Mandrit: a system for automatic generation of musical visualizations for rhythm analysis

Rute Moura[1*], **Giordano Cabral**[1] **Horhanna Almeida**[1] **Ricardo Scholz**[1]

[1]Mustic– Centro de Informática/Universidade Federal de Pernambuco
Av. Jornalista Aníbal Fernandes, s/n, Cidade Universitária(Campus Recife) – 50.740-560, Recife, PE

rutymaxsuelly@gmai.com, grec@cin.ufpe.br, hao@cin.ufpe.br, ricardo@marineframework.org

Abstract. *Faced with the representational challenge of visually communicating musical information, we developed Mandrit: a system for automatic generation of musical visualizations for rhythm analysis. It uses data extracted from MIDI files to plot graphs for different songs, representing their rhythmic signatures. The system is customizable and presents new ways to visualize pace through different metrics. We aim to encourage the discussion in this field and the development of tools to generate musical visualizations, as a means to help musicians and scholars in musical analysis, teaching, composing and complementing musical performances.*

1. Introduction

Humans are visual. Thus, it is reasonable to expect that communicating a message is faster through a visual representation. Music has many representational challenges, as it is rich in abstract, complex and subjective information. In this sense, there is a continuous need for analytical studies in Musicology. Therefore, its representational aspects are associated with "an aesthetic dimension of information, memory, cognition, sensitivity, and knowledge of the musical work" [1].

The theoretical basis of this work is in the interdisciplinary area of Computational Music Visualization, also called *MuVis*. It has a growing community, which held the 1st MuVis Symposium in 2018 [2]. For its wide applicability, MuVis brings together studies from various areas, such as Information Visualization, Musicology, MIR (Music Information Retrieval), Education, and Design. It consists of contributions, documentation, and practical studies, aimed at the development of tools, algorithms, techniques, and methods. It is concerned with musical information and the creation of musical visualizations applied to different contexts, such as visual communication of musical concepts [3], assistance in the performance and to teach music [4], musical analysis [5], or even the creation of compositions and artistic performances [6].

In this work, we emphasize the study of possibilities for visual communication of rhythmic elements. Knowing the potential of software resources - for processing and manipulating data from digital files -, we developed the Mandrit system: a system for automatic generation of musical visualizations for rhythm analysis.

*Supported by FACEPE.

2. Generation of Music Visualizations

During the development process of Mandrit, we carried out a case study applying the Design Thinking (DT) approach, formulated and expanded by IDEO [7]. It helped us to explore the generation of personalized views through a structured process in four steps: problematization, ideation, prototyping, and evaluation. In this article we focus on describing the last two steps: prototyping - the generation of visualizations - and evaluation of the system.

We addressed the complex problem of visually communicate musical information through a user-centered qualitative-quantitative research based on feedback. We held individual sessions and focus groups, in which we collected data, further analyzed. Specialists and beginners in Music and Information Visualization participated in the experiments, collaboratively generating paper prototypes, as shown in figure 1. From these sketches, we were able to glimpse the graphic possibilities and challenges to visually represent and communicate musical information.

Figure 1: Paper prototypes generated by participants of individual sessions and focus groups

We performed workshops and tutorials, seeking to explore the process of creating visual representations of music information. During this phase, we noticed a concern of the participants about representing emotional aspects associated with context, designing the instruments played in the song, and trying to communicate their elementary characteristics. They used terms such as timing, beats, intensity, silences, pauses, tempo, and expressiveness, directly relating them to graphic features, such as shapes, colors, textures, contours, and fills, seeking to represent what they recognized as musical information to visually explain music.

The participants created paper prototypes, each of which being a possibility of visual representation for musical content, from the user's point of view. In this article, we focus on their most recurrent demands and needs: the analysis of rhythmic elements and the generation of graphs that communicate them, as rhythmic signatures.

2.1. Mandrit Computational Prototyping

Computational prototypes allow the use of technologies and software resources to develop visualizations, exploring data from digital music files. In addition to making it possible to design systems based on the prototypes, it also allows to simultaneously perform simulations and validations with users, what can directly contribute to verify the feasibility of the project or the use of a given technology. To develop musical computational visualizations, we defined a structured prototyping process in three steps, as shown in the flowchart of figure 2.

