Visual and Aural: Visualization of Harmony in Music with Colour

Bojan Klemenc, Peter Ciuha, Lovro Šubelj and Marko Bajec
Faculty of Computer and Information Science, University of Ljubljana

ABSTRACT—Music is strongly intertwined with everyday life, however its inner structure may not be comprehensible to everyone. Using other senses like vision can help us to understand the music better and produce a synergy between two senses. For this purpose we designed a prototype visualization that shows the structure of music and represents harmony with colour by connecting similar aspects in music and visual perception. We improve current visualization methods by calculating a common colour for a group of concurrent tones based on harmonic relationships between tones. Moreover we extend the colour calculation to broader temporal segments to enable visualization of harmonic structure of a piece. The basis for mapping of tones to colour is the key-spanning circle of thirds combined with the colour wheel. The resulting visualization is rendered in real time and can be interactively explored.

Index terms— music visualization, colour, concurrent tones, MIDI

1. INTRODUCTION

VISUALIZING data is a challenge. Visualization helps us to grasp, what would otherwise be difficult to comprehend and may enable us to see patterns that were unnoticed without visualization. It should not include redundant elements and it should be intuitive. We have to search for appropriate mapping of source data into visual dimensions. In this paper we focus on a specific domain of visualizing music. In the case of music we are dealing with a stream of sound data. The basic data unit we use is a musical tone, so the input to the visualization is a stream of tones. The stream does not necessary represent music – it can be a stream of arbitrary tones, as only a small subset of possible streams is usually referred to as music. However the visualization has to account for these as well and visualise them appropriately.

As the aim is to make visualization meaningful and useful in practice, we have to explore possibilities of different mappings. We try to find interconnecting aspects of sound and visual perception. In accordance with this idea, we developed a prototype visualization that connects similar aspects of music and visual perception. The input to the visualization tool is in MIDI format. The basis for the visualization is a modified piano roll notation, which uses spatial dimensions for visualising time, pitch and instruments. Harmony, which is one the most important aspects in tonal music, is represented with colour. In comparison to existing related visualizations that use colour to denote pitch classes or a predefined set of chords, our visualization takes into account that concurrent sounding tones are not perceived as separated, but also as a whole. For this purpose the musical piece is segmented into time slices and each segment is assigned a colour based on a method using vector addition inside a key spanning circle of thirds assigned to colour wheel [6, 2]. As human perception of harmony is not limited to a moment in time we expanded the method to encompass a broader time range and used it to visualise harmonic structure of broader temporal segments.

The resulting visualization offers a view of the composition as a whole. Additionally it can be observed in real-time together with listening to the source data, which enables the user to make a more direct connection between the source and the visualization thus enabling faster comprehension.

The rest of the paper is organised as follows. In section 2 we review relevant related work, in section 3 we give a detailed explanation of our visualization, details about implementation are given in section 4. The resulting visualization is reviewed and discussed in section 5 and concluding remarks are in section 6.

2. RELATED WORK

There are many possibilities for mapping tonal data or whole musical structures into visual elements. Some of them are only aesthetically pleasing, such as transformation of a physical property of sound like amplitude into visual effects. However the real value is in visualizations of music that offer additional information that may otherwise stay unnoticed or be difficult to understand by a musically untrained listener.

A well known visualization is musical notation, however it takes years of training for someone to look at a score and know what it sounds like. An intuitive visualization is comprised of a time axis and an axis with some other value of interest. In case of using time on x-axis and pitch on y-axis we get a piano roll notation, which is used as basis for some visualizations. Colour usage also varies throughout different visualizations.

Smith and Williams [13] discussed a MIDI based visualization of music in 3-dimensional space, using colour to denote timbre[1]. Music Animation Machine [7] encompasses a number of visualizations including piano roll and Tonnetz. It also uses colours to mark pitch classes. The assignment of colour to pitch class is based on assigning the colour wheel to the circle of fifths. Similar assignment was proposed by Scriabin (beginning of the 20th century). The basic idea of this assignment is that closely related keys or tones are mapped into related colours. Prior to Scriabin a commonly used mapping was colour to pitch, used already by Newton. However is not well suited to represent harmony because adjacent tones are weakly harmonically related. An outline of historical development of mappings of colour to pitch classes is given by Wells [14].

