RapViz: Rhyme Detection and Visualization of Rap Music

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Keywords: Text Visualization, Rap Music, Rhyme Detection.

Abstract: RapViz transforms lyrics and audio of rap music into interactive visualizations, highlighting assonance rhymes and rhyme schemes. To accomplish this task, we have built a custom rhyme detector and extract respective timestamps from the audio file. The visualization integrates dynamic, time-based components to present insights from the rhyme analysis. Two linked views provide textual and temporal perspectives on a song. They can be viewed as an animation while the song plays and explored interactively afterwards. We demonstrate how our approach helps analyzing different songs covering different styles of rap.

1 INTRODUCTION

Over the past decades, hip-hop and rap music has grown from an underground genre into an influential part of today's music landscape. In 2021, for instance, the genre held a US market share of about 30% (Statista, 2024). With lyrical similarities to poetry, rap places a significant emphasis on rhymes and rhyme structures. While listeners can, of course, just enjoy the music, at some point of engagement, it might become more and more interesting for them to understand what makes this type of music so poetic and how rhymes interact with each other. However, analyzing rhymes is challenging and might require specialized knowledge.

There are already examples demonstrating how animated visual representations of rhyme patterns can facilitate the understanding of rap. Visualizations of rhymes in popular songs can be found on platforms like *YouTube* (e.g., *Highlighted*[1]) or on *Genius* (e.g., *Check the Rhyme*[2]). These visualizations feature text scrolling that is synchronized with the song. Rhymes are highlighted in color. However, these examples are described as, or clearly appear to be, handcrafted for each song individually. They provided inspiration for us, but, in contrast, we wanted to develop an automatic processing and visualization solution, as well as provide more interactive options for exploration. Partly, we already found this in an example by *The Wall Street Journal*, who visually illustrated the rhymes of the Broadway hip-hop musical *Hamilton* (Eastwood and Hinton, 2016a). Their approach involves translating words into phonetic language and computing phonetic syllable similarity to assign rhyme groups (Eastwood and Hinton, 2016b). Additionally, they manually timestamped words to display them synchronized with the music playback. We strive to extend and automate this approach.

Hence, to make rhyme analysis of rap music more accessible and widely applicable, we present RapViz, an approach that automatically analyzes lyrics and corresponding audio files for producing interactive visualizations. In the absence of an adequate rhyme detection tool that met our requirements, we developed a method to identify rhyme groups among syllables within the lyrics. To enable a dynamic visualization, we further extract timestamps for each syllable from the corresponding audio file. As shown in Figure 1, the visualizations we propose consist of two interactively linked views. First, the lyrics of the song get enriched by color to encode rhyme groups and arcs to reveal end rhyme schemes. Second, a timeline view complements an undistorted temporal perspective of the internal rhyme patterns. When playing the song, in both views concurrently, the visual encodings dynamically unfold. They stay persistent to allow retrospective analysis of the whole song when the playback stops. While an expert panel allows more ex-

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[1]https://www.youtube.com/@Highlighted
[2]https://genius.com/shows/ctr

Müller, P., Panzer, L. and Beck, F.
RapViz: Rhyme Detection and Visualization of Rap Music.
DOI: 10.5220/0013190700003912

In *Proceedings of the 20th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2025) - Volume 1: GRAPP, HUCAPP and IVAPP*, pages 730-739
ISBN: 978-989-758-728-3; ISSN: 2184-4321

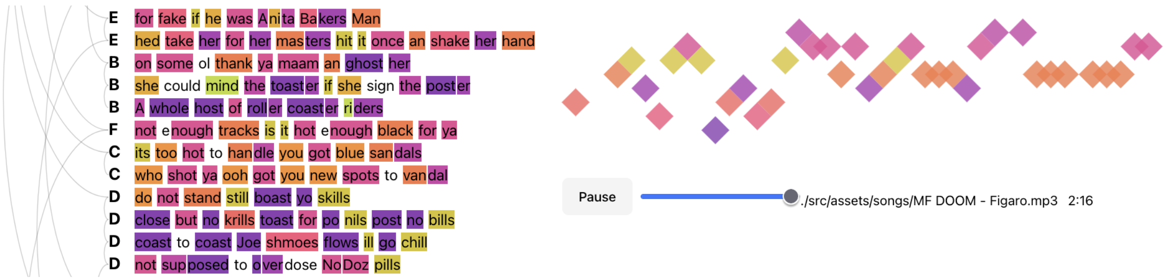


Figure 1: Main interface of RapViz consisting of the lyrics text with colored rhyme group highlighting (left; partly clipped) and a corresponding timeline visualization (right); playback options and a slider (bottom-right) support navigation and listening to the song while the visual encoding materializes. Example from *Figaro* by MF DOOM.