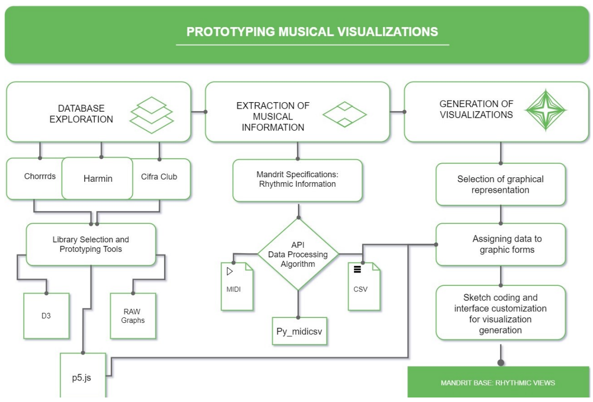

Figure 2: Prototyping process

In the first step, "Database Exploration", we looked for similar existing tools and methods already used to develop musical visualizations. In the second step, "Extraction of Musical Information" (specifically rhythmic information, in Mandrit), we processed the source data to extract meaningful musical information. The last step, "Generation of Visualizations", involved selecting the best graphical representations, with real data, to generate visualizations. Mandrit[1] was developed in the last two steps, and its name references "rhythmic mandalas". Through the attribution of rhythmic information to graphic forms and computational manipulations, it generates three types of graphic models aiming to communicate rhythm.

We carried out tests focused on the automation process and the generation of visualizations. We structured a configurable graphic space to plot the chosen representations according to data extracted from the MIDI files.

[1]DOI Mandrit: https://zenodo.org/record/4118575

2.1.1. Extracting rhythmic data from MIDI

MIDI files are symbolic musical information. Nevertheless, rhythmic features are not given directly in this format. Thus, we needed to perform a feature extraction step, before generating the graphs. As we sought to develop visual signatures of the rhythm, we initially determined which properties of the rhythm would be assigned to the visualization: the type of instrument performing the song, the data about the bar subdivision, and the number of notes with their respective values. To capture this information, we developed a rhythmic extraction algorithm for MIDI files that transforms, organizes and stores this data in variables in a structured way. Table 1 shows a snippet of data from the song "Bateria04" that we produced to develop the algorithm. Column *X* is the track in which the instrument is played, while column *Y* is the subdivision in which the onsets occurred, in the bar. Finally, column *Total notes* sums up the onsets corresponding to that specific tempo. In other words, in this snippet, we show the sequence of track 2 with its respective values of time and number of notes played.

X	Y	Total_notes
2	0	49
2	1	48
2	2	65
2	3	56
2	4	71
2	5	55
2	6	69
2	7	56
2	8	33

Table 1: Snippet of rhythmic data extracted.

This was used to set up the Mandrit database, which has a collection of more than 60 music files already structured in CSV format and processed according to their rhythmic information. Thus, in order to transpose this information and make it visually communicable with rhythmic signatures, we use the information from each song as input.

Moving on to the visualization generation step, we applied a cyclical validation process and selected some paper prototypes to transform them into graphic models.

2.2. Generating Mandrit Graphics

To generate graphically communicable, automated, generalized visualizations applicable to different songs, we attributed elementary rhythmic information to visual structures and graphic forms.

We carried out practical experiments aided by software resources, i.e., we used computational functions of order, rotation, and translation to arrange the musical parameters in a configurable area with graphical representations - points, lines, circles, polygons, colors, size - and manipulate each visual property in order to associate it to the preprocessed data.

Due to research cutout, the views generated by Mandrit are static and two-dimensional, having the geometric figures and orientations associated with aspects of the metrics of the bars. In the first experiments, shown in figure 3, the results of manipulations and graphical plots allowed us to observe the challenges of visually processing large volumes of data in a temporal sequence. These challenges include graphic pollution, difficulties in following the musical sequence and reading the graph - due to the accumulation of information -, and interactivity limitations to hide or analyze components separately.