The comp-i system [9] expands the piano roll notation into three dimensions to allow the user to visually explore the source MIDI dataset and offers a view of the structure of the music as a whole, additionally allow to explore the hierarchy of music using ConeTree visualization [11]. Mardirossian and Chew [8] visualise tonal distribution of a piece by using Lerdahl's two-dimensional pitch space – they divide the piece into uniform slices and use a key-finding algorithm to determine the most likely key for the each slice. Keys are coloured by aligning the colour wheel and the circle of fifths. Bergstrom's isochord [1] visualization highlights consonant intervals between tones and chords at a given time. It is based on Tonnetz grid and offers a view of changing of the harmony over time. Sapp [12] visualizes hierarchy of key regions of a given composition, where horizontal axis represents time and vertical axis represents the duration of the key-finding algorithm's sliding window. Colour hues are assigned to keys by taking a part of the circle of fifths and mapping it into the colour wheel. A summary of visualizations is given by Isaacson [5].

[1]Timbre is also called tone colour.

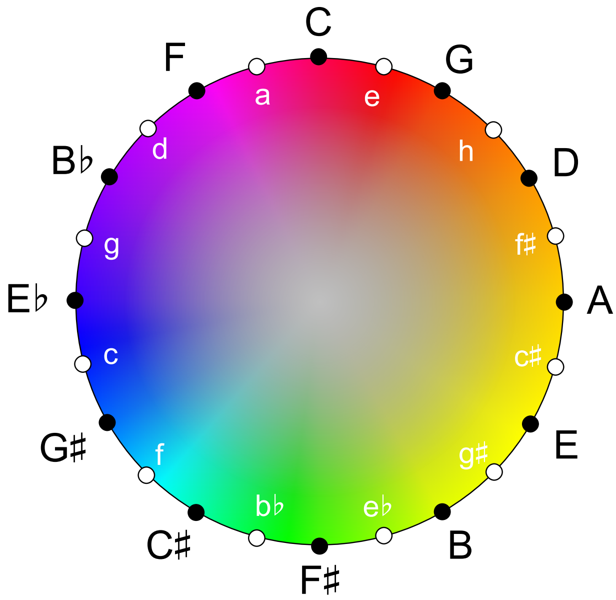


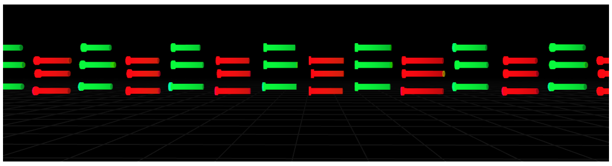
Figure 1: The key-spanning circle of thirds assigned to the colour wheel.

3. VISUALIZING HARMONY WITH COLOUR

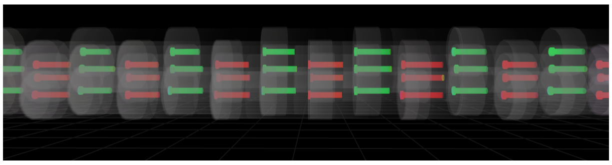
3.1 Assignment of colours to musical tones

The term of harmony encompasses consonance (especially of concurrent sounding tones), but more broadly it also involves the study of tonal progressions. The perception of consonance and dissonance of concurrent tones is related to the ratios of the tone frequencies [3]. In order of rising dissonance the most consonant interval between two tones is unison with a tone ratio of 1:1, followed by octave (ratio of 1:2), perfect fifth (2:3), major third (3:4), minor third (4:5) etc. Tones with simple (small integer) frequency ratios are perceived as similar – unison is made up of two same tones, similarity of octaves is also called octave equivalence and in consequence two tones that lie an octave apart belong to same pitch class. Following a series of perfect fifths from a chosen tone (belonging to a certain pitch class), after 12 steps we arrive roughly to the same pitch class. In this way we can generate all 12 pitch classes of the chromatic scale. These pitch classes can be organised in a circle of fifths where to adjacent tones are a perfect fifth (or perfect forth in opposite direction) apart. Similar tones are close together and dissimilar tones are on opposite sites. In addition of representing tones, the circle of fifths can also represent tonalities.

Because we want to map similar tones to similar colours, the colour wheel is assigned to the circle of fifths. In the colour wheel the colours that are perceived similar are close together while complementary colours are on opposite sides. With such mapping the difference



(a) Without broader temporal segments.



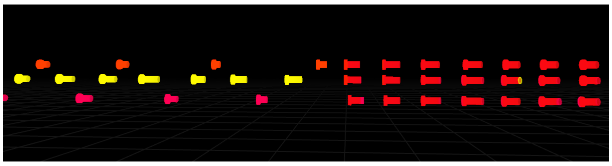
(b) Visualised with broader temporal segments. Dissonance of the sequence is visible trough grey layers surrounding the chords.