perienced users to test out different configurations of algorithms and their key parameters, we made sure to select a reliable default configuration so that manual optimization is not required for a first analysis. In this paper, we demonstrate the approach and its configurations through analyzing the rhyme pattern of two rap songs of different types.

2 RELATED WORK

While we are not aware of automated systems designed for rhyme visualization of rap music, our work relates to certain areas of text and music visualization. Especially, the idea of visualizing rhymes in poems has been explored before. Related are also music visualizations that focus on analyzing individual songs. Specific to rap, Meinecke et al. (2022a,b) use automated methods to visualize similarities between artists based on their lyrics; however, this does not specifically address rhymes, and comparing artists is beyond the scope of this work.

Noh et al. (2019) discern *graphical* from *textual* poetry visualization—the former describing visual art work to graphically complement a poem (comparable to a music video complementing a rap song), the latter characterizing data-driven visual representations to analyze the text. As an example for a textual visualization, *ProseVis* (Clement et al., 2013) analyzes parts-of-speech, phonemes, stress and tone, and visualizes the data through color highlighting. *Poem Viewer* (Abdul-Rahman et al., 2013) concentrates on the phonetic elements of a poem and provides rich visual encodings of consonant properties, vowel length and position, stress, syllables, as well as word classes and sentiment analysis. *SPARSAR* (Delmonte, 2015) enriches the poem's text in three different views with phonetic, poetic, and semantic information. *Poemage* (McCurdy et al., 2016) visualizes sonic devices and sonic topology in poetry, revealing connections of words through sonic or linguistic similarity across the poem. In contrast to such *close reading* support, other approaches provide more aggregated representation, rather for *distant reading* (Mittmann et al., 2016; Benito-Santos et al., 2023; Lein et al., 2018). They propose multi-level visualization techniques that display poetic elements, visualize sonic depth in poetic texts, and employ statistical analysis to visualize rhythmic patterns in poetry. We can specifically draw inspiration from close reading, textual approaches and adapted a rhyme-based text highlighting. As poems, unlike music, do not carry clearly defined timing information, those approaches, however, lack a distinct temporal perspective.

Among visualization techniques for musical data (Khulusi et al., 2020), however, we find related time-oriented methods. When visualizing musical alignment, similar sound patterns from sound or scores can be detected (Dannenberg and Raphael, 2006). There are various approaches that focus on enhancing existing score notations. Wattenberg (2002), for example, enrich musical notation using arc diagrams to show repeated sound patterns. Similar to rhymes in the domain of rap, there are approaches that visually classify different harmonies using color and saturation (Ciuha et al., 2010). While all visualizations in these approaches are static, there also exist relevant animated methods. Both the visualization of active musical components, e.g., harmonies, orchestration, phrases and leitmotiv (Goss and Carson, 2016), as well as the general structure of a music sheet (Bergstrom et al., 2007) can be visualized using animated approaches that demonstrate the dynamics or structure of a song while it plays.

3 BACKGROUND

To study rap lyrics, first, clarifying some rap and poetry terminology is helpful. A *verse* is a section of the lyrics comparable to a paragraph in a poem. In rap, it is common for a verse to comprise 16 *lines* or

My son said, daddy, I don't wanna go to school (A)
Cause the teacher's a jerk, he must think, I'm a fool (A)
And all the kids smoke reefer, I think it'd be cheaper (B)
If I just got a job, learned to be a street sweeper (B)

Figure 2: End rhyme scheme in *The Message* by Grandmaster Flash & The Furious Five.

People really think my life is perfect (A)
Maybe 'cause I'm laughin' through the worst shit (A)
Yeah, I know the Devil is alive but (X)
The way that I been movin' got him nervous (A)

Figure 3: End rhyme scheme in *Colorado* by Kota the Friend.

bars (Edwards, 2009). Generally, a line is defined as "a group of words arranged into a row that ends for a reason other than the right-hand margin" (Poetry Archive, 2024). In contrast, a *bar* is a unit of time; in almost all hip-hop tracks, one bar is equivalent to four beats (Edwards, 2009). Note that in most cases, one bar aligns with one line (Edwards, 2009). Hence, we treat the terms *bar* and *line* interchangeably.

