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Visualization and Music Harmony: Design, Implementation, and Evaluation

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***Abstract*—Music expertise is the ability to understand the structural elements of music compositions by reading musical scores or 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 concepts. Learning musical rules is hard, especially for classical music. To simplify this task, visualization is one of the most promising approaches, also thanks to the human visual cognition ability (i.e., visual memory, visual attention, and so on).**

This work aims at building a visual tool, named VisualHarmony, to help people in composing music pieces in a quick and efficient way (i.e., avoiding specific errors as dictated by classical music theory rules). More specifically, a visualization technique able to represent harmonic structures has been evaluated by teachers of Conservatory classes and from domain experts in order to collect requirements used to define graphical features needed to facilitate the study of the rules used in classical music, and to implement VisualHarmony.

We have focused our attention on a specific type of music compositions, i.e., the chorale style (4-voice music). VisualHarmony was tested in order to analyze system usability and user satisfaction. Results of these studies provided us with positive feedback about the effectiveness of the idea, the pleasantness of the graphical choices, the satisfaction of the users with regard to the easiness and the usefulness of the provided tool.

I. Introduction

Music is a ubiquitous activity, that exists in every human culture, in many forms and with different users' perceptions. Individuals listen to music for several reasons: to create a remarkable atmosphere in which to dream and to evoke memories, to influence emotions and so on. No complex task or a special ability is needed. Users can sense the nature of music and what music want to evoke, without any need to understand its underlying structure.

A different situation arises when listen to music requires a conscious experience and participation, when musicians have to compose music and when students have to learn complex musical rules. Here, some efforts are required to understand the structure of musical compositions.

Music expertise is the ability to understand the harmonic, melodic, and rhythmic structural elements of music compositions by reading musical scores or even simply listening to music performance. Learning musical rules is hard, 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 contains 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. This is a time-consuming process, especially when large corpora have to be analyzed [1].

Making this task accessible to everyone, even for those who do not have *strong* knowledge of music theory, is an issue that we address in our paper. We investigate whether Information Visualization techniques [2], through the use of supporting tools, could be efficiently employed to help users in quickly understand complex theoretical rules. Furthermore, visualization could be efficiently used to convey music concepts in a meaningful and pleasant way.

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. The harmonic succession is fundamental to ensure coherence in tonal music. Additionally, the harmonic succession term does not only refer to the simple sequence of chords, but also that such a sequence is organized according to certain rules and a certain order [3]. In most cases harmony exercises are written on two lines, using a schema of the *4-voice chorales*, which is, for example, available in the Bach's chorales harmonizations [3], [4]. Specifically, a chorale consists of 4 independent voices, called *bass*, *tenor*, *alto* and *soprano*, connected through classical music rules [3]. In our work we focus on this type of music genre.

The main contributions of our work are as follows.

- Propose a tool, named VisualHarmony, that implements the visual approach designed and preliminarily evaluated in [2]. This tool offers to the user a music editor featuring a visualization part that provides, on-the-fly, visual clues about important aspects of the music being written and about the violation of the classical music rules.
- Validate the effectiveness of VisualHarmony, in terms of time to complete tasks and their corresponding cor-

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rectness (i.e., reduced number of errors), as well as its usability and the overall user satisfaction.

The rest of the paper is organized as follows. In Section II we present interesting works in the same field. In Section III we briefly introduce the harmonic analysis problem. In Section IV we present VisualHarmony, while in Section V we discuss the results of a usability study aiming at explore the user satisfaction when interacting with it. Finally, in Section VI we conclude with some final remarks and future directions.

II. Related Work

To understand the harmonic structure of a musical composition is important in every genre of music, from classical to pop music. In particular, the harmonic analysis is an important step for many techniques and problems of classical musical composition, for example in the so-called *unfigured bass harmonization problem*: a bass line is given and the composer has to write other 3 voices to have a complete 4-voice piece of music with a 4-note chord for each bass note. In order to correctly complete this task, the composer needs to understand the harmonic structure inducted by the bass line [5], [6], [7].

Several works aims at explore the harmonic analysis rules has attracted numerous computer music researchers to investigate the automaton of the analysis and generation of harmony. Automated harmonic analysis is an interesting research topic. Many frameworks have been developed for the automatic harmonic analysis. An example is the Rameau framework [8], that contains a collection of re-implemented existing algorithms for the harmonic analysis in the literature and that allows to easily evaluate their accuracy and to study their errors. In [1] the authors present the HarmTrace system, in which the relations between the structural elements in the harmony are represented by the productions of a context-free grammar.

