

Visualizing Harmony Using Chordal Glyphs and Color Mapping

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Abstract

Musical scores are frequently annotated with harmonic information, but widely used text-based methods rely on a limited number of visual channels. Though glyph-based methods exploit more channels, existing systems often violate perceptual design principles when employing color and rarely capture the frequency of chordal changes or their harmonic function. In this work, we introduce a new design idiom for augmenting sheet music through chordal glyphs embedded directly within musical staves. Harmonic concepts, weighted by saliency and categorized by data type, are mapped to visual channels ranked by discriminability. Preattentive processing is leveraged to support various user tasks, alongside redundant encodings of foundational harmonic elements to improve overall perceptual effectiveness. Key names and chord roots are displayed using parallel hue-based 12-step categorical colormaps. We then distill several design implications inherent in assigning colors to musical pitches regarding perceptual and linguistic effectiveness. Following this discussion, we outline open research directions.

Introduction

While the most salient aspects of musical harmony are immediately evident when music is heard, harmonic effects typically remain obscured when a musical score is merely seen. We outline a new visual design idiom to bridge this gap using a visual vocabulary comprehensible to both expert and novice users. Using the framework of a four-level nested design scheme [29], we begin at the domain level for harmonic representation in Common Music Notation (CMN). Section 1 outlines current annotation practices and then shifts to the next design level to discuss harmonic abstraction and visualization practices. Going one design level lower, sections 2 and 3 explain the creation of the visual encoding idiom itself. The fourth nested vis-design level is the algorithm layer, where detailed procedures are created for a computer to automatically encode the harmonic information visually ... this is discussed in the conclusion.

Traditional annotation methods do not sufficiently convey, visually, the breadth and richness of music that one perceives aurally. Given the information density of CMN, the insertion of any additional visual encodings faces several hurdles from a design perspective. Although numerous mark and channel types are not typically used in CMN [26], the way in which musical dimensions (particularly spatial and temporal) are encoded significantly constrain the available design space. We navigate this complexity by using a familiar concept, bar lines, as building blocks for encoding harmonic annotation via bar-line-like glyphs. While this restricts the available tools to a very particular range of marks and channels, we argue that the benefits of directly embedding information related to harmony and chordal movement within the musical staff are worth the effort.

1 Motivations and Related Work

This paper presents a new glyph-based method for visualizing harmony in CMN following basic tenets of visualization and color design. Three issues that are not fully addressed in the current literature motivate our design.

1. We would like *a design that maximizes the effectiveness of how elements are encoded visually* as glyphs within their musical context.

2. We would like to *visualize the most salient harmonic concepts* and ensure that the most prominent harmonic aspects are linked to the most impactful visual channels.
3. We would like to *use color in a way that maximizes visual discernibility* by using color *values* that are strongly associated with familiar color *names*.

Harmonic annotation is usually written in a space commonly used for lyrics and other instructional features, typically below the musical staves or sometimes above them. Similarly, glyphs are often placed above musical lines to avoid occluding critical material, a frequent requirement due to their size. Guidance around glyph usage consistently emphasizes the relevant task and data characteristics [2, 12, 17, 32], and related work on multiple views highlights the adverse effects of context switching. It underscores the importance of consistency and appropriate perceptual cues [33]. Discussion of glyph placement in complex situation-dependent situations, such as CMN, remains rare despite the overall volume of research [4, 10].

Although the use of glyphs specifically for augmenting CMN is less common, recent work has successfully demonstrated using glyphs for visualizing rhythmic patterns [11] and aggregated harmonic patterns [25]. However, these methods use glyphs that are too large for repetition at a high enough frequency to be repeated once per chord change. Star glyphs [15, 27] are similarly too large for insertion within or overlay upon musical lines. While placing glyphs outside of the musical staff utilizes the available space in a familiar way, externally placed glyphs are often too large to fit in a small enough space to keep up with the frequency of chord changes. Though adequate for information that will be aggregated at the grain of once per measure, glyphs as currently used are a poor match for representing swiftly-changing harmonic patterns. Although not glyph-based, basic visual representations have been shown to support simplified harmonic analysis [24]. Our first requirement, effective visual encoding, must therefore find a better format for augmenting CMN.