Along with rhythm, rhymes are one of the two things that make the spoken word stand out in rap (Edwards, 2009). Generally, rhymes are the repetition of similar sounds (Wikipedia, 2024). There are different rhyme types. *Perfect rhymes* adhere to two conditions: The stressed vowel sound shared between the two words must be identical, extending to any subsequent sounds, and the onset of the stressed syllable in the words must differ. *Identical rhymes* occur when the first condition for perfect rhymes is met, but the second is not (Wikipedia, 2024). In contrast, *assonance* is the "repetition of stressed vowel sounds within words with different final consonants" (Encyclopaedia Britannica, 2024). Assonance is considered the most widely used poetic device and type of rhyme in rap (Edwards, 2009).

Patterns of rhymes form rhyme schemes that exceed the scope of two words. *End rhymes* refer to the rhymes that occur between the terminal syllables of verses (Merriam-Webster, 2024a). Figure 2 and Figure 3 provide different examples of end rhymes denoted as color and through identifiers. The first uses perfect rhymes and scheme of *AABB*, the second assonance and a scheme of *AAXA* (*X* denotes a non-rhyming line ending). *Internal rhymes* consist of "rhyme[s] between a word within a line and another either at the end of the same line or within another line" (Merriam-Webster, 2024b). The internal rhymes of one bar can form a pattern that the artist uses in multiple bars. In the example given in Figure 4, almost every word in these two bars contributes to internal rhymes (here, denoted by color only).

It's too hot to handle, you got blue sandals
Who shot you? Ooh got you new spots to vandal?

Figure 4: Internal rhymes in *Figaro* by MF DOOM.

For analyzing rhymes, we need to transcribe spoken language sounds into written symbols. *Phonetic alphabets* provide the required basis through encoding *phonemes*, which are "the smallest phonetic unit in a language capable of conveying a distinction in meaning, as the *m* of *mat* and the *b* of *bat*" (The American Heritage Dictionary, 2024). For English, two widely accepted phonetic alphabets are the *International Phonetic Alphabet (IPA)* and *ARPAbet*. In this paper, we will use the two-character version of *ARPAbet* because it is the one used by *The CMU Pronouncing Dictionary*[3], which is an open-source pronunciation dictionary for the English language.

4 DATA PROCESSING AND ANALYSIS

As a basis for our visualization approach, we have designed an automated processing method for rap songs to detect rhymes, to group them, and to synchronize the lyrics with the audio playback. The method requires the audio file and lyrics as input, and returns rhyme groups and timestamps for the lyrics at syllable level.

4.1 Pronunciation

Although the audio information is the most authoritative source for rhyme in a song—including the artist's pronunciation—, the automatic extraction of rhymes from audio is complex and might be highly unreliable. As a more manageable heuristic, hence, we use the lyrics as a proxy. The objective is to effectively categorize words from a given text into distinct rhyme groups. To incorporate perfect, identical, and assonant rhymes in the detection, the approach must consider the phonetics of words. Our primary source for syllables is the dictionary *How Many Syllables*.[4] However, since a dictionary entry is not available for every word, in those cases, we turn to an algorithmic method to segment words into syllables: The Sonority Sequencing Principle (SSP) as implemented

[3]http://www.speech.cs.cmu.edu/cgi-bin/cmudict
[4]https://www.howmanysyllables.com/

in *nltk*.[5] Through ARPAbet, we phonetically transcribe the syllables. We choose ARPAbet over IPA because of the ease of querying CMUDict through the Python *pronouncing* library.[6] To address words beyond the dictionary, we use a recursive partitioning method. We split words into individual partitions until each partition is present in the CMU dictionary. Afterward, we reassemble those partitions to approximate pronunciation.

4.2 Rhyme Score

Next, we construct a *rhyme score* σ to quantify the level of rhyming between two syllables. The score ranges from 0 to 1, with 0 indicating no rhyme, and 1 being a strong indicator for rhyme. It is stored in a similarity matrix S holding all the scores for all syllable pairs. The score is determined by considering three key features.