From the visualization point of view, 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 [9], [10]. The *Isochords* system [11] 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 [13] 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. In [14] authors designed and implemented a simplified 3D particle system to generate real-time animated particle emitter fountains choreographed by music, for visual entertainment and for music composition. Another MIDI-based system available in literature is *Music Animation Machine* [15]. 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 well-known circle of fifths[1]. Colors based on a circle of fifths for visualization of tonal distributions and for understanding consonance and dissonance intervals have also been explored in other works [16], [17].

Finally, in [18] 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.

III. The harmonic analysis problem

In this paper we consider the tempered music system used in Western countries. It is based upon well-established harmonic and melodic rules. Several rules concern sequences of chords. Some sequences are "*better*" than others, where the term better 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 succession* 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 successions.

We focus our attention on the *harmonic analysis problem*: given a musical composition, the objective is to find the best harmonic successions of chords. The harmonic analysis can be made on compositions of any *musical genre*. In this work, as anticipated in Section I, we focus on the *chorales* genre.

We refer the interested reader to a standard textbook on harmony for more detailed explanations [3].

IV. VisualHarmony

In this section we first describe the tool implementing the visual approach described in [2], and next we discuss some interesting insights about how to change preferences (i.e., colors) to address the system's accessibility.

A. Functionalities and Use Cases

Feedback, suggestions as well as criticisms raised during the evaluation study presented in [2] were addressed during the development of a visualization tool, named *VisualHarmony* (see Fig. 1). This system has been designed and developed to provide individuals with augmented information about the music and its background structure, in order to complement the users' experience and facilitate the study of classical

[1]The Circle of Fifths shows the relationships among the twelve tones of the chromatic scale, their corresponding key signatures and the associated major and minor keys.

compositions. The tool is also able to assist musicians during the composition of chorales, and in particular, during the definition and the analysis of the harmonic structure of the composition itself. It must be emphasized that VisualHarmony can also be used for the study of harmonic analysis of chorales already composed. The system has been implemented in Java language, using the Swing API for the development of the graphical user interface and the JFugue library [19] for Music Programming.

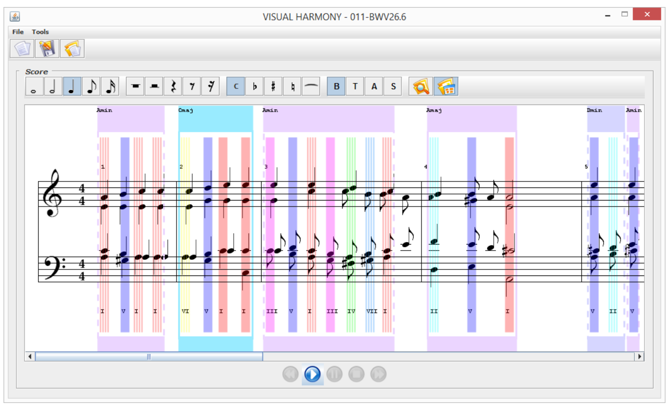

Fig. 1. VisualHarmony Tool with the visualization applied on a fragment of the Bach's BWV26.6 chorale.

The functionalities provided with this system can be summarized as follows:

- **Music editing**. VisualHarmony provides a music editor for the composition of 4-voices music. The tool is designed to edit most of the musical figures.
- **Harmonic visualization**. VisualHarmony allows to display a visual representation of the harmonic structure of a choral. The provided representation follows the rules defined above, enhanced with changes provided as feedback by participants at that preliminary evaluation study. Users can save both the score and its corresponding harmonic visualization (in .vis format).
- **Melodic checker**. During the composition of a chorale, or during the definition of the harmonic structure of the chorale, the melodic error checker can be used by musician to improve the music composition. VisualHarmony allows to display the melodic errors, and to resolve each problem by intervening on the score through the editor.
- **Music playing.** VisualHarmony allows to play the composed music. During the configuration phase it is possible to assign a specific instrument to play for each voice.

Given the main objective of VisualHarmony to be used for learning purposes, we will describe in the following a typical usage of the tool, organized in steps, within a class of Classic Harmony in a music Conservatory.

- The teacher provides students with explanations about the theoretical concepts needed to understand the harmonic structure of musical compositions (standard learning).
- The teacher proceeds with the explanation about the rules of our visualization approach (innovative learning).
- Students absorb the theoretical concepts as well as the idea behind the visualization approach.
- The teacher provides students with a set of chorales for training purposes (that can be loaded through the tool).
- Students start with the learning process. They are encouraged to harmonize bass lines to 4 parts, step by step, with the aid of the representation provided by VisualHarmony.

