervals have also been explored [2, 8].

Finally, in [11] the author visualizes hierarchy of key regions of a given composition, where x-axis represents time (from the start to the end of the composition) and y-axis represents the duration of key-finding algorithm's sliding window. When the window size increases more notes are included and may affect the analyzed tonality. These hierarchical key analysis diagrams are useful for comparing the impact of using different time scales, and for viewing the harmonic structure and relationships between key regions in the composition.

From the *musical point of view*, the most significant difference with our work is that most of the discussed works focus on melodic patterns and melodic intervals. Conversely, we designed an approach to address the complexities that arise when studying the harmonic structure of music compositions, that is, understanding and remembering the strict rules about modulations and sequences of degrees (i.e., cadences). Additionally, in our approach we also take into account the relations between the degrees of a tonality, and not only between the modulations of tonalities.

From the *visualization point of view*, the graphical representations that the analyzed works propose are disconnected by the musical scores. Conversely, our aim is to embed the visualization directly upon the musical score, to convey *augmented* information, when studying harmonic compositions. Although colors based on a circle of fifths for visualization have been already proposed, none of the discussed works have conducted formal studies to assess the efficacy of the approach they provide. In our work, we defined a two-level color based graphical representation (i.e., tonality-degree) and we assessed its effectiveness and its usefulness through a preliminary evaluation study conducted with participants having musical background.

3 The harmonic analysis problem

In this paper we consider the tempered music system used in Western countries. Tempered music is based on the notion of *tonality*. To wit, a tonality is a group of notes which form a scale. Each tonality can be either *major* or *minor*. For example, the major scale of C is C, D, E, F, G, A, B, while the major scale of D is D, E, F#, G, A, B, C#. Western music's twelve well-tempered tonalities can be arranged in the well-known circle of fifths that orders them according to the number of alterations in their key signatures.

Usually, given a music composition, there exist a *main tonality*, and therefore notes of the corresponding scale are considered more important than notes outside the scale. Moreover, a music composition consists of a sequence of measures, whereas each of them consists of a given number of beats. Each beat is associated to a musical *chord*, that is a set of notes. Chords are identified primarily by their position in the tonality or, by the scale degree serving as root. Hence, chords succession can be reduced to root succession (or root progression), which in turn can be translated into Roman numerals representing a succession of scale degrees. Therefore, the notes of a scale are often denoted also by I, II, III, IV, V, VI, VII especially when one wants to emphasize only the degree of the scale and not the particular note, which depends on the tonality. We refer the interested reader to a standard textbook on harmony [10], for more detailed explanations.

Western music is based upon well-established harmonic and melodic rules. Several rules concern sequences of chords. Some sequences are "*better*" than others, where the better term is hard to define given its subjective evaluation. Anyway, in music community it is largely accepted that particular sequences of chords work better than others. Specifically, some chords are "*more important*" than others because they suggest, prepare, enforce or device tonal centers. Overall, the art of tonal music consists precisely in arranging chords in such a way that their interplay is pleasant and meaningful.

The *harmonic progression* of a music composition is a sequence of chords that represents one of the harmonic structures of the composition. It is worth to note that, for each musical composition, is possible to find several harmonic progressions.

We focus our attention on the *harmonic analysis problem*: given a musical composition, the objective is to find the best harmonic progressions of chords. Obviously, the harmonic analysis can be made on compositions of any *musical genre*. Here, we focus on the *chorales* genre [10]. A chorale consists of 4 independent voices, called *bass*, *tenor*, *alto* and *soprano*, connected through classical music rules. The most famous examples of such type of compositions are the J.S. Bach's chorales [3] (see Fig. 1 for an example of harmonic analysis of a chorale in D major).

4 Our approach

In this Section we describe the mapping between musical constructs (i.e., tonality and degree) and the graphical representations we chose for our harmonic visualization approach.

Tonality representation. We remark that a musical composition starts with a main tonality, but during the sequence of chords the piece can undergo a modulation, i.e., it may to change tonality. In the specific context of chorales, the harmonic rules drive the modulation among tonalities that are close in the circle of fifths. Therefore, the choice for a visual representation has to ensure that similar tonalities have similar representations. Our idea is to map similar tonalities to similar colors, by assigning a color wheel to the circle of fifth, as shown in Fig. 2.

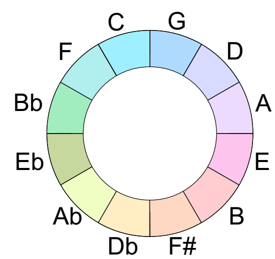

Figure 2: Circle of fifths enhanced with a color-based representation: mapping of colors to tonalities.

Given the musical score we decided to:

- assign to each tonality a specific color, in our enhanced circle of fifths (as an example the light blue color for the G major tonality).
- highlight the area of a major tonality with a rectangle having continuous lines; two rectangles, having as background color the color assigned to the tonality, are shown at the top and the bottom of the musical score.
- highlight the area of a minor tonality with a rectangle having dashed lines; two rectangles, having as background color the color assigned to the tonality, are shown at the top and the bottom of the musical score.

