Mandrit: A system for visualization and analysis of rhythm

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Abstract. *Faced with the representational challenge of communicating musical information visually, we developed Mandrit: a system for automatically generating musical visualizations for rhythm analysis. It plots graphs for different musical works representing their properties with rhythmic signatures of data extracted from digital MIDI files. As a result we have parameterized and presented new ways to visualize the pace by its metrics. With this article, we encourage the discussion and need for the development of tools to generate musical visualizations, as a means to help musicians and scholars in the processes of musical analysis, teaching, creation of compositions and complementing musical performances.*

1. Introduction

Humans are visual. Thus, it is inherent that the communication of a message is done quickly if it is represented visually. Faced with the diverse representational challenges of Music, art rich in abstract and complex information that has a subjective character. It is in this sense that there is a continuous need for analytical studies in the area of Musicology, as this information has been communicated since ancient times. Thus, the relation of its representational aspect is associated with "an aesthetic dimension of information, memory, cognition, sensitivity, and knowledge of the musical work" [1].

We have as a theoretical basis, Computational Music Visualization an interdisciplinary area, also called *MuVis* that has a growing community that holds its 1st MuVis Symposium in 2018 [2], and for its wide applicability brings together studies from various areas such as Information Visualization, Musicology, MIR, Education, and Design. Consisting of the contribution, documentation, and sharing of researchers with their practical studies, aimed at the development of tools, algorithms, techniques, and methods. Its object of study is musical information and the creation of musical visualizations applied in different contexts, whether for visual communication of musical concepts [3], to assist in the performance and teaching-learning process of music [4], musical analysis [5], or even in the creation of composition or artistic performance.

In this work, we emphasize the study of the rhythmic element as information to be communicated visually. Knowing the potential of software resources - for processing, processing, and manipulating data from digital files -, we developed the Mandrit system: A musical visualization generator, which plots graphics to communicate and demonstrate information about the rhythm of a musical work.

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2. Generation of Music Visualizations

For the development of Mandrit, we carried out a case study applying the Design Thinking (DT) approach, formulated and expanded by IDEO [6], which helped us to explore the process of generating personalized views through a process structured by the steps of problematization, ideation, prototyping, and evaluation.

With this, we immersed ourselves in the complex problem of visually communicating musical information. And through qualitative-quantitative research, centered on the user, we carried out data and feedback collections, with focus groups and individual sessions. We talked with experts and experimenters in the areas of Music and Information Visualization, and collaboratively generated paper visualizations as demonstrated by the set of sketches in the figure 1, where we verified the graphic possibilities and the challenges of visually representing and communicating musical information.

Figure 1: Drawing music information

After a series of workshops and tutorials, seeking to explore the process of creating and transposing the visual communication of musical information. We noticed a concern of the participants to represent the functionality of the musical instruments of the musical work they sought to draw, referencing terms such as the demarcation of time, intensity, silences, pauses, tempo and also using graphic forms and colors to facilitate the recognition of musical events associated with the visualizations.

With paper prototyping, we obtained a targeting of representative possibilities of the musical content, from the user's point of view and with the demands of their most recurrent needs, referring to the focus of this article: the analysis of the rhythmic element and the generation of visualizations that communicate their musical signature.

2.1. Mandrit Computational Prototyping

Computational prototyping allows us to use technologies and software resources to develop visualizations with the exploration of data from digital music files. In addition to making it possible to design systems through prototypes, performing simulations and validations with users in parallel, which can directly contribute to verifying and directing the feasibility of the project and the use of a certain technology. To develop musical computational visualizations, we defined a structured prototyping process divided into the three steps shown in the flowchart of figure 2

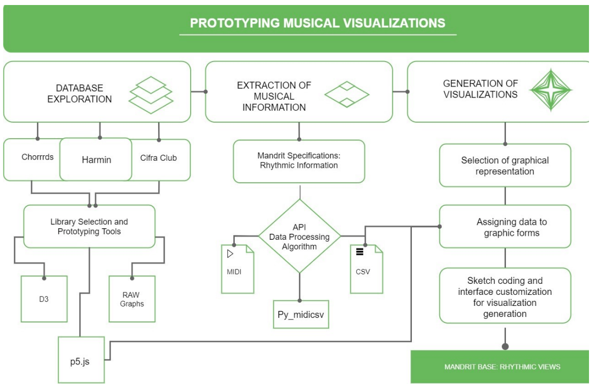

Figure 2: Prototyping Process

The first "Database Exploration" is to do a similar search where we check existing tools and filter methods already used to develop musical visualizations. The second step is the extraction "Rhythmic information extraction" and the "Generation of visualizations". It is in these last two that we have developed the Mandrit[1], so named because it makes reference to "rhythm mandalas", which through the attribution of rhythmic information to the graphic forms and by computational manipulations generates three types of graphic models to communicate rhythm. With its development we were able to carry out tests more focused on the automation process and on the generation of a visualization, with the creation of algorithms we structured a configurable graphic space to plot the chosen representations according to data extracted from songs through their MIDI files.