Secondly, successfully visualizing musical harmony's complexity requires prioritizing the most important musical aspects to be encoded. Ideally, a project such as this would begin with a pre-existing hierarchy of tonal harmony that unambiguously informs a taxonomy-centered design process [23]. Though unable to find such guidance, we have used the work of Krumhansl regarding tonal hierarchies [19, 20, 21], functional harmony, and tonal harmony's statistical characteristics more generally as a starting point for our prioritization [3, 8, 28].

Finally, for color to represent 12 categorically distinct keys successfully, numerous pitfalls must be avoided. While designers of qualitative color palettes should strive to assign colors that provide each color the same perceptual weight [5, 35], their use for encoding harmonic categories requires that memorable, robust, and easily discernible names be prioritized over consistency. This paper's considerations of assigning color names are limited to English, but work on naming and perceptual differences across languages [1, 16, 30, 34] suggests that speakers of languages other than English might benefit from targeted adjustments to the selected colors (both color names and the hues themselves). Overall, the use of categorical color names that are distinct both linguistically and perceptually is recommended [6, 7, 13, 18, 22, 31].

2 Methodology

2.1 Glyph Design

To satisfy our goal of creating *a design that maximizes the effectiveness of how elements are encoded visually* as glyphs within their musical context, we begin at the level of the visual encoding idiom. Just as bar lines establish regularity and discretize the element of time into measures, we will use bar-line-like glyphs to discretize harmonic shifts at the grain of one glyph per chordal change. As the harmonic function and effect of any given chord depend on its surrounding context, we will seek a means of visualizing supportive elements through background effects rather than within the glyphs themselves. Table 1 outlines this general process: Each visual channel is assigned a rank of how effectively it functions with both categorical and magnitudinal variables, the *Channel Bins Available* column provides a rough number of how many variables each channel can reasonably encode, and the *Summary Visual Salience* column provides an overall rank across both categories.

Visual Aspect	Summary Visual Saliency	Glyph Channel Type	Glyph Attribute Type	Attribute Ordering Direction	Categorical Saliency (What-Where)	Magnitudinal Saliency (What-Where)	Channel Bins Available
Length	1	Magnitude / Continuous	Quantitative	Sequential	1	1	6+
Vertical displacement	2	Magnitude / Ordinal	Ordinal	Diverging	2	2	3+
Plumbness	3	Magnitude / Continuous	Quantitative	Diverging	6	3	3+
Width	4	Magnitude / Continuous	Quantitative	Sequential	5	4	3+
Glyph Hue	5	Identity / Categorical	Categorical	Cyclic	3	6	12
Shape	6	Identity / Categorical	Categorical	-	4	-	6+
Saturation	6	Magnitude / Ordinal	Ordinal	Sequential	3	6	2x hue
Sharpness	14	Identity / Categorical	Categorical	-	13	-	2
*Background Lightness	*1	Magnitude / Ordinal	Ordinal	Sequential	*1	-	2
*Background Pattern	*2	Identity / Categorical	Categorical	-	*2	-	6+
*Background Hue	*3	Identity / Categorical	Categorical	Cyclic	*3	-	12

Table 1: Suitable visual channels for glyphs embedded within CMN (not all shown). *Summary Visual Saliency* is an estimate and is meant as a rough guide within this specific design idiom.

2.2 Harmonic Encoding Targets

Having created a suitable carrier of additional information, we return to the data abstraction level to identify and prioritize the harmonic targets to encode. In the absence of a definitive hierarchy (the creation of a comprehensive taxonomy being beyond the scope of this project), we created a proof-of-concept catalog for illustrative purposes. Table 2 shows several of the selected aspects alongside some of their relevant attributes: Each harmonic concept is assigned a rank based on its importance as either categorical or magnitudinal variables, the *Harmonic Bins Required* column provides a rough number of how many values the concept contains, and the *Total Harmonic Saliency* column provides an overall rank of each concept across both categories.