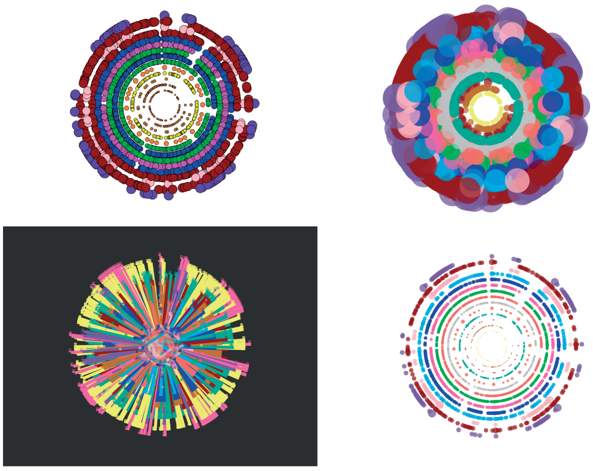

Figure 3: First experiments

Furthermore, we noticed that MIDI files used in these prototypes were not well organized. Their tracks were arranged randomly, without a consistent ordering, neither they presented instrumental descriptions. This turned to be an additional issue when structuring data. In order to quickly overpass this issue, we decided to use MIDI files from Musescore[2], as it is a platform aimed at professional productions, providing MIDI files structured according to the musical score.

2.2.1. Visualizing the rhythm

Then, we remodeled the visual outputs, seeking to improve visualization and readability, communicate rhythm, avoid graphic pollution, and deliver a more intuitive and understandable graphic result. We selected some default values according to musical parameters and visual structures, as described in table 2.

By associating musical and visual parameters, in addition to valuing the rhythmic signature, we set default values to configure the graphic spaces and present communicable results. These customizable values were based on loyalty tests [8] with user ratings through musical analysis applying an online form to collect qualitative and quantitative data regarding the readability of the views, this step is detailed in section 4. Then, we defined the three types of graphs that would be generated by Mandrit: *Polar Bubble Chart, Polar Radar chart* and *Radial Column*.

[2]Musescore: https://musescore.com/sheetmusic

Musical Parameters	Visual Parameters	Generalizations
Amount of notes	Rotation and Translation Geometric shapes: Circles, Polygons and straight segments.	Variation data from matrix of each song
Tracks	Equidistant spacing	Smaller radius = 100; Larger radius = 300;
Temporal cycle and Granularity	Length of circumference	64; or 32; or 8;
Ordering of Notes	Ratio between bubbles; Positions' alignment	Smaller size = 1; Bigger size = 3;
Analysis Window	Reference variation of the measure	2 to 5;

Table 2: Music visualization parameters

The graphs were projected with its elements arranged in a polar area, with angular rotation depending on the subdivisions of the beat of each song. In addition, we applied a color pattern to the tracks, which role is to represent a given quantitative data, transmitting balance, composition, proportion and harmony to the views. The difference between Mandrit's graphics lies in the attribution of geometric shapes, specific to each one of them. The Polar Radar chart generates polygons, while the Radial Column chart draws straight radial lines and the Bubble chart uses circles of different sizes.

With the *Polar Radar Chart*, shown in figure 4, the graphic model is formed by irregular polygons that are traced by varying the amount of notes played at each beat of the musical sequence - and, consequently, according to the stored data of each song -, which are plotted through rotations, vertex connections and considering the time displacement of the measure. This generates the resulting figure, which, depending on the moment in the musical sequence, presents rhythmic accents in the visualization, allowing to easily spot which parts of the song have more onsets, for instance.

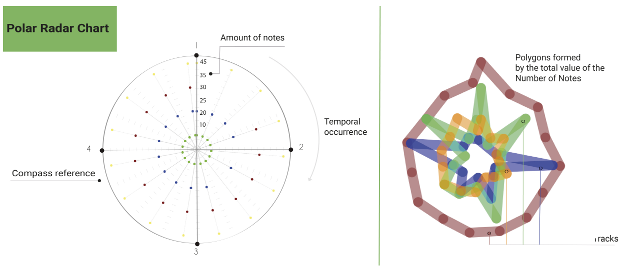

Figure 4: Polar Radar Chart

We emphasize that the polar and the cyclic projections prioritize the temporal aspect of the rhythm and, as a result, they are visualizations of the whole song, with its rhythmic signature. They split instruments hierarchically, based on the amount of onsets, and organize them in the polar orientation, through angular variations, rotating clockwise. According to the subdivision of the measure during the musical sequence, they demarcate the rhythm and refer to a clock, as a metaphor to the temporal aspect, having as reference the representation of rhythm by Toussaint[9].