2.1.1. Extracting rhythmic data from MIDI

Rhythm information is stored in a digital MIDI file as metadata, meaning we need to perform specifications to extract it. As we seek to develop a visual signature of the rhythm, we initially determine which properties of the rhythm element to assign the visualization to be plotted, the type of instrument that performs the musical performance, the data of the bar subdivision, and number of notes with their respective values. To capture this information, we developed a rhythmic extraction algorithm for MIDI files, and we transform, organize and store this data in variables in a structured way in a spreadsheet format, as shown in the table 1, a snippet of some data of the song "Bateria04" that we produced to develop the algorithm for extracting and structured processing of rhythm data.

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: Rhythmic data extracted

Where *X* is equivalent to the track of the instrument played, *Y* the subdivision of the measure, and *Total notes* the accumulation of notes corresponding to that determined tempo. In other words, in this exemplary song, we demonstrate the sequence of track 2 with its respective values of time and number of notes.

With this, we set up the Mandrit database, which has a collection of more than 60 music files already structured in CSV format and completely processed according to their rhythmic information. Thus, in order to carry out the transposition of this information and make it visually communicable with rhythm signatures, we use the information from each musical work as input. Moving on to the visualization generation stage, we applied a cyclical validation process and selected some sketches developed with paper prototyping to transform them into graphic models.

2.2. Generating Mandrit graphics

To generate graphically communicable, automated, generalized visualizations applicable to different music, we attribute elementary rhythm information to visual structures and graphic forms.

For this, we carry out practical experiments with the aid of software resources, that is, we use computational functions of order, rotation, and translation to arrange the musical parameters in a configurable area with graphical representations - whether they are: points, lines, circles, polygons, colors, and by sizing and manipulating each visual property to associate the data in the spreadsheets, in each row and column bringing the properties of the track collection, bar subdivision and total notes of each song to be plotted from the Mandrit database.

By a research choice, the views generated by Mandrit are static and two-dimensional, with the geometric figures and orientations associated with aspects of the metrics of the compass. In the first experiments, as shown in figure 3, we observed with the result of manipulations

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

and graphical plots the challenges of visually processing the large volume of data in a temporal sequence.

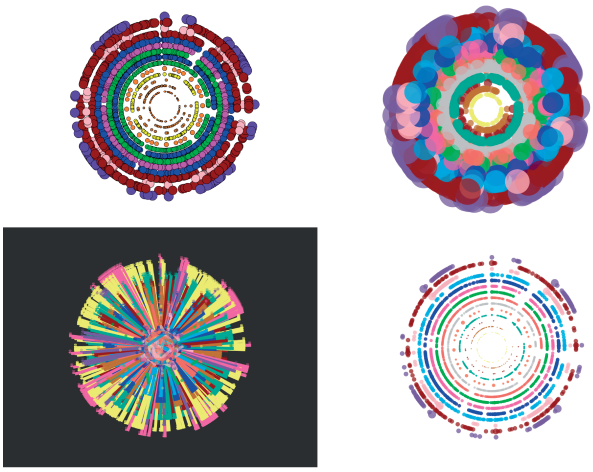

Figure 3: Starting Experiments

Furthermore, we noticed that the MIDI files used in these prototypes made it difficult to structure the data due to the disorganization of the MIDI file produced, such as arranging tracks randomly without any ordering or instrumental description. Therefore, we started to use Musescore[2] as our source for downloading the files, as it is a platform aimed at professional productions structured according to the musical score.

2.2.1. Visualizing the rhythm

After modeling and remodeling the visual processing, seeking to improve visualization and communicate the rhythm, avoiding graphic pollution, to obtain clarity in reading and a more intuitive and understandable graphic result.We selected some default values according to musical parameters and visual structures, as described in table 2.