Now, the teacher can assist students during the training phase, and only observe them during the learning phase. At this stage, in fact, students can leverage VisualHarmony functionalities, exploiting also the feedback provided by the Melodic checker. Specifically, the tool is able to show, for each musical piece, the correct visualization. If errors were made, students will be immediately aware of them, since the wrong visualization on the musical score. Students, only glancing at the score, can immediately understand the errors made, and therefore, re-perform the analysis, continuously querying the tool for the corresponding visualization.

The software, a user guide with a detailed description of the functionalities, and examples of J.S. Bach's chorales, that could be loaded through the tool, are available online[2].

B. *Circle of Fifths color customization*

An interesting feedback obtained during the evaluation study in [2] was about the colors chosen for the circle of fifths. 13% of participants at the study had a color visual deficiency. To this aim, given the usage of colors to represent music constructs, in order to make the visualization accessible for all people, including people with color deficiencies we decided to allow a color customization.

We have to emphasize that the most common forms of color deficient vision, called Protanopia and Deuteranopia, are characterized by difficulties in distinguish between green and red. Colorblind is not normally a problem except in cases where the colors convey important information. In our case, since: (1) colors convey important information about how to distinguish tonality and degree, and (2) we do not want to provide an additional means of obtaining the same information as described, for example in [20], [21], we decided to change the graphical representation. Specifically, with the support of two colorblind users, we chose a different set of colors for our circle of fifths, trying to identify distinguishable colors without violate our rules described in [2] (similar colors that map similar information). In the left side of Fig. 2 we show our original circle of fifths, and how people with protanopic and deuteranopic color deficiencies perceive it[3]. As we can see from that figure, most of the selected colors are indistinguishable. In the right side of Fig. 2, we show how we modified colors to make them recognizable for colorblind. In Section V we describe the results of the usability study that we carried out to test the usability of the tool, and in particular, the satisfaction of colorblind users in terms of color vision.

We allowed people to change the default settings in two ways:

[2]http://www.isislab.it/delmal/VisualHarmony/Tool/

[3]Images obtained by using Vischeck, http://www.vischeck.com/

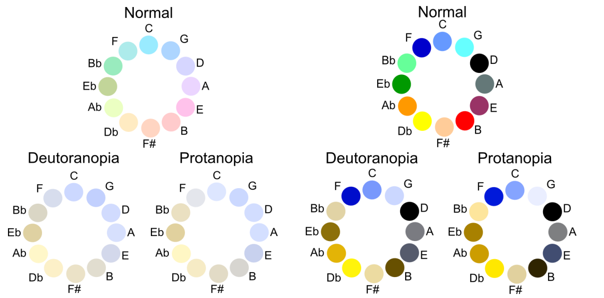

Fig. 2. Changes made to our circle of fifths to make colors distinguishable for all people, including people with protanopic and deuteranopic deficiencies.

- selecting the configuration that we designed with the aid of two colorblind (top-right side of Fig. 2, Normal).
- customizing the configuration according to the own needs (selecting the more visible colors for each tonality).

In Fig. 3 we show how the musical score appears when applying the Option 2 customization, built with the aid of two colorblind people.

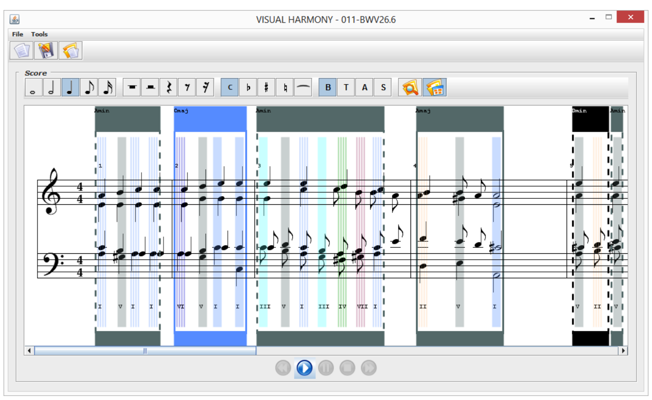

Fig. 3. VisualHarmony Tool: score with colors changed when selecting the Option 2.

V. Usability Study

In this Section we describe the results of the usability study conducted to test the system usability and the user satisfaction when interacting with VisualHarmony. The study consisted of different phases as defined and implemented in other contexts [22], [23], [24].

A. Methodology

For this study recruits comprised 11 participants among music students (60%) and music experts (with a Conservatory degree, 40%). The sample was fully male with an mean age of 38. Prior research has shown that five users is the minimum number required for usability testing, since they are able to find approximately 80% of usability problems in an interface [25], [26]. However, other research studies stated that five users are not sufficient and specifically, authors in [27] expressed that the appropriate number depends on the size of the project, with 7 users being optimal in small projects and 15 users being optimal in a medium-to-large project.