Figure 2: Visualization of C major and F♯ major triads played successively.

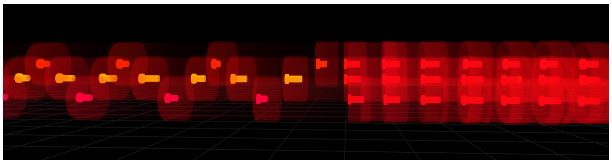
or similarity between two colours is much more important than the psychological meaning of the colours so in consequence the initial orientation and alignment of the colour wheel and the circle of fifths can be chosen arbitrary. Our initial assignment is shown in Figure 1.

3.2 Calculating common colour for concurrent tones

Concurrent tones are not perceived as entirely separate, but also as a whole [10]. To model this perception we can calculate a common colour for a group of tones. To reflect the difference between dissonant tone combinations, which are perceived as unpleasant and unstable on one side, and consonant, which are perceived as pleasant, dissonant combinations are represented by unsaturated colours and consonant by saturated colours. Combinations in between are also possible. Colour hue should represent similarity of the tone combinations. The tones of the 12-tone chromatic scale are represented by a vector originating in the centre of the circle and pointing towards the appropriate pitch class. To calculate a common colour for a combination of tones, the vectors are added together. The direction of the resultant vector represents the hue and the length represents the saturation. This method does not produce satisfactory for every combination because although the circle of fifths shows the similarity of unison, octave, perfect fifth and perfect forth, it does not show similarity of major and minor thirds. To account for this we use a revised method [6] for calculating colour of concurrent tones that uses key-spanning circle of thirds [4] instead of the circle of fifths. The key-spanning circle of thirds is made up of two circles of fifths slightly rotated in correspondence to each other, so that the clockwise neighbour of a tone in the circle signed with capital letters is its major third (Figure 1).



(a) Without broader temporal segments.



(b) With broader temporal segments.

Figure 3: Visualization of a C major triad played as a broken chord on left and as a block chord on the right.

3.3 Common colour of broader temporal segments

The method for calculating colours works on concurrent tones – the piece has to be segmented in small time slices, with each analysed separately. But the concept of harmony more broadly encompasses more than just the consonance of concurrent sounding tones, it includes tonal progressions. If we have a series of random major chords, each chord's colour would be fully saturated, but the sequence itself may be dissonant (Figure 2(a) shows C major and F♯ major triads being played in succession – each triad is consonant, but the sequence is dissonant). Broken chords are coloured tone by tone, although they are a spread out variant of a block chord (Figure 3(a) shows C major triad being played first as broken chord and as a block chord thereafter; the yellow coloured E tone in the broken chord visualization is noticeable). To address these problems neighbouring segments are joined to form broader segments and the colour is calculated for each joined segment using the method for calculating the colour of concurrent tones. The size of the joining window can be adjusted.

3.4 Integrating colour with spatial dimensions

The basis for visualization is the piano roll notation. In the piano roll notation the x-axis represents time and the y-axis represents pitch. As a particular pitch may be played by instruments with different timbre at the same time, we extended the visualization with z-axis representing instruments. Each tone is drawn as a cylinder of fixed thickness with varying opacity depending on the loudness of the tone in given moment – silent tones are almost transparent, while loud tones are opaque. Decaying tones get gradually more transparent. The colour of tones varies and depends on colours of the segments. As very small segments are impractical for real-time visualization, they are extended to reduce calculations and render time. The boundary between two extended segments is one of following events: start of a new tone, end of a tone, explicit change of loudness. Colour is calculated at the beginning and at the end of the segment, the colour values for the inside of the segment are linearly interpolated between the beginning and the end colours. This greatly reduces calculation time as in most cases change between two minimal segments is just gradual decay of tones.

Harmonic structure of broader temporal segments is visualised by drawing semi-transparent layers around the tones (Figure 2(b) and 3(b)). The colour of the layer is determined by joining the segments with appropriate size of the joining window and calculating the colour for the joined broad segment. The factor of transparency of the layers is dependent on the number of joining window sizes to be displayed at a time (transparency of layers increases with their number). For performance reasons the number of layers and maximum joining window size is limited.