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	Spacings equidistant	Smaller radius = 100; Larger radius = 300;
Temporal cycle and Granularity	Length of circumference	64; ou 32; ou 8;
Ordering of Notes	Ratio between bubbles; Alignment of positions	Smaller size = 1; Bigger size = 3;
Analysis Window	Reference Variation of the measure	2 to 5;

Table 2: Parameters Music Visualizations

With the association of musical and visual parameters, in addition to valuing the rhythmic signature, we obtained generalizable values to configure the graphic spaces and present communicable results. The parameterized values are based on loyalty tests and user evaluations regarding the reading of visualizations. Thus, we define the three types of graphs generated by Mandrit. They are: *Polar Bubble Chart, Polar Radar chart* and *Radial Column*.

They are projected graphics, by elements arranged in a polar area, that is, with angular rotation depending on the subdivision of the beat of the music. In addition to applying a pattern with a range of colors to the tracks, whose role is to be a representative entity of a given quantitative data, transmitting balance, composition, proportion and harmony to the views. However, the graphic differences of Mandrit views are related to the modification of their geometric shapes.

With the *Polar Radar Chart*, shown in figure 4, your graphic model is formed by irregular polygons that are traced by varying the amount of notes according to the values of the musical sequence. And consequently, according to the stored data of each song, which are plotted through rotations, vertex connections and with the time displacement of the measure, generating the resulting figure, which depending on the moment in the musical sequence presents rhythmic accents in the visualization, helping the check whether the occurrence of the notes is long or short.

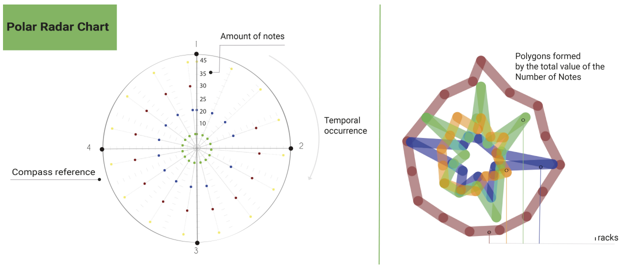

Figure 4: Polar Radar Chart

We emphasize that when we use the polar and cyclic projection, we prioritize the temporal aspect of the rhythm and as a result we have a complete visualization of all the music with its rhythmic signature. With a hierarchy of instruments with a greater amount of notes and an organization in the polar orientation, that is, with angular variations about a center, with clockwise rotations. According to the subdivision of the measure during the musical sequence, demarcating the rhythm and referring to a clock and a metaphor to the temporal aspect, besides having as reference the representation of the rhythm of [7].

Seeking to better understand the behavior of temporal data, we generate the *Radial Column* view of the figure 5. Allowing us to visualize only the temporal sequences about the tracks, that is, the time 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.

With it, it was possible to bring a visual cleaning of the temporal data, as the data remained grouped, their intervals and silences being more visible. However, in it we miss the crucial information which is the amount of notes.

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

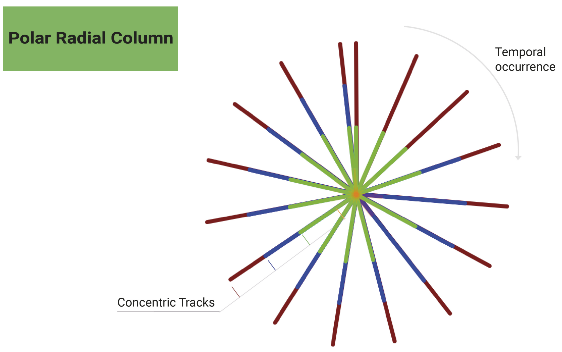

Figure 5: Radial Collumn

That's why we finally developed the *Polar Bubble Chart*, which groups the data on the amount of notes and the occurrence of time in just one geometric shape, which is the circle. Where its volume demonstrates the variation in the quantity of notes, and its angular position is determined and graphically recorded by subdivision of the bar according to the length of the temporal sequence, all this varies depending on the music and the data matrix of the Mandrit base spreadsheet.

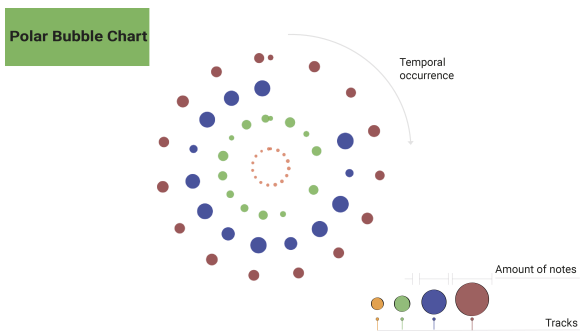

Figure 6: Polar Bubble Chart

The process of graphic projection of musical information allowed to generate customizable graphic models for Mandrit, which can be manipulated and changed via code as shown in the figure 7, if necessary to improve the visualization depending on the data volume of a given song.