Harmonic Concept	Total Harmonic Saliency	Channel Type	Attribute Type	Attribute Ordering Direction	Categorical Saliency (What-Where)	Magnitudinal Saliency (How Much)	Harmonic Bins Required
Key Modal Brightness	1	Magnitude / Ordinal	Ordinal	Sequential	-	1	2
Chord Function	2	Magnitude / Ordinal	Ordinal	Sequential	-	2	4
Cadence Strength	4	Magnitude / Ordinal	Ordinal	Sequential	-	4	4
Chord Triad Type	6	Identity / Categorical	Categorical	-	3	-	4
Chord Circle of Fifths Distance	9	Magnitude / Ordinal	Ordinal	Diverging	-	5	6
Chord Inversion	16	Identity / Categorical	Ordinal	Sequential	10	-	4
Chord Root Scale Degree	17	Identity / Categorical	Ordinal	Sequential	11	-	7
Chord Root Pitch	18	Identity / Categorical	Ordinal	Cyclic	12	-	12
Key Pitch	19	Identity / Categorical	Ordinal	Cyclic	13	-	12

Table 2: Harmonic concepts that are candidates for encoding via glyphs (not all shown). *Total Harmonic Saliency* is an estimate designed to streamline subsequent encoding steps.

3 Visual Encoding

3.1 Mapping Harmonic Aspects to Visual Channels

In order to visualize the most salient harmonic concepts and ensure that the most prominent harmonic aspects are linked to the most impactful visual channels, our next task is to map the available visual channels to the set of harmonic targets. Assignments balance harmonic importance, channel appropriateness, channel saliency, and metaphorical fit. Several background effects provide the required environmental context: Key modal brightness is mapped to page lightness, key pitch to background hue, and key mode and modal brightness values to background pattern. Glyphs themselves convey the remaining information, beginning with harmonic motion. Chord function is mapped to plumbness (tonic chords as vertical and at rest, dominant chords

as decelerating and tilting backward, weak predominants tilting slightly forward, and strong predominants accelerating further forward still). Cadences receive three encodings: additional weighting via bolding, depth via a drop shadow, and increased width proportional to their cadential strength. The four chord triad types are mapped to orientation. Modulations are mapped to a second glyph, according to the new key, overlaid directly upon the glyph from the previous key. Harmonic distance is mapped to increasing chromatic distance between glyph hues and the key itself. Seventh chords (and their type) are mapped to glyph orientation and curvature, and chord inversions to vertical displacement from a shared baseline. Finally, chord names as chord root pitch are mapped to glyph hue and saturation/lightness.

3.2 Color as Pitch

Our third goal was *to use color in a way that maximizes visual discernibility* by using color *values* that are strongly associated with familiar color *names*. Color values were selected based on overall discernibility (a property of the geometric distance between any two points in color space) in combination with the saliency and familiarity of the color names themselves. Included are 8 out of the 11 most common, or basic, color names in English – *pink, red, brown, orange, yellow, green, blue, and purple* (*white* and *black* were skipped for obvious reasons, as was *grey* based on expected confusion given the complexity of CMN). *Olive, teal, pale blue, and lilac* are added to these eight to subdivide the hue space [24] further.

We select one shade that is relatively bright alongside another that is darker or more muted within each color. This serves to metaphorically encode modal brightness for keys (such as major or minor) and as a redundant encoding of a chord's triad type (augmented or major as brighter, minor or diminished as darker). An additional advantage of this technique is that it provides a more robust namespace to differences in color naming – users can always fall back to a meaningful color term that encompasses two different color values if needed. Selection of the specific shades was an iterative process that balanced several goals: ensuring the fidelity of the chosen color value to the color set's name, maintaining the spirit of darker or lighter shades for two parallel palettes, and maximizing the geometrical distance between neighboring values (see Figure 1). Colors also cannot be too dark or too light, as either would undermine accessibility based on the required contrast against a very light page background. Given the relatively small size of glyphs, contrast ratios of 3.0 were targeted (an accepted benchmark in web accessibility for large text, graphical objects, and user interface components).

Conclusion & Future Work

In this manuscript, we presented a new method for visualizing harmony using bar-line like glyphs. Encoding decisions were guided by channel attribute types, both harmonic and visual, while color guidelines emphasized categorical color geometry. Although we have not yet fully automated this process (the 'algorithm' layer of Munzner's design scheme), Figure 2 provides a proof-of-concept illustration of this new design idiom in use. We plan to further refine these initial steps alongside creating integrations with Verovio and the broader ecosystem of MEI encoding tools.