Vowel Similarity (σ_v). For two syllables to rhyme, they must share a similar vowel sound. The *CMU Pronouncing Dictionary* assigns one of 15 distinct vowel sounds to each syllable. Syllables with the same vowel sound, denoted by the same ARPAbet character, have the potential to rhyme. Syllables with vowel sounds that are similar but not identical are also considered potential rhymes, as they can be easily turned into rhymes depending on pronunciation. Rappers often intentionally go with pronunciations that result in rhyming for these words (Edwards, 2009). To compute vowel similarity, we use a confusion matrix based on research by Phatak and Allen (2007). This matrix represents how likely one vowel sound is to be confused with another in speech perception experiments, which we interpret as similarity.

Stress (σ_s). The ARPAbet notation also indicates the level of stress on a vowel. This refers to the degree of emphasis placed on the individual vowel sound. For instance, for the word "water", the ARPAbet encoding is "W AO1 T ER0". Here, the "AO" sound is stressed, while the "ER" sound is unstressed. Drawing a parallel to the WSJ example and the Hamilton algorithm, we assert that rhyme is most prominent between two stressed syllables. Two stressed syllables earn the highest score. Pairs with one stressed syllable receive a lower score, and two unstressed syllables get the lowest score.

Consonant Suffix (σ_c). Aside from vowels, the subsequent sounds also play a crucial role in rhyming. We will refer to the phonemes of the consonants that follow the vowel of a syllable as *suffix*. If two pairs of syllables share the same or a similar suffix, it will increase their rhyme score. Similar to vowels, we not only consider identical suffixes but also the similarity of their consonant sounds. To quantify the similarity between different consonant sounds, we use confusion matrices based on studies by Woods et al. (2010). To account for cases where suffixes may have different lengths, we employ a weighted average. Each consonant in the suffix is compared to its counterpart in the other syllable, with consonants closer to the end of the word given more weight.

Our complete rhyme score between two syllables a and b is expressed as a weighted arithmetic mean of these factors, modulated by the vowel similarity σ_v:

$$\sigma(a,b) = \sigma_v(a,b) \cdot \frac{\sum_{i\in\{v,s,c\}} w_i \sigma_i(a,b)}{\sum_{i\in\{v,s,c\}} w_i} \qquad (1)$$

The score is structured with σ_v acting as a filter, as we only want to detect syllables with similar vowels as potential rhymes. The coefficients w_v, w_s and w_c are the respective weights for each factor. Typically, w_v should carry the highest weight to, again, acknowledge the importance of vowels for the rhyme.

4.3 Rhyme Groups

Rhyme groups form the foundation of our visualization and are assigned to each syllable based on the similarity matrix. We propose clustering using DBSCAN or HDBSCAN. These algorithms are chosen for their ability to classify unclear data points as noise, as we need to identify both rhyming and non-rhyming syllables. For the rhyme assignment, we convert the similarity matrix into a distance matrix $D = 1 - S$. The default parameters are chosen dynamically, providing lay users a rhyme assignment out of the box. For this, we evaluate various parameter combinations and choose the one with the highest Silhouette Score, which measures how well each data point fits within its cluster compared to others. Experts can enhance these settings (see Section 5.4).

4.4 Lyrics Synchronization

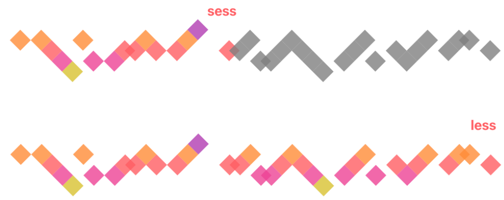
To synchronize audio playback and the animated visualization of rhymes, we need to retrieve the specific timestamps of every syllable. We use OpenAI's

[5] https://www.nltk.org/_modules/nltk/tokenize/sonority_sequencing.html

[6] https://github.com/aparrish/pronouncingpy

Whisper API through a Python module[7], providing the audio file as input. The module outputs a JSON file that includes the transcription with timestamps at word level. However, we need even finer granularity, at the level of individual syllables. Furthermore, the timestamps are linked to the transcribed text generated by *Whisper*, which might contain mistakes, but it is necessary to align them with the original lyrics.