Degree representation. Given a tonality, we decided to represent the seven degrees with a rectangle. It is worth to note that each degree can be classified according to its harmonic function. Specifically, the I degree has *tonic* function, the V has *dominant* function, and the IV has *subdominant* function. Given

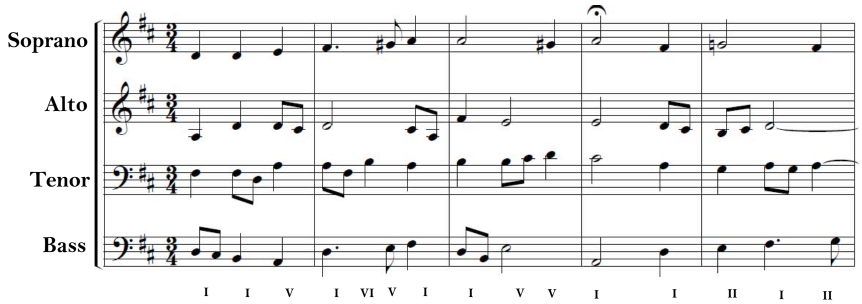

Figure 1: Example of harmonic analysis performed by using a standard approach, looking at the musical score (Example of a chorale in D major).

their most important role, we decided to represent them with the primary colors (sets of colors that can be combined to make a useful range of colors), according to the following mapping: (1) I → RED, (2) IV → GREEN, (3) V → BLUE.

The II degree has two notes in common with the IV and the V degrees, so we decided to represent it with the secondary color CYAN, that is the color obtained by the combination of the GREEN (IV) and BLUE (V) colors. The III degree has two notes in common with the I and the V degrees, so we decided to represent it with the secondary color MAGENTA, that is the color obtained by the combination of the RED (I) and BLUE (V) colors. The same happens for the VI and VII degrees whose colors, as shown in Fig. 3, are YELLOW and AZURE, respectively.

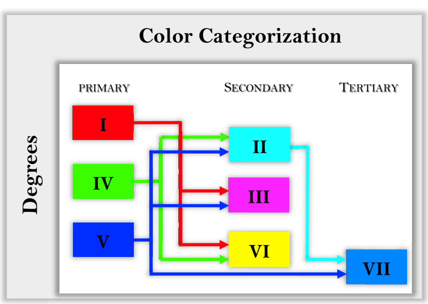

Figure 3: Degree representation: how to assign background colors to degrees according to the RGB Model.

As an example, let us consider the degrees for the C major tonality. Notes for the I degree are C, E, and G; the notes for the V degree are G, B, and D. Notice that the notes for the III degree are E, G and B and so the III degree has two notes in common with the I degree (E, G) and two notes in common with the V degree (G, B). As result, we decided to assign as background color for the III degree the MAGENTA color, that is the color output of the combination of the background colors assigned to the I degree (RED) and the V degree (BLUE).

Moreover, given a degree, the rectangle has a background color that corresponds to the color assigned to the degree itself, and it must be the smallest rectangle that includes all the notes in the corresponding beat. In this way, each rectangle could also give a melodic description of the degree. A large rectangle denotes a beat with many notes (horizontal view), while a tall one denotes a beat with very large vertical intervals between the 4 voices (vertical view).

Finally, it is important to emphasize that we applied a slight transformation to colors (i.e., increase of transparency) in order to avoid to fully cover the musical information on the score.

Tonality and degree representations are the foundation of our two-level color based visualization approach. In Fig. 4 we show an example of the application of our approach for the chorale shown in Fig. 1.

5 Evaluation study

In this Section we first describe the methodology that we employed for our preliminary evaluation study, afterward we discuss the results obtained when a group of people was involved in testing two different approaches for the harmonic analysis. The data set used has been taken from J.S. Bach chorales.

5.1 Methodology

The objective of this study was to explore the effectiveness of our visualization approach to understand and perform harmonic analysis. To this aim we conducted a pilot study with twelve participants, to compare the standard way (i.e., *"Standard Approach"*) to perform the harmonic analysis by simply looking at the musical scores against a visual one (i.e., *"Color-based Approach"*), exploiting visualization techniques to perform the same task.

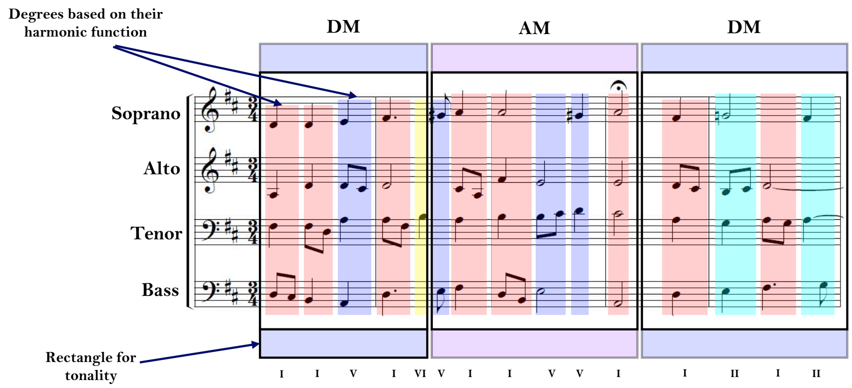

Figure 4: Implementation of our approach: visualization of the harmonic analysis shown in Fig. 1.