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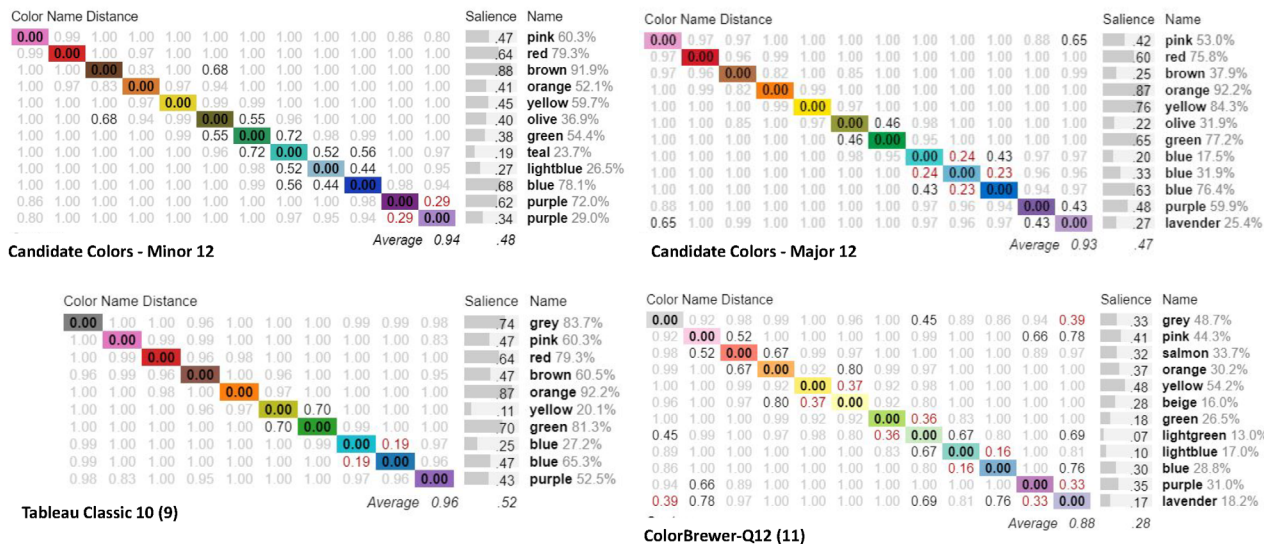


Figure 1: Name-based comparison of qualitative color palettes. The color names shown in this figure are generated automatically by algorithm [14] hence the slightly darker-than-lilac color top-left tagged as purple. Color-name distances shown via matrices; salience scores with bar charts. Salience scores below 0.2 suggest likely naming confusion. The proposed palettes provide better saliency with less name overlap than “ColorBrewer-Q12” and are comparable to the 10-color “Tableau Classic 10” while encoding more values (these are two popular categorical palettes commonly used in visual design).