Seeking to better understand the behavior of temporal data, we generated the *Radial Column* view, shown in figure 5. It allows to separately visualize the temporal sequences of the tracks, i.e., when onsets occur for each track, within the bars. The tempo leaves traces in the form of straight segments rotating from the center, directed like a polar axis, moving in angular rotations exploring the entire area determined by the cyclical visualization.

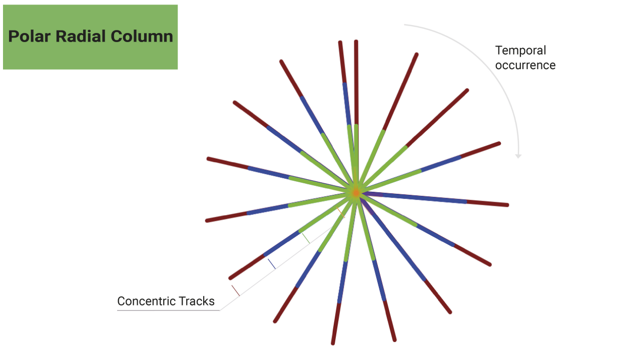

Figure 5: Radial Column Chart

This graph is a minimalist view of temporal data, as it remains grouped, and music intervals and silences become more visible. However, we miss the amount of notes, a crucial information for some analysis.

For this reason, we finally developed the *Polar Bubble Chart*, which groups the amount of onsets and their temporal occurrence in a single geometric shape, a circle. Its area demonstrates the variation in the amount of onsets, and its angular position is determined by the subdivisions of the bar and the length of the temporal sequence.

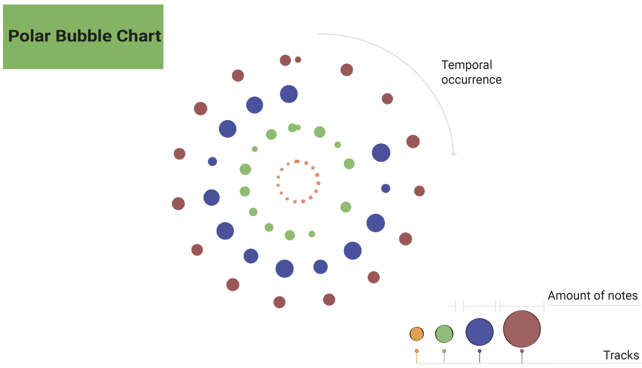

Figure 6: Polar Bubble Chart

The prototyping process led to the graphic models used by Mandrit, which can be customized by manipulating code, if necessary to improve visualization, depending on the volume of data in a given song. Figure 7 shows an example, in which we need to increase the radius of the track view to better occupy the graphic space.

Therefore, visual parameters can be set according to the musical parameters. It is possible to vary the size of the temporal cycle according to the granularity and the analysis window, allowing users to perceive the rhythmic information contained in the visualization, improving

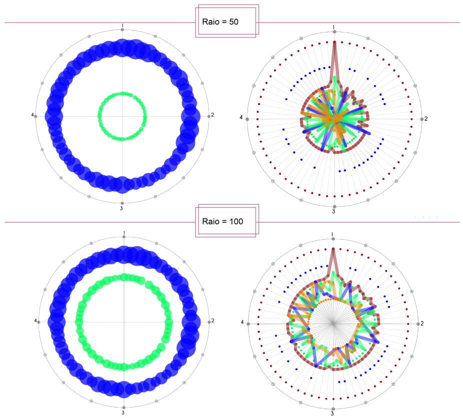

Figure 7: Visual parameters

Prägnanz [10] of the form, and increasing visual organization.

It is important to highlight that during the entire prototyping phase, in addition to the specifications of the graphic projection associated with the musical parameters, we also improved the interface, including subtitles and interactive aspects to enable the selection of the type of visualization, and allowing to hide tracks, in order to analyze them separately. And we have also developed an animated cursor which helps to follow the musical performance, as shown in figure 8.