In this example, we need to increase the ratio of the central radius of the track view to better occupy the graphic space. Therefore, visual parameters can be given by inputs, according to the musical parameters, and vary the size of the temporal cycle according to the granularity and analysis window, allowing users to relate the rhythmic information contained in the visualization, improving the pregnancy of the form, and apply visual organization.

It is important to highlight that during the entire prototyping process, in addition to the specifications of the graphic projection associated with the musical parameters, we also implemented improvements in the interface, including subtitles and interactive aspects to enable the selection of the type of visualization, and even allowing to hide tracks to analyze separately. And we have also devel-

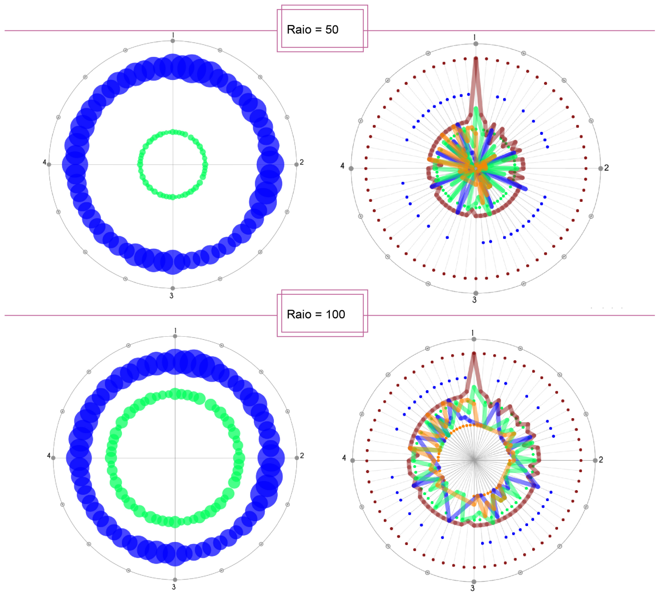

Figure 7: Visual Parameters

oped an animated cursor that helps to follow the musical performance, as shown in the figure 8.

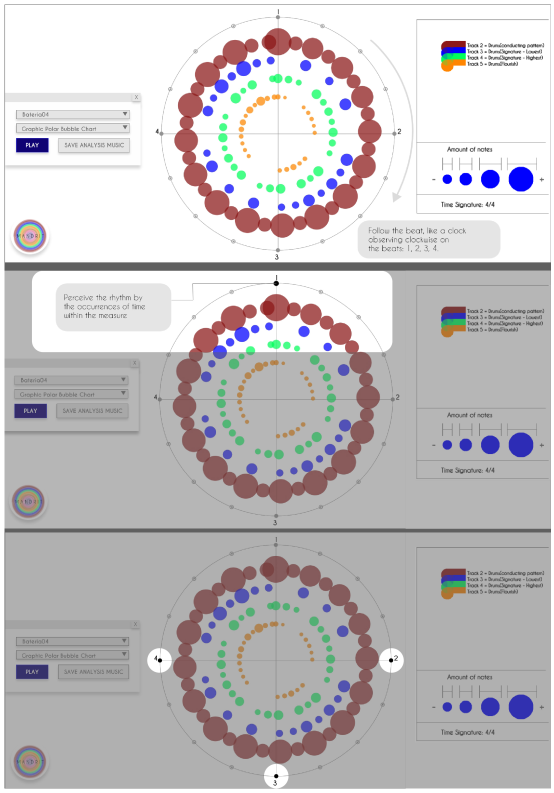

Figure 8: Tutorial Mandrit

The cursor moves according to the rhythm metric according to the sound file of the music played and associated with the data extracted by the Mandrit database. With these views, and being able to change to the three graphic models for the same song, it is possible to identify and perceive musical individualities in relation to rhythmic aspects as a function of tracks, bar subdivisions and the quantities of notes. Thus, we started to carry out comparative musical analyzes with rhythm visualizations to assess the system and its communicative usefulness.