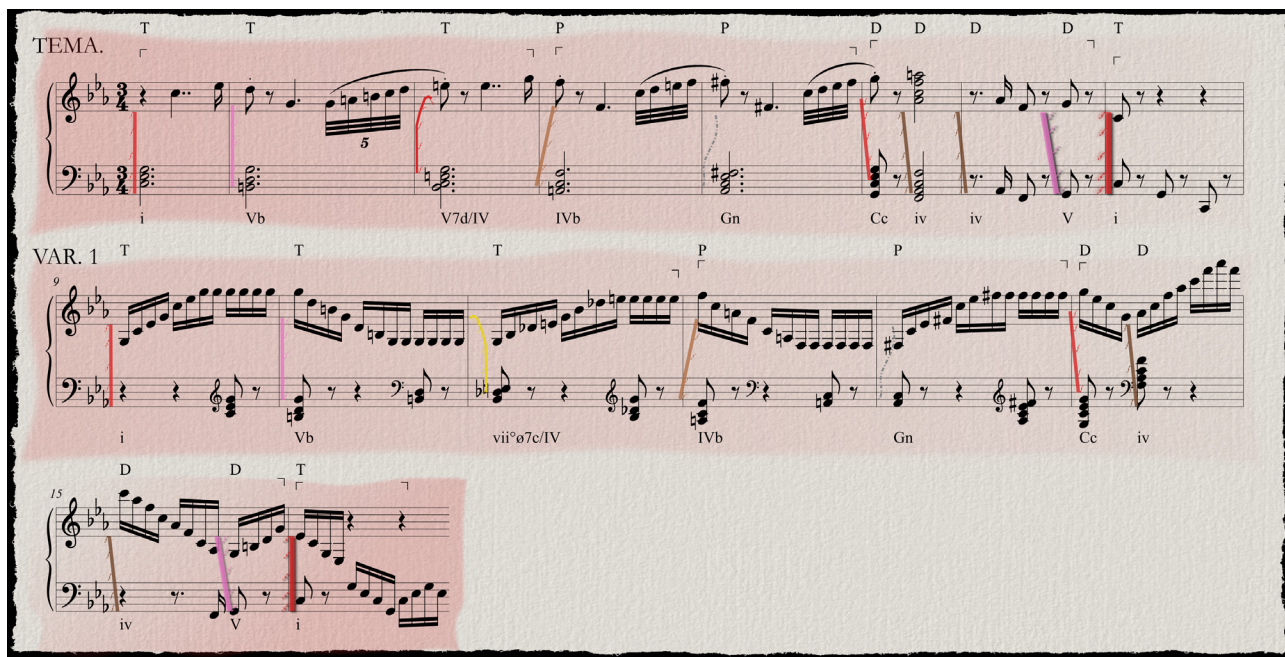


Figure 2: Beethoven’s ‘32 Variations on an Original Theme in C minor’, WoO 80, mm. 1–16. Harmonic and functional analysis sourced from the TAVERN data set [9]. Score rendered using Verovio Humdrum Viewer. Proof-of-Concept chordal glyphs were added manually alongside key pitch and key modal brightness (the red background indicating C minor) using Inkscape vector graphics software.

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1. Harmonic Concepts and 2. Effectiveness-weighted are combined for use in Chordal Glyphs with Familiar Color Names

Harmonic Concept	Root Chord Type	Attribute Direction	Categorical (Pitch/Interval)	Magnitude (Interval/Scale)	Chordal Glyph	Chordal Glyph Type	Visual Channel	Summary Glyph Channel Type	Visual Channel	Summary Glyph Channel Type	Attribute Direction	Categorical (Pitch/Interval)	Magnitude (Interval/Scale)	Chordal Glyph	Chordal Glyph Type
Key Model (Bach)	1. Major/Minor	Octave	Sequential	1	5a	Major/Minor	Length	1. Magnitude / Contour	Octave	1. Magnitude / Contour	Sequential	1	5a	Major/Minor	
Chord Function	2. Major/Minor	Octave	Sequential	2	3a	Major/Minor	Vertical displacement	2. Magnitude / Contour	Octave	2. Magnitude / Contour	Sequential	2	3a	Major/Minor	
Chord Quality	3. Major/Minor	Octave	Sequential	3	4a	Major/Minor	Width	3. Magnitude / Contour	Octave	3. Magnitude / Contour	Sequential	3	4a	Major/Minor	
Centric Strength	4. Major/Minor	Octave	Sequential	4	5a	Major/Minor	Shape	4. Magnitude / Contour	Octave	4. Magnitude / Contour	Sequential	4	5a	Major/Minor	
Key Mode	5. Identity / Categorical	Categorical	Sequential	5	6	Major/Minor	Color	5. Identity / Categorical	Categorical	5. Identity / Categorical	Sequential	5	6	Major/Minor	
Chord Staff Type	6. Identity / Categorical	Categorical	Sequential	6	7	Major/Minor	Height	6. Identity / Categorical	Categorical	6. Identity / Categorical	Sequential	6	7	Major/Minor	
Major/Minor	7. Identity / Categorical	Categorical	Sequential	7	8	Major/Minor	Weight	7. Identity / Categorical	Categorical	7. Identity / Categorical	Sequential	7	8	Major/Minor	
Chord Color of F#B Distance	8. Major/Minor	Octave	Sequential	8	9	Major/Minor	Phase	8. Major/Minor	Octave	8. Major/Minor	Sequential	8	9	Major/Minor	
Chord Borrowing?	9. Major/Minor	Octave	Sequential	9	10	Major/Minor	Line-Midline	9. Major/Minor	Octave	9. Major/Minor	Sequential	9	10	Major/Minor	
Chord Quality	10. Major/Minor	Octave	Sequential	10	11	Major/Minor	Line-Upper	10. Major/Minor	Octave	10. Major/Minor	Sequential	10	11	Major/Minor	
Chord Function	11. Major/Minor	Octave	Sequential	11	12	Major/Minor	Outline	11. Major/Minor	Octave	11. Major/Minor	Sequential	11	12	Major/Minor	
Chord Staff Type	12. Identity / Categorical	Categorical	Sequential	12	13	Major/Minor	Sharpness	12. Identity / Categorical	Categorical	12. Identity / Categorical	Sequential	12	13	Major/Minor	
Chord Borrowing?	13. Identity / Categorical	Categorical	Sequential	13	14	Major/Minor	*Background Lightness	*1. Magnitude / Contour	Categorical	*1. Magnitude / Contour	Sequential	*1	14	Major/Minor	
Chord Function	14. Identity / Categorical	Categorical	Sequential	14	15	Major/Minor	*Background Opacity	*2. Identity / Categorical	Categorical	*2. Identity / Categorical	Sequential	*2	15	Major/Minor	
Chord Staff Type	15. Identity / Categorical	Categorical	Sequential	15	16	Major/Minor									
Chord Borrowing?	16. Identity / Categorical	Categorical	Sequential	16	17	Major/Minor									
Chord Function	17. Identity / Categorical	Categorical	Sequential	17	18	Major/Minor									
Chord Staff Type	18. Identity / Categorical	Categorical	Sequential	18	19	Major/Minor									
Chord Borrowing?	19. Identity / Categorical	Categorical	Sequential	19	20	Major/Minor									