4. IMPLEMENTATION

The rendering of the visualization is made in OpenGL as the volume of data needed to be rendered in real-time can become large for some pieces. The visualization takes MIDI data as input, which is sufficient as colour calculation method takes the 12 tones of the chromatic scale as input. Tones that lie outside of the 12-tone chromatic scale are displayed with proper height in the 3-dimensional space, however for the purpose of calculating colour they are rounded to the nearest tone in the scale. Another reason for using MIDI is that it eliminates the problem of extracting tones from recorded sound. Input data is processed and rendered in real-time, allowing live input and observations of results. Figure 4 shows the main window of the visualization tool.

5. RESULTS AND DISCUSSION

The purpose of our visualization is to show harmonic relationships with colour. For example consonant tone combinations like C and G, C and F, C and E have saturated colours, dissonant combinations like C and F♯, C and C♯ have low saturation. Related triads like C major, A minor, G major have similar colour hues (red to magenta), while C major and C minor, which are not harmonically related have distant hues (magenta and blue respectively). Complex tone combinations involving dissonant tones result in low saturated colours.

As tone loudness is also taken into account when calculating colour, the resulting visualization has smooth transitions of colour and changes in transparency. This is especially noticeable in the visualization of decaying of the tones.

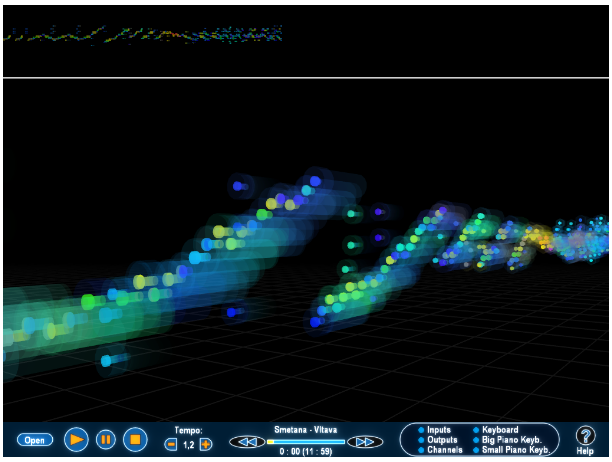
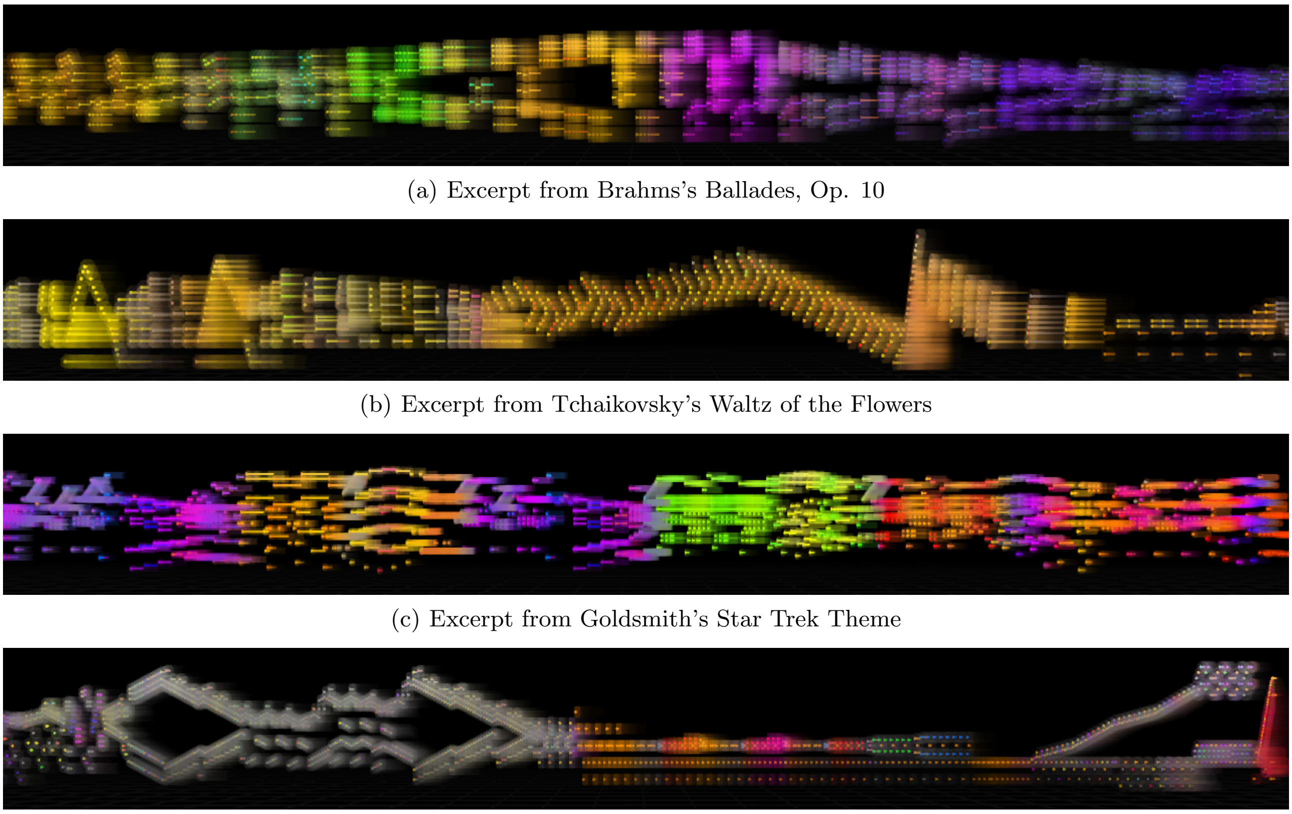