3. Musical Analysis

Parallel to the prototyping process, we carry out musical analysis, collecting feedbacks reported by potential users and Music experts. Which helped in visually communicating rhythm signatures. When performing several plots to visualize different songs, we use graphic images to make qualitative and quantitative musical analyzes regarding the visual, musical, and communicative perception of Mandrit's graphics.

As an example of these continuous improvements, we have the musical parameter of the analysis window, which made it easier for visual reading and the musical accompaniment of the regularity of each bar cycle. Simplifying and generalizing the subdivisions of the beat, with a musical language already established and closer to music professionals, using timestamps based on the 1,2,3,4 count of the rhythm. For example, as shown in the figure 9 with songs in different measures 2/4, 3/4, 4/4, and 5/4, having the references of the bar subdivision in the gray lines of the visualization.

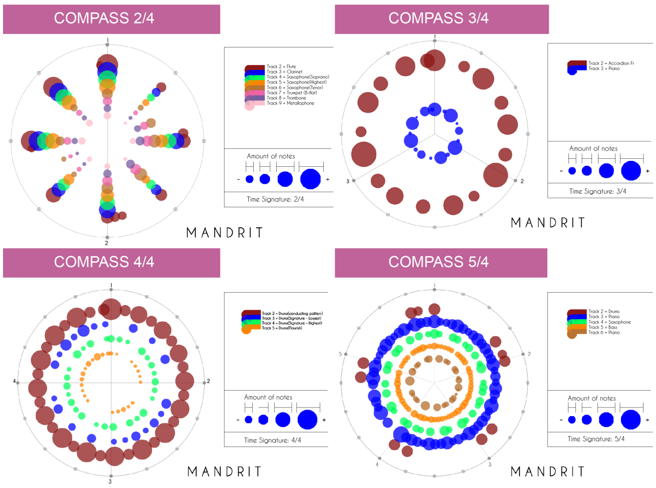

Figure 9: Compass

With this we facilitate comparative and discursive analysis of songs with the same beat, to understand complexities through visualizations. As an example, in the figure 10 where we seek to analyze the graphic results in four songs from different musical genres.

In these plotted songs we reference their measures, by the divisions equivalent to their metrics. And we demonstrate the song "Asa Branca-Luiz Gonzaga" in bar 2/4 by dividing the circumference into 2 beats. As well as "João e Maria - Chico Buarque" in 3/4 and its 3 beats with a production of only two instruments. We also used a file produced by a collaborator, in the song "Bateria 04" with 4/4 time signature and its 4 beats. And finally a more complex analysis, with the song "Take five - Dave Brubeck" 5/4 in 5 beats. Thus, the graphic customization varies according to the beat of each song loaded.

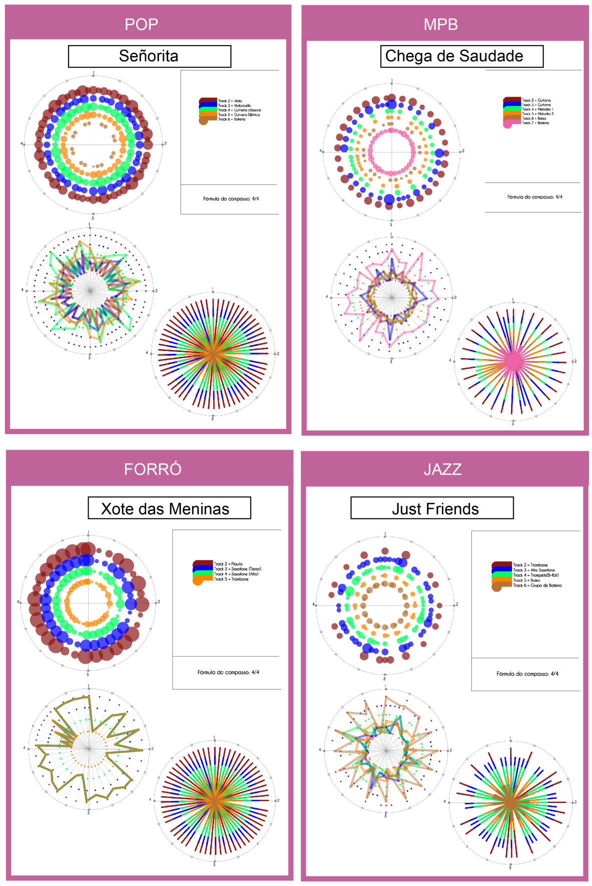

Figure 10: Musical genres

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