Harmonic Concept	Root Chord Type	Attribute Direction	Categorical (Pitch/Interval)	Magnitude (Interval/Scale)	Chordal Glyph	Chordal Glyph Type	Visual Channel	Summary Glyph Channel Type	Visual Channel	Summary Glyph Channel Type	Attribute Direction	Categorical (Pitch/Interval)	Magnitude (Interval/Scale)	Chordal Glyph	Chordal Glyph Type
Key Model (Bach)	1. Major/Minor	Octave	Sequential	1	5a	Major/Minor	Length	1. Magnitude / Contour	Octave	1. Magnitude / Contour	Sequential	1	5a	Major/Minor	
Chord Function	2. Major/Minor	Octave	Sequential	2	3a	Major/Minor	Vertical displacement	2. Magnitude / Contour	Octave	2. Magnitude / Contour	Sequential	2	3a	Major/Minor	
Chord Quality	3. Major/Minor	Octave	Sequential	3	4a	Major/Minor	Width	3. Magnitude / Contour	Octave	3. Magnitude / Contour	Sequential	3	4a	Major/Minor	
Centric Strength	4. Major/Minor	Octave	Sequential	4	5a	Major/Minor	Shape	4. Magnitude / Contour	Octave	4. Magnitude / Contour	Sequential	4	5a	Major/Minor	
Key Mode	5. Identity / Categorical	Categorical	Sequential	5	6	Major/Minor	Color	5. Identity / Categorical	Categorical	5. Identity / Categorical	Sequential	5	6	Major/Minor	
Chord Staff Type	6. Identity / Categorical	Categorical	Sequential	6	7	Major/Minor	Height	6. Identity / Categorical	Categorical	6. Identity / Categorical	Sequential	6	7	Major/Minor	
Major/Minor	7. Identity / Categorical	Categorical	Sequential	7	8	Major/Minor	Weight	7. Identity / Categorical	Categorical	7. Identity / Categorical	Sequential	7	8	Major/Minor	
Chord Color of F#B Distance	8. Major/Minor	Octave	Sequential	8	9	Major/Minor	Phase	8. Major/Minor	Octave	8. Major/Minor	Sequential	8	9	Major/Minor	
Chord Borrowing?	9. Major/Minor	Octave	Sequential	9	10	Major/Minor	Line-Midline	9. Major/Minor	Octave	9. Major/Minor	Sequential	9	10	Major/Minor	
Chord Quality	10. Major/Minor	Octave	Sequential	10	11	Major/Minor	Line-Upper	10. Major/Minor	Octave	10. Major/Minor	Sequential	10	11	Major/Minor	
Chord Function	11. Major/Minor	Octave	Sequential	11	12	Major/Minor	Outline	11. Major/Minor	Octave	11. Major/Minor	Sequential	11	12	Major/Minor	
Chord Staff Type	12. Identity / Categorical	Categorical	Sequential	12	13	Major/Minor	Sharpness	12. Identity / Categorical	Categorical	12. Identity / Categorical	Sequential	12	13	Major/Minor	
Chord Borrowing?	13. Identity / Categorical	Categorical	Sequential	13	14	Major/Minor	*Background Lightness	*1. Magnitude / Contour	Categorical	*1. Magnitude / Contour	Sequential	*1	14	Major/Minor	
Chord Function	14. Identity / Categorical	Categorical	Sequential	14	15	Major/Minor	*Background Opacity	*2. Identity / Categorical	Categorical	*2. Identity / Categorical	Sequential	*2	15	Major/Minor	
Chord Staff Type	15. Identity / Categorical	Categorical	Sequential	15	16	Major/Minor									
Chord Borrowing?	16. Identity / Categorical	Categorical	Sequential	16	17	Major/Minor									
Chord Function	17. Identity / Categorical	Categorical	Sequential	17	18	Major/Minor									
Chord Staff Type	18. Identity / Categorical	Categorical	Sequential	18	19	Major/Minor									
Chord Borrowing?	19. Identity / Categorical	Categorical	Sequential	19	20	Major/Minor									