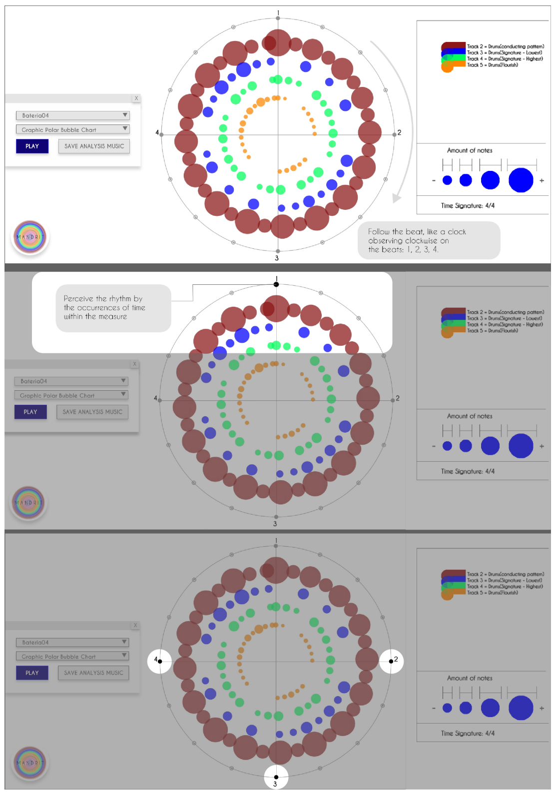

Figure 8: Mandrit tutorial

The cursor follows the rhythm metric according to the music being played and its associated data extracted by Mandrit. With these views, and being able to change to the three graphic models for the same song, it is possible to identify musical peculiarities in relation to rhythmic aspects as a function of tracks, bar subdivisions and the amounts of onsets. Thus, we carried out comparative musical analysis with rhythm visualizations to assess the system and its communicative usefulness.

3. Musical Analysis

Simultaneously to the prototyping process, we carried out musical analysis, collecting feedback from potential users and Music experts. These analyses helped us to understand how to visually communicate rhythm signatures. When performing several plots to visualize different songs, we used graphic images to make qualitative and quantitative musical analyses regarding visual, musical, and communicative perception of Mandrit's graphics.

The musical parameter of the analysis window is an example of these continuous improvements. It made visual reading and musical accompaniment of the regularity of each bar cycle easier. We simplified and generalized the subdivisions of the beat, with a musical language already established and closer to music professionals, by using timestamps based on the count of rhythm. For example, figure 9 shows songs in different measures - 2/4, 3/4, 4/4, and 5/4 -, with the references of the bar subdivisions plotted in gray lines.

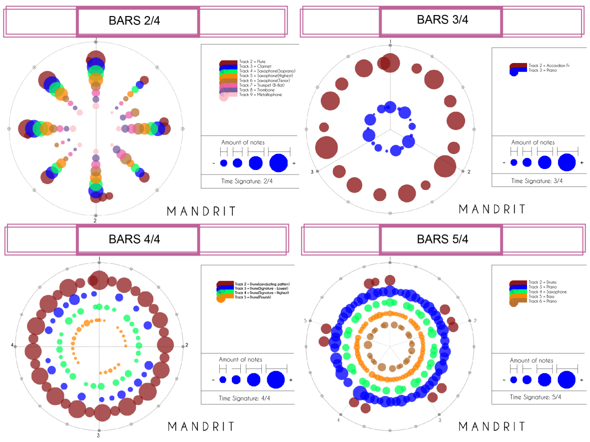

Figure 9: bars

In these plotted songs, we reference their measures by the divisions equivalent to their metrics. For instance, we plotted the song "Asa Branca, by Luiz Gonzaga", in 2/4, by dividing the circumference into 2 beats (180 degrees apart from each other). As well as "João e Maria, by Chico Buarque", in 3/4, and its 3 beats (120 degrees apart) with a production of only two instruments. For a 4/4 example, we plotted a custom file, produced for test purposes, named "Bateria 04" (each beat, 90 degrees apart). And finally a more complex analysis, with the song "Take five, by Dave Brubeck", in 5/4, with 5 beats (72 degrees apart). Thus, the graphic customization varies according to the measure signature of each song loaded.

Mandrit allows performing comparative and discursive analyses over songs with the same time signature, but having peculiarities, according to their musical genres and visualizations. It also complements the analytical process, aiding it with a visual perspective, and helping to understand rhythmic complexities. For instance, figure 10 shows graphic results of four songs from different musical genres.