The study envisioned three different phases in which we carried out *(a)* a Preliminary Survey, *(b)* a Testing Phase, *(c)* a Training Phase, and *(d)* a Summary Survey, as defined in other contexts [5, 6].

In the first phase we collected information about demographics and musical background. In the Testing Phase we asked users to perform the harmonic analysis of three different chorales, organized in three different tasks. Tasks were submitted in a random order. Users were provided with printed musical scores. To evaluate the quality of the provided solution, we calculated the musical distance between such a solution and the best musical harmonization [4]. Being the chorales chosen from the J.S. Bach chorales, their best harmonization is well-known in the field. Briefly, the musical distance between two chords is given by the sum of the distance between the tonalities of the chords and the distance between the degrees of the chords; the distance between tonalities is given by their distance in the circle of fifths; the distance between the degrees is given by the difference between the inversion numbers of the bass notes. However, the shorter the distance, the better the proposed solution. A zero value corresponds to the optimal solution.

Next, we asked users to perform a Training Phase, looking at several chorales augmented with our visual representation. No information were given to the participants about the meaning of colors, lines, and size of objects. At the end of this phase we asked participants to repeat the harmonic analysis on the three chorales analyzed in the Testing Phase. Here, chorales were augmented with our visual representation. We provided three different solutions for each task, by including the best harmonization, too. Participants had to select what they thought was the best harmonization, trying to explain (as open-ended text) the reasons behind their choice. Finally, four further questions were submitted to inspect whether participants were able to understand the rules behind our approach. The main goal here was to assess the effectiveness of our visual approach to understand the harmonic analysis.

In the fourth and last phase we asked participants to express their opinion about the usefulness of the proposed approach. We were also interested in gathering perceptions about the pleasantness of our aesthetic choices as well as perceptions about the usefulness of an instrument that automatically could show different graphical representations of a given chorale. Surveys, tasks, and training chorales are available online[1].

5.2 Results

Results in the preliminary survey showed that the full sample was male, the mean age was 37, and 50% of participants had a Conservatory degree. The majority of participants (i.e., 67%) spent more than 2 hours per day playing music, 75% consider themselves as competent with the harmonic analysis, while the remaining consider themselves expert in that field.

Results about the Testing Phase are shown in Fig. 5, where we report the average distance values, calculated for all tasks, across all participants. As we can see, our approach is able improve performance for all the analyzed tasks. Additionally, most of the participants (83%) correctly identified the rules behind our approach, while the remaining users were not able to understand just one rule, that is the visual difference between a minor and a major tonality. We got suggestions on how to make more clear this difference as open comments.

Finally, as shown in Table 1, the majority of participants agreed with the usefulness and with the pleasantness of the proposed approach. Most importantly,

[1] `http://www.di.unisa.it/~delmal/research/usability/IV2015`

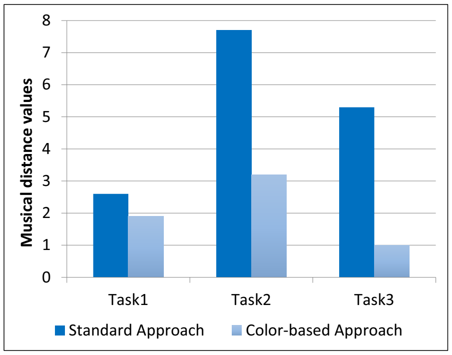

Figure 5: Comparison between the tested approaches in terms of overall participants' performance.

they agreed with the usefulness of a system implementing our approach.

Table 1: Summary Survey. 5-point Likert scores.

ID	Question	Mean	Dev.st
Q1	I found it a useful idea	4.4	0.5
Q2	I found it an interesting idea	4.1	0.3
Q3	I found it aesthetically pleasing	4.2	0.6
Q4	I found useful a forthcoming software implementation	4.4	0.5

6 Conclusion

In this paper we presented an approach to visualize the harmonic structures of musical compositions by using graphical constructs. Specifically, we designed a low-level representation in order to make recognizable complex musical rules, such as modulations and sequences of degrees, as well as the relations between degrees and tonalities. Our main goal was to simplify the harmonic analysis problem, recognized as a complex activity by experts in this field, and improve individual performance when studying classical music. We evaluated, through a user study, whether the proposed approach was really helpful in improving performance of participants with both experience in harmonic analysis and even without classical background. Results showed that when augmenting musical scores with graphical elements individuals improved their performance in all the analyzed tasks. An interesting result is about the opinions of participants about the usefulness of a forthcoming software implementation for the proposed approach. We also got interesting comments about changes in the graphical representation to improve the overall visualization. Future works include a study, with domain experts, in order to compare several graphical representations (output of this pilot study) and the software implementation of the best representation. A large experimental study, with a larger number of subjects, and with diversified skills, will finally provide statistically significant results.

Acknowledgements

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