Abstract

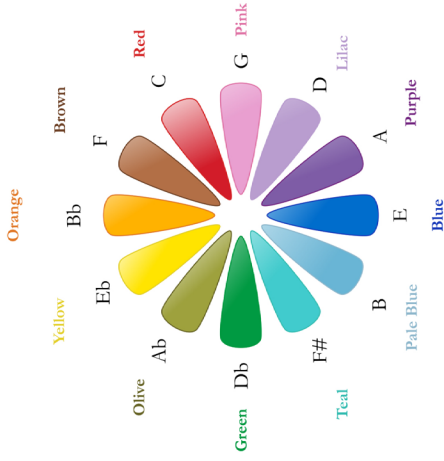
Musical concepts are frequently annotated with harmonic information, but widely used text-based methods rely on a limited number of visual channels. Though glyph-based methods exploit more channels, existing systems often violate perceptual design principles when employing color and rarely capture the frequency of chordal changes or their harmonic function. In this work, we introduce a new design idiom for augmenting sheet music through chordal glyphs embedded directly within musical staves. Harmonic concepts, weighted by saliency and categorized by data type, are mapped to visual channels ranked by discriminability. Preemptive processing is leveraged to support various user tasks, alongside redundant encodings of foundational harmonic elements to improve overall perceptual effectiveness. Key names and chord roots are displayed using parallel hue-based 12-step categorical colormaps. We then distill several design implications inherent in assigning colors to musical pitches regarding perceptual and linguistic effectiveness. Following this discussion, we outline open research directions.

Proof-of-Concept

The image shows a musical score with two systems: 'TEMA.' and 'VAR. 1'. Chordal glyphs are placed within the staves, color-coded according to the chord function. The glyphs are integrated into the musical notation, showing how they affect the visual space and readability of the score.

Proof-of-Concept: chordal glyphs shown in Beethoven's 32 Variations on an Original Theme in C minor, WoO 80, measures 1-16. Harmonic and functional analysis sourced from the TAVENK data set. The red background encodes key pitch and key modal brightness, indicating c minor.

4. Circle of Fifths-arranged Familiar Color Names



Future Work

The image shows a musical score with two systems: 'Tema.' and 'Var. 1'. Chordal glyphs are placed within the staves, color-coded according to the chord function. The glyphs are integrated into the musical notation, showing how they affect the visual space and readability of the score.

An example of an alternative chordal glyph design. Here, the scale degrees of the root of each chord is mapped to its Solfege letter using parallelized alphabetic characters. Chord Function continues to be shown by glyph verticality, leaning forward if Pre-Dominant, leaning backward if Dominant, and straight-up and down when serving a Tonic function. Drop shadows again indicate a PAC.

There is still a great deal of work to be done in refining this design, from the capturing of harmonic concepts to the breadth of visual channels used. This design idiom may also be suited to encoding harmonic textual information, something that I would like to explore. The color space, in terms of 12 distinct families of colors for the 12 western pitch classes, seems surprisingly robust. This suggests numerous possible routes for employing consistent color mapping to keys / chords across musical domains, from pedagogy, to guitar tablature, to more abstract real-time musical visualization.

The diatonic chords of C Major are shown here, this time with their corresponding Roman numerals sized roughly based on their overall likelihood of appearance in Western Art Music between 1750-1900.