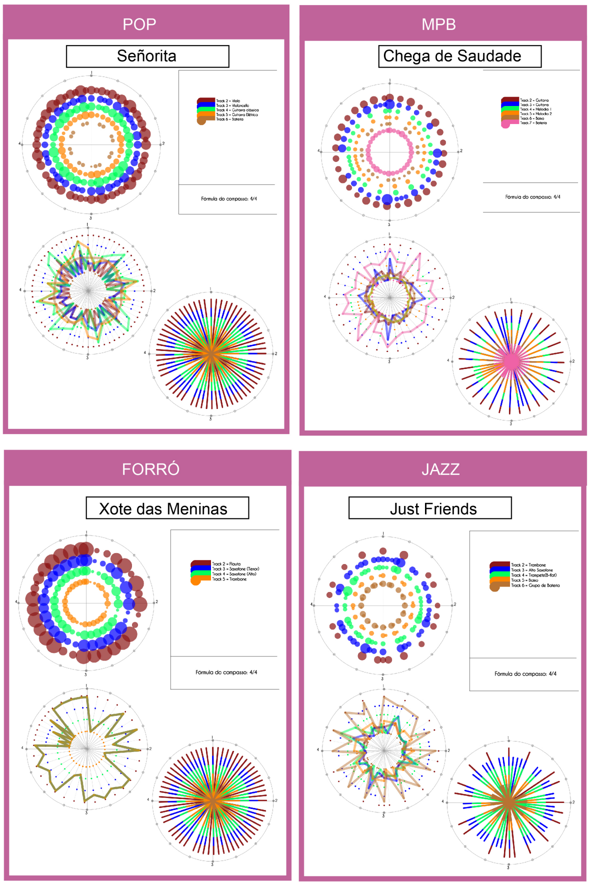

Figure 10: Musical genres

The musical visualizations generated by Mandrit also made it possible to identify macro-structural characteristics of rhythm in Brazilian music, as shown in the graphic results of figure 11. All songs are in 2/4, but their representative signatures can generate different qualitative and interpretive impressions. They show various heterogeneous or homogeneous visual variations, corresponding to their rhythms, instrumental aspects, temporal synchronization, and sequential repetitions performed in the songs, each with its originality.

The song "Aquarelas do Brasil", by Ary Barroso, one of the most recorded songs in Brazil, considered MPB classics, has a cyclic symmetrical signature along the musical performance, meaning that it has a proportion and balance in the variation of the amounts of onsets. This is demarcated in the quadrants of the polar area, enriched by several notes throughout the temporal cycle, and also by the greater presence of values at certain times represented by the circles shown in larger dimensions. Similar to the second song, "Rosa Amarela", by Villas Lobos, both structured around the theme of popular music, they emphasize culture and customs, and regarding visualization, they ex-

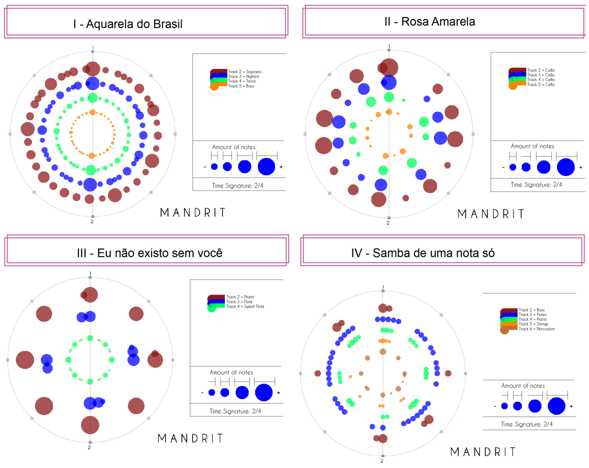

Figure 11: 2/4 Song Analysis

plore the graphic area filled with musical information.

In the case of the second song, we used a file with the complete arrangement, with all the Cello tracks. This raised questions about how to analyze songs more accurately, for instance, in productions with instruments with the same timbre. As the visualization demonstrates, the instruments perform the same rhythm, but micro variations are perceived, considering that the different tracks are equivalent to the expressiveness of each musician. Thus, in this visualization, we notice factors such as synchrony and a remarkable search for the resemblance musical aesthetic, familiar to a symphony or concert, in addition to the fact that the instrumental execution of the cello provides the tempo and enriches the musical dynamic. In the third and fourth songs - ”Eu não existo sem você” and ”Samba de uma nota só”, by Tom Jobim, compositions by the same artist that have a focus on words and melody, both with the same metric, 2/4, we observe a clean visualization in keeping with its simple beat rhythm.