The aims of this study were: (1) derive the general audience's opinion and reaction to the software, (2) collect qualitative feedback on the visualization, and (3) inspect opinions about the behavioral intention to use the tool in the future.

The usability study envisioned three different phases in which we carried out: a Preliminary Survey, the Tool Testing Phase, and finally, a Summary Survey, respectively. In the first phase we asked participants to fill in a preliminary questionnaire, composed of 8 questions asking for *(a)* demographic information, *(b)* information about music expertise and background, *(c)* information about ICT expertise. We also added to the questionnaire a colorblindness test, in order to verify if participants had some color deficiency, such as a colorblind deficiency. The test consisted of a colored plate, called Ishihara plate [28], which contained a circle of dots appearing randomized in color and size. Within the pattern, dots form a number clearly visible to those with normal color vision, and invisible, or difficult to see, to those with a red-green color vision defect, or the other way around. In this way, we were able to identify people with normal color vision (they will see a 42), Protanopic colorblind people (they will see a 2) or Deuteranopic colorblind people (they will see a 4).

In the tool testing phase, we asked users to use VisualHarmony for a 15-minutes session. Users were free to make a composition or to use any of the provided chorales (5 predefined chorales available online). We also asked them to freely use any of the tool's functionalities. We gave them details about VisualHarmony goals and main features. We also provided them with basic information on how to use it. Users were not directly monitored, so that they could feel free to test and explore the tool, but they could call for assistance if they did not understand any of the instructions posed. The test was performed in an isolated environment in order to avoid distractions due to the presence of other people. Users were also encouraged to provide informal feedback such as general comments, suggestions or observations for developers.

At the end of the testing phase we asked users to spend other 10 minutes to fill in the standard QUIS [29] and CSUQ [30] questionnaires. The aim was to provide additional information about system usability and user satisfaction when using VisualHarmony. Specifically, the original QUIS questionnaire was composed of 27 questions. We dropped 8 that did not seem to be appropriate to our tool (e.g., questions about task to execute). Each question was a rating on a 10-point scale with appropriate anchors at each end (e.g., "Overall Reaction to the software: Terrible/Wonderful"), where small values corresponded to unsatisfactory or negative responses and large values corresponded to satisfactory results. The original CSUQ questionnaire was composed of 19 questions. As we did for the QUIS questionnaire, we dropped 3 of them that not seem appropriate for our objectives. Specifically, we asked users to answer to the provided questions indicating their agreement or disagreement through a 7-point Likert scale with *strongly agree* and *strongly disagree* as verbal anchors.

Finally, in the third phase, we asked participants to fill in a summary questionnaire composed of 12 questions. The questions included in this questionnaire were questions asking to give a preference up to 5 possible choices and questions on 5-point Likert scale (e.g., Strongly disagree to Strongly agree). The entire study lasted between 35 and 45 minutes. The preliminary survey, the summary survey and the QUIS and CSUQ questionnaires are publicly available[4].

B. Results

Now we describe the results of the study aiming at inferring users perceptions and general satisfaction about VisualHarmony. As we can see in Table I all questions were rated positively. The most positive result (mean value of 8.3) was relative to the Learning metric, highlighting the easiness of the tool in terms of general usage and learning to operate it.

TABLE I
USER SATISFACTION QUESTIONNAIRE. 9-POINT LIKERT SCALE.

Metric	Mean	Dev.st
Overall reaction to the software		
Terrible/Wonderful	7.5	0.8
Difficult/Easy	8.0	1.1
Frustrating/Satisfying	7.5	1.0
Dull/Stimulating	7.5	1.1
Rigid/Flexible	7.2	1.3
Screen		
Reading Characters on the screen	7.5	1.4
Organization of information	7.2	1.7
Sequence of screens	6.8	1.4
Terminology and system information		
Use of terms throughout the system	7.5	0.7
Terminology is intuitive	7.5	1.0
Position of messages on the screen	6.8	1.3
Prompts for input	7.6	0.8
Error messages	6.6	1.1
Learning		
Learning to operate the system	8.3	1.3
Performing tasks is straightforward	8.3	0.9
System capabilities		
System speed	8.0	0.9
System reliability	7.9	0.9
System tends to be	7.3	1.3
Designed for all levels of users	7.8	1.3

Items in CSUQ relate to efficiency, ease of use, likability of the system interface, overall satisfaction. Specifically, we computed five factor scores: System Efficacy, Usefulness, Satisfaction, Easy of Use, and Easy of Learning. Similar to the QUIS, as we can see from Fig. 4, all questions were positively evaluated, especially for the Easy of Use, Easy of Learning, and Satisfaction metrics. The most positive answers (on average 6.6), in fact, were about the question 1 ("*It was simple to use this system*") and question 7 ("*It was easy to learn to use this system*") in the questionnaire available online.