Figure 4: The main visualization window displaying the extended piano roll visualization of an excerpt from Smetana's Vltava. The harmonic relationships between concurrent tones and broader temporal segments are shown with colour.

As perception of harmony extends also in time dimension, colour for broader temporal segments is also calculated and displayed. This solves the problems with broken chords, arpeggios and dissonant sequences of tones or chords as can be seen in Figure 3 and 2. In this way tones that are played in sequence instead of concurrently are given properly coloured "context". Colours of broader temporal segments of appropriate length also point to the possible chord for that part of the piece.

Figure 5 depicts some examples of visualization of different musical pieces. In Figure 5(a) we can see slowly changing colours that indicate progression trough related chords, but at the end the colour settles in violet of D minor in which the piece is written. The piece in Figure 5(b) is centred around orange colour of D major. Arpeggio in the middle has a proper coloured context, although the constituent tones have varying colours. Goldsmith's Star Trek Theme employs a lot key modulation, which can be seen as stable regions of one dominating colour and sudden changes of hue between the regions (Figure 5(c)). The use of dissonance depends on music styles – some avoid dissonances, some use it in very short segments that are afterwards resolved to stable consonances, some use it very extensively. Prokofiev's Toccata in D minor has extensive regions of dissonance that can be seen as grey areas in Figure 5(d). The dissonant part consists of consonant and dissonant concurrent tone combinations, but the calculation of common colour for broader temporal segments results in dominant grey colour.

Other types of music genres like popular music, jazz, folk music can be visualised without problems. Sounds



(a) Excerpt from Brahms's Ballades, Op. 10

(b) Excerpt from Tchaikovsky's Waltz of the Flowers

(c) Excerpt from Goldsmith's Star Trek Theme

(d) Excerpt from Prokofiev's Toccata in D minor, Op. 11

Figure 5: Examples of visualization of different compositions demonstrating the representation of harmony with colour.

from instruments without definable pitch (i.e. most percussion instruments) are omitted. The input to visualization can be an arbitrary stream of tonal data so performances with mistakes or even random input can be visualised. Mistakes in performance are noticeable when compared to properly performed pieces for example in differences in colour. Random input results in numerous dissonances and the dominant colour is grey.

6. CONCLUSIONS

The proposed visualization of music strives not only to be aesthetically pleasing but to reveal the structure of music and show harmonic relationships in music using colour. To achieve this it uses a mapping that translates similarity in perception of tones to similarity in perception of colour. We use a method based on vector addition inside the key-spanning circle of thirds, which takes a group of tones as input and calculates a common colour for the group. This functions in similar way our auditory system perceives a group of tones as a whole, sometimes even completely merging the tones. However, given a resulting colour it is not possible to figure out which tones were used to calculate it. Nevertheless this is similar to the way colour perception works, where light with different spectrums may produce same colour sensation. The original method for calculating colour considered only concurrent sounding tones. As human perception of harmony is not limited to a moment in time we expanded the method to encompass a broader time range and used to visualise harmonic structure of broader temporal segments of different lengths.

The aim of the proposed visualization is to enable easier understanding and learning of harmony in music, to have an overview over the whole composition, compare it with other compositions and see what we may have missed by only listening. The visualization approaches these goals by creating a synergy between two distinct senses.

The approach are still open for improvement. For instance, although major and parallel minor chords are differentiated by minor differences in hue, the psychological difference is bigger. Further work could also be done on improving the method for calculating the colour of tones to include more than only 12 tones of the chromatic scale or visualising rhythm as well.

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