4. Results and Discussion

In this section, we show quantitative data related to the results of musical analysis performed against Mandrit visualizations. We interviewed 17 potential users, who filled an online evaluation form. The form included a textual presentation of Mandrit application, tutorials, videos, and graphic models, as well as visualization of 10 songs: ”Baião and Xote das Meninas” (Luiz Gonzaga), ”Maracatu Atômico” (CSNZ), ”Girl from Ipanema” (Tom Jobim), ”Frevo Mulher” (Zé Ramalho), ”Take Five” (Dave Brubeck), ”Yesterday” (The Beatles), ”Machine Gun” (Jimi Hendrix), ”Just Friends” (John Klenner), and ”Señorita” (Shawn Mendes and Camila Cabello).

We carried out an assessment of Findability [11] of musical information associated with the visual structures of the graphics, questioning the participants impressions about these aspects and their cognitive perceptions while reading the graphic visualizations. Through this, we gathered quantitative-qualitative data concerning the advantages and disadvantages of visualizations for rhythm analysis, and suggestions and feedback regarding continued improvements of Mandrit system.

As shown in figure 12, 58.8% of the public (10 participants out of 17) perceive and identified the ”occurrences of notes” and ”metrics”. Only 3 (17.0%) participants recognized the time signature by the views and 4 (23.0%) were able to perceive accents, metrics, duration of silences, and the time signature itself. Two other participants were able to perceive the sequences and the notes played in syncopation and only one of them was able to understand all the musical information in the visualization.

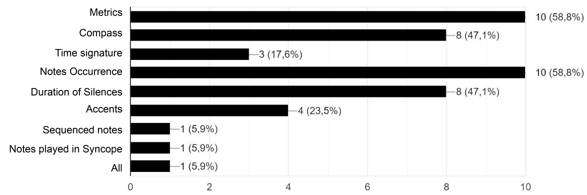

Figure 12: Music Information Findability

There is a notable difficulty for participants to understand musical properties in the first contact with Mandrit visualizations. However, after some time they develop the ability to grasp the visualization and understand its musical aspects, and keep track of rhythm in the musical performances. In general, participants considered a complex exercise to understand the rhythm in static views, due to the amount of information in the graphic area, making it difficult to read and follow the rhythm. Figure 13 shows a comparative evaluation between the three graphs generated by Mandrit: Polar Bubble Chart (Graph A), Polar Radar Chart (B) and Radial Column (C).

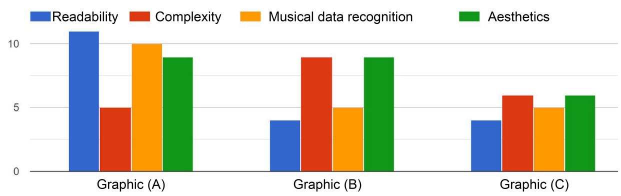

Figure 13: Comparative Evaluation

The Polar Bubble Chart (A) was considered legible, not very complex, having good aesthetics and allowing to recognize musical information. The Polar Radar Chart (B) has lower readability, being more complex to analyze and consequently more difficult to recognize musical information, despite its high aesthetics valuation. Finally, the Radial Column (C) was rated as having lower relevance as a whole. One of the participants reported that its cyclical bar chart becomes very confusing, lowering readability. Despite its aesthetics having been valued by some of the participants for its visual cleanliness, they considered it a little complex and could not recognize musical information well.

When asked which of the three views generated by Mandrit were more communicative/informative, 58.8% of the participants selected the Polar Bubble Chart (A), as shown in figure 14, arguing that association between the graphic and musical information was better.