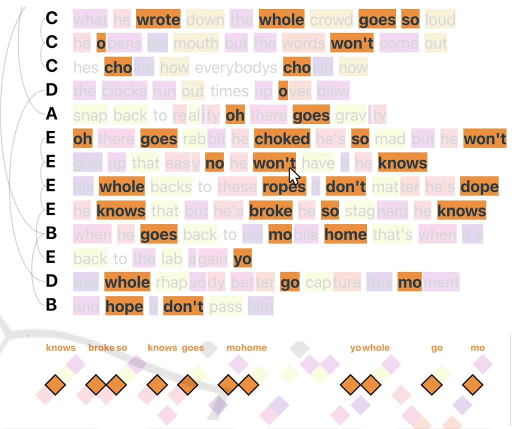
We first match equal segments in both text versions by moving two frames. If the two current frames contain the same sequence of words, a match is noted and both frames are moved forward by one word. If they do not match, only the frame in the transcribed text is moved until the words within the two frames match or a maximum look-ahead length is reached. In the first case, a match is recorded, and the frames are moved to the respective next words; in the latter case, only the frame in the lyrics is moved by one position. This procedure repeats until the end of the text is reached and outputs a sequence of links between perfectly matching words. They are employed to transfer the timestamps of each matched word from the transcript to the lyrics. However, not all words might match and hence cannot yet be linked with the original lyrics. With matched neighbors as references, in such ranges, timestamps are interpolated linearly for each word in the lyrics. Similarly, to finally assign timestamps to the syllables, we interpolate linearly between the timestamps of this and the next word.



(a)

(b)

Figure 5: Dynamically revealing the rhyme groups in the timeline view (a: half revealed; b: fully revealed). Example from *Ready or Not* by The Fugees.



(a)

(b)

Figure 6: Hovering over a syllable highlights all syllables within the same rhyme group in the (a) text highlighting (partly clipped) and (b) timeline visualization. Example from *Lose Yourself* by Eminem.

5 VISUALIZATION

Our contribution further is the design and implementation of an interactive visualization approach (Figure 1). It promotes active engagement with the music and provides a clear temporal guide. To navigate the song, we incorporated a music player with basic functionality such as play, pause, and direct navigation through the song using a slider. Visualizations are linked to the current playback time (Figure 5) and between each other (Figure 6).

5.1 Text Highlighting

We use color-highlighted text to provide the user with a way to follow along with the lyrics. To avoid overwhelming the user with too much text, only a sufficient portion of the text is displayed. As the audio file plays, the text scrolls automatically, similar to a teleprompter used by news anchors. RapViz highlights syllables that share the same rhyme group with the same color. This highlighting appears as the syllables are pronounced in the playback and, over time, all rhyming syllables will be highlighted. When the song concludes, the entire text is presented. Consequently, the text zooms out, allowing for an analysis of the entire content. With the full text shown, arc diagrams are added to the left of the lines of text, visualizing end rhymes and their corresponding schemes (Figure 1, left). Bars without participation in an end rhyme scheme are marked with the letter *X*.

5.2 Timeline

The intention of the timeline is to expose the structures of internal rhyme schemes as discussed in Section 3 and to better link rhymes with time (beat). For this, we represent syllables as squares, inspired by *The Wall Streets Journals*'s approach (Eastwood and Hinton, 2016a). These squares are color-coded, with the same colors as in the text highlighting visualization. Redundantly encoded in addition to color, the vertical position of each square indicates the rhyme group to which the syllable belongs. This partly mim-

[7]https://github.com/linto-ai/whisper-timestamped

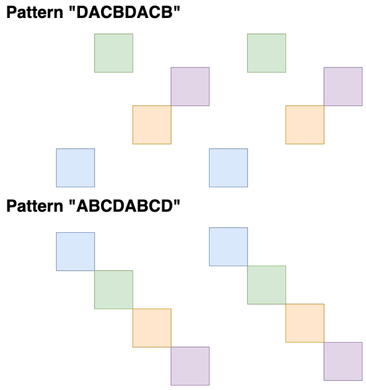


Figure 7: Schematic timeline visualization of the same internal rhyme scheme, comparing the pattern seuquence *DACBDACB* (top) and *ABCDABCD* (bottom).

ics sheet music notation, where the vertical position indicates pitch. Initially gray, the squares adjust to match the relevant rhyme group once the syllable is heard. To aid in identifying the currently visualized syllable, we provide a text label containing the syllable's text.