In Tables II and III we can see the results of the summary survey. Specifically, in Table II we can see that the reaction to the software was strongly positive, and that the sample was fully agree with willingness to use the tool in the future.

[4]http://www.isislab.it/delmal/VisualHarmony/UsabilityStudy/

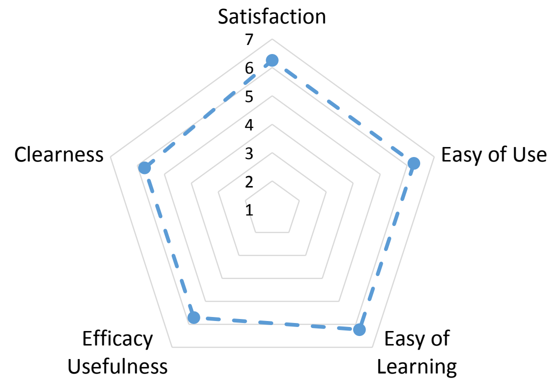

Fig. 4. CSUQ results organized according to five metrics: Satisfaction, Easy of Use and Learning, Efficacy/Usefulness, and Clearness.

TABLE II
SUMMARY SURVEY. 5-POINT LIKERT SCORES. N=11.

ID	Question	Mean	Dev.st
Q1	Overall, I found easy to use the proposed system	4.4	0.5
Q2	In general, the proposed system was very interesting	4.5	0.5
Q3	In general, the proposed system was very useful	4.3	0.6
Q4	In general, I find useful the functionalities offered to users who have visual impairments	4.4	0.7
Q9	Would you consider the possibility to continue to use this system?	4.3	0.5
Q10	Would you recommend it to a friend / colleague?	4.4	0.5

In Table III we show the results of the questions answered only by participants with colorblind deficiency (n = 3). They rated very useful the support for colorblind and very easy the task of configuring colors to make them distinguishable. It is worth to note that the lowest result (even if above the mean value) was about the question Q6, i.e., *"I found effective the options provided (I was able to distinguish colors on the musical score"*. One out of three participants, a red colorblind, had difficulties in distinguishing two colors in the circle of fifths. A possible explanation is that colors were assigned by taking into account the suggestions of only two colorblind people, probably with a different color's anomaly. A larger number of individuals could be useful to find colors more distinguishable.

TABLE III
SUMMARY SURVEY. 5-POINT LIKERT SCORES. ANSWERS BY COLORBLIND. N=3.

ID	Question	Mean	Dev.st
Q5	I found useful the functionalities offered to make accessible the system for colorblind users	4.0	0.0
Q6	I found effective the options provided (I was able to distinguish colors on the musical score	3.7	0.6
Q7	I found easy to select the Colorblind options	4.0	1.0
Q8	I found easy to configure the Custom option, which allows to select the most suitable colors for me	4.3	1.2

In summary, the result of this study is that our participants found very useful and easy to use the experimented tool. Their overall reaction to the software was very positive, and they expressed high satisfaction and their willingness to continue to use the system in the future.

VI. Conclusion

The ability to understand the harmonic structure of a musical composition is important in every genre of music, from classical to pop music. In particular, the harmonic analysis is an important step in many techniques and problems of classical musical composition. Furthermore, the study of the harmonic analysis of classical compositions is considered, in this field, as a time-consuming and tedious task, given the need to understand and remember complex music rules.

In this work we present a tool, named VisualHarmony that implements a visual approach designed and tested in [2], with the main goal of assisting users during learning activities as well as during composition activities. Moreover, VisualHarmony was tested in order to analyze system usability and user satisfaction. The results of these studies provided us with positive feedback about the effectiveness of the idea and of its implementation, the pleasantness of the graphical choices, the satisfaction of the users with regard to the easiness of the tool and the willingness of participants to advertise it and to continue to use it in the future.

As future work, we are planning an extensive and representative experimental study involving a large sample of students, from Conservatory classes, mainly interested in learning complex music constructs, and musicians mainly interested in music composition. A larger number of subjects would also provide more statistically significant results. Another future direction could be the investigation of machine learning techniques [31], [32] for improving the ability to understand the harmonic analysis of chorales.

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