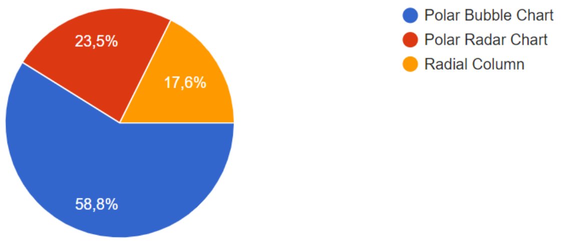

Figure 14: Mandrit Charts Evaluation

However, 23.5% of them chose the Polar Radar Chart (B) for its aesthetic that demonstrates the musical aspects in polygonal format. Even considering its chaotic complexity, they claimed that songs have a lot of information that matches the chart. And 17.6% of participants considered Radial Column (C) as more communicative and informative, according to the data collected.

During the case study for the development of Mandrit, we noticed several barriers in this area of Musical Computer Visualization, which is still maturing. These include the representational challenge of transforming musical data to make them visually communicable, accessing musical files and structured and organized information about Brazilian musical works, as well as the need for new databases to enrich the study of rhythm through digital technology.

In this same context, we consider that multidisciplinary teams as crucial to contribute to the growth and development of research in Musical Computer Visualization. The area brings together and attract artists and music professionals to explore computational capabilities and use technology as a facilitating means to support the development of tools. These tools allow to assist in the experimentation and creation of communicative processes of musical content and expand collaborative discussions between different areas.

However, we also observed that one of the greatest difficulties in this field is connecting and finding bridges with professionals in Music, due to communication bottlenecks, which generate technical dependencies.

5. Final Considerations

During this case study, we obtained data stimulating the continuity of our research in Computational Music Visualization due to the need to develop animated and interactive systems to further assist the visual communication of musical information.

Therefore, for future work, we intend to improve technical applications for automating instrumental sets that are the basis of musical arrangements and composition, and mapping individual tracks to have a greater detail of micro variations in the information of each instrument. Also, we intend to work on treatment of musical content aided by visualizations for the recognition of patterns, similarities, and instrumental correspondences, highlighting through the graphic forms and visual structures juxtapositions, correspondences, singularities, and complexities. In addition, we aim to help in musical transcription for creating visualizations, such as animations and further studies of musical dynamics.

Seeking to expand access to musical information, we have made available in the Mandrit repository a reading base with references for researchers and future explanations in the area of MuVis. This way, we contribute to academic documentation for the construction of Computational Music Visualizations, with tutorials, database and rhythm visualizations developed in this project.

References

[1] Hugo Carlos Cavalcanti. *Da partitura Musical: Um olhar estético a preservação da memória*. Master Dissertation, Center for Arts and Communication, Postgraduate Program in Information Science, Federal University of Pernambuco, Recife, 2013.

[2] Delfina Malandrino, Donato Pirozzi, and Rocco Zaccagnino. Visualization and music harmony: Design, implementation, and evaluation. In *2018 22nd International Conference Information Visualisation (IV)*, pages 498–503, Fisciano, Italy, July 2018. IEEE.

[3] Ulrich Michels. *Atlas de Musica, 1*, volume 1. Alianza Atlas, Madrid, 1987.

[4] Ethan Hein. *Designing the Drum Loop: A constructivist iOS rhythm tutorial system for beginners*. PhD thesis, Steinhardt School of Culture, Education, and Human Development, New York University, 2013.

[5] Giordano Cabral and Robert Willey. Analyzing Harmonic Progressions with HarmIn: the Music of Antônio Carlos Jobim. page 12, 2007.

[6] Julian Scordato. Composing with Iannix. In *Proceedings of the Fifth Conference on Computation, Communication, Aesthetics and X.*, volume V, page 389, Lisboa, Portugal, 2017.

[7] Tim Brown. IDEO: Design Thinking, 2018.

[8] Maurício Vianna, Ysmar Vianna, Isabel K Adler, Brenda Lucena, and Beatriz Russo. *Design Thinking : Inovação em Negócios*. [recurso eletrônico]. MJV Press, Rio de Janeiro, 2012.

[9] Godfried T Toussaint. *The Geometry of Musical Rhythm: What Makes a "Good" Rhythm Good?* CRC Press, 2013.

[10] João Gomes Filho. *Gestalt do Objeto: Sistema Visual de Leitura da Forma*. Escrituras, São Paulo, 8 edition, 2008.

[11] Fernando Luiz Vechiato and Alessandra Stefane Cândido Elias da Trindade. Encontrabilidade da informação em ambientes informacionais: diálogo teórico entre os conceitos Intencionalidade e affordance. *Prisma.com*, (42):3–20, 2020.