To improve pattern recognition in the visualization, we limit the number of syllables displayed at once. Showing an entire verse in one view would introduce many rhyme groups simultaneously, resulting in large vertical variation, which would make it harder to spot patterns. For a balance of complexity and expressiveness, RapViz consistently displays four bars in a row, in accordance with the typical structure of a rap verse that comprises 16 bars, split into four blocks of four (Edwards, 2009).

We visually represent patterns minimizing vertical distance (Y-axis) between consecutive syllables. For instance, the pattern *DACBDACB* is more recognizable when it is relabeled and arranged as *ABCD-ABCD*, as displayed in Figure 7. For optimizing that neighboring syllables are positioned vertically close to each other, we rely on *simulated annealing* and thereby approximate an optimal ordering of rhyme groups. Our cost function measures the quality of a solution by calculating the difference between the positions of adjacent syllables' rhyme groups. For a sequence of n syllables $\mathbf{s} = [s_1, s_2, \ldots, s_n]$ and a mapping function p that assigns each rhyme group to a position, the cost function is defined as:

$$C(\mathbf{s}, p) = \sum_{i=1}^{n-1} |p(s_i) - p(s_{i+1}) - 1|\,. \tag{2}$$

It penalizes deviations from a perfect sequential arrangement. The simulated annealing switches positions in the mapping until the system cools, yielding the best found order.

5.3 Color Selection

A key visual feature of RapViz is its use of colors to represent rhyme groups. However, a challenge arises due to the potentially large number of rhyme groups in a song. For instance, the largest categorical color palette in d3.js offers only 10 unique colors,[8] while songs in RapViz can easily exceed this number of groups. We provide a color gradient as input for the color selection. Just mapping to this scale, however, results in some groups having similar colors, given the limited variation in the gradient. We address this limitation by trying to place similarly sounding rhyme groups closer to each other. To this end, we apply *multidimensional scaling* to leverage the similarity between rhyme groups for projecting them onto the one-dimensional color scale, allowing a clear visual distinction between dissimilar groups.

5.4 Expert Settings

The expert settings are designed for advanced users to fine-tune the rhyme group assignment beyond the defaults. While the default settings aim for broadly applicable results, experts may leverage these options to achieve better context-specific outputs.

Experts can modify how the distance matrix D is calculated using two main approaches. The first approach allows considering not only syllable similarity, as shown in Equation 1, but also relative positioning within the text. This can be applied to avoid categorizing two syllables as a rhyme that are far apart in the text. To punish distance we apply the equation

$$D'_{ij} = d_{ij} + w \cdot \left(\frac{|i-j|}{N-1}\right)^p \tag{3}$$

where D'_{ij} is the adjusted distance, d_{ij} is the base distance, w is the position weight (adjustable by the expert), i and j are the indices of the syllables, N is the total number of syllables, and p (adjustable by the expert) determines the degree of non-linearity of the position effect. The second approach allows for the consideration of contextual information surrounding each syllable. This method looks at sequences of up to four syllables in both forward and backward directions from the current syllable pair. It calculates similarities for these extended sequences and selects the highest similarity score. Both the relative positioning and contextual similarity options have the potential to enhance rhyme detection accuracy. However, they require parameter tuning to achieve strong results. Consequently, they are not enabled by default.

[8]https://d3js.org/d3-scale-chromatic/categorical

Figure 8: Text highlighting and timeline visualization of the first four (timeline) and sixteen (text highlighting) bars from *Lose Yourself* by Eminem; (left) Results using default settings; (right) Results using expert-adjusted settings.

The next set of options directly controls the rhyme assignment process. Experts can fine-tune parameters for the DBSCAN and HDBSCAN clustering. For DBSCAN, settings allow adjusting the parameter ε and the minimum cluster size; and for HDBSCAN, tuning the minimum cluster size as well as the minimum number of samples.

6 APPLICATION EXAMPLES

To showcase the value for both laypeople and experts, we will explore two songs, analyzing their rhyme structures and internal patterns with RapViz.

***Lose Yourself* by Eminem (2002).** The song was released accompanying the movie *8 Mile*. It is his most popular song, staying on top 1 of the billboard top 100 for the last nine weeks of 2002 and being the first rap song to win the *Academy Award for Best Original Song*. Focal points of the song are both rhyme complexity and assonance, making it a compelling case for analysis with RapViz.

RapViz effectively highlights some key rhyme patterns in the song already using default settings (Figure 8, left). The pattern of two /a/ (pink) sounds next to each other are particularly prominent and easily identifiable. Additionally, the visualization outlines the verse structure, showing that the song's overall rhyme pattern changes across bars 1-4, 5-8, and 9-16. However, the default settings do not capture the song's nuanced complexity and assonance.

To achieve a more detailed view of the rhyme structure, we optimized the expert settings (Figure 8, right). By switching the clustering algorithm from HDBSCAN to DBSCAN and manually adjusting the parameters, we were able to reveal a more nuanced representation of the internal rhymes. Focusing on the color coding of the first four bars, two dominant rhyme patterns occur frequently (Figure 8). The primary rhyme group centers around the /a/ sound, as in "palm" (purple). This is followed by a multi-syllabic rhyme that includes three sounds: /a/, /ɛɪ/, and /y/, as in "are sweaty" (purple → magenta → pink). In bars 5-8, we observe a pattern centered around the /oʊ/ sound (as in "wrote") and the /aʊ/ sound (as in "down"); and in bars 9-16, a pattern around the /oʊ/ sound (as in "goes"), complemented with the pattern of the multi-syllabic rhyme sequence of /æ/-/ə/-/i/ sounds (as in "gravity"). Assonance is employed numerous times throughout the song. For instance, words like "spaghetti" and "and ready" do not form perfect rhymes on their own. Instead, the artist alters these words to create similar vowel sounds, thereby creating assonance. The result allows him to maintain frequent internal and multi-syllabic rhymes while effectively telling a story.

***Feelings* by Mickey Factz (2023).** Following his feature on XXL's Freshman Issue in 2009 and a decade-long career in the music industry, Factz established the Pendulum Ink Academy. In collabo-

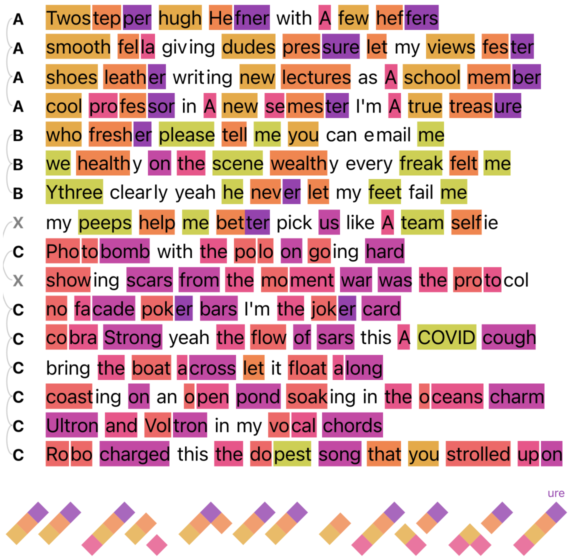


Figure 9: Text highlighting and timeline visualization of the first four (timeline) and sixteen (text highlighting) bars from *Feelings* by Mickey Factz.

Table 1: Rhyme patterns in *Feelings* by Mickey Factz. Gray-shaded syllables were not or falsely classified, obscuring their visual association with the rhyme pattern.

/ʊ/-/ɛ/-/ə/	/i/-/ɛ/-/i/	/ʊ/-/ə/-/ɑ/
Twos-tep-per	please-tell-me	Pho-to-bomb
Hugh-He-fner	e-mail-me	po-lo-on
few-hef-fers	we-health-y	go-ing-on
smooth-fel-la	scene-wealth-y	show-ing-scars
dudes-pres-sure	freak-felt-me	mo-ment-war
views-fes-ter	(Y)three-clear-ly	pro-to-col
shoes-lea-ther	feet-fail-me	no-fa-cade
new-lec-tures	peeps-help-me	po-ker-bars
school-mem-ber	team-self-ie	jo-ker-card
cool-(pro)fes-sor		co-bra-strong
new-(se)mes-ter		flow-of-sars
true-trea-sure		co-vid-cough
who-fresh-er		boat-a-cross
		float-a-long
		coast-ing-on
		o-pen-pond
		soak-ing-x
		o-ceans-charm
		ul-tron-x
		vol-tron-x
		vo-cal-chords
		ro-bo-charged
		do-pest-song
		strolled-up-on

ration with renowned hip-hop artists including Wu-Tang Clan's Method Man and Inspectah Deck as well as Phonte, he aims to teach emerging artists on rhyme and rap techniques. Given Factz's knowledge of lyricism and his focus on advanced rhyme schemes, his work provides an interesting case.

Focusing on local patterns first, the internal rhyme scheme within the first four bars is prominently visible in the timeline visualization (see Figure 9). The artist consistently employs a multi-syllabic rhyme composed of a /u/-/ɛ/-/ə/ sound sequence (see Table 1, first column). Upon examining the broader structure of the entire part, as depicted in Figure 9 (text highlighting), the color coding reveals a structured pattern between bars. The composition can be visually segmented into three main sections: bars 1-4, bars 5-8, and bars 9-16. Each of these sections utilizes unique rhyme schemes. With bars 5-8 focusing on the patter of /i/-/ɛ/-/i/ and bars 9-16 focusing on the pattern of /ʊ/-/ə/-/ɑ/ (see Table 1, second and third column). This bears similarity to patterns observed in *Lose Yourself*, where the same structure of 4 then 4 then 8 bars of the same scheme was employed.

7 DISCUSSION

While exploring different songs in RapViz as discussed above revealed many relevant insights, there are also some clear limitations. Although our text-based rhyme detection analyzes the lyrical component of rap songs, our approach only partially includes the interplay of sound and rhythm with the text (indirectly through the timeline and audio playback, but not directly through visualizing the beat). Since related works have already explored automated analysis of music, we suggest that future research should focus on developing visualizations that include the analysis of musical features and text, ensuring a more comprehensive visualization of songs.

Another challenge is in the pronunciation variability based on context, which is not addressed by our context-agnostic, dictionary-based approach. Lacking semantic and grammatical context causes issues; for instance, the interpretation of terms such as 'MC' (short for a rap artist referred to as *master of ceremonies* or *mic controller*) versus 'Mc' (as in Scottish family names) or the distinction between 'lead' as a verb and 'lead' as a noun significantly affects the accuracy of our rhyme detection. But even if context is properly determined (e.g., through AI), artists might intentionally mispronounce a word to enhances rhymes or speak with an accent not reflected in the dictionary. Hence, achieving further quality improvements regarding automatic rhyme detection might necessitate analyzing the rhymes through the audio channel directly. Additionally, for the task of detecting multi-syllabic rhymes, our system currently relies on the user's abilities to review the visualizations. In future work, an automatic detection and highlighting of these rhymes could be investigated.

Furthermore, our approach includes various parameters and our default configuration cannot be ideal for every song. Users might be willing to try out different configurations through our setting panels, but this can be time-consuming. Moreover, as shown in Table 1, the system may incorrectly classify words even when users have the expertise to understand and configure the different options. Since there is not one default best setting suitable for every song, future research could try to optimize the default parameters by determining them dynamically based on the characteristics of the given song (e.g., through learning from manually optimized examples).

While the detection quality and application examples presented in this paper demonstrate potential, a user evaluation is still necessary to assess the usability and usefulness of the visualization. However, a traditional task-based study might be too limited, as it would be difficult to specify meaningful, representative low-level tasks—how users would want to use and interact with an explorative music visualization is too open and likely individual. In contrast, a more qualitative study methodology focusing on insights and personally perceived value could provide more relevant results.

8 CONCLUSIONS

With the goal to provide an automated visualization approach to reflect on rhymes in rap music, we presented RapViz. It builds on a processing pipeline that takes the song and its lyrics as input and provides distinct rhyme groups and text–audio synchronization as output. To display the data, the approach connects two main visualizations, one focusing on the lyrics, the other one presenting a temporal perspective. Interactive playback with congruent animation provides a basis for understanding rhyme patterns while listening. Further interactions and visual encodings also support a retrospective analysis. The studied songs give examples of findings and insights that lay listeners can realistically discover using the approach, show added potentials when optimizing the expert settings, and reveal current limitations. While the approach overall already provides results of good quality, we see that future improvements can be made through an AI-based audio analysis and parameter optimization, as well as conducting in-depth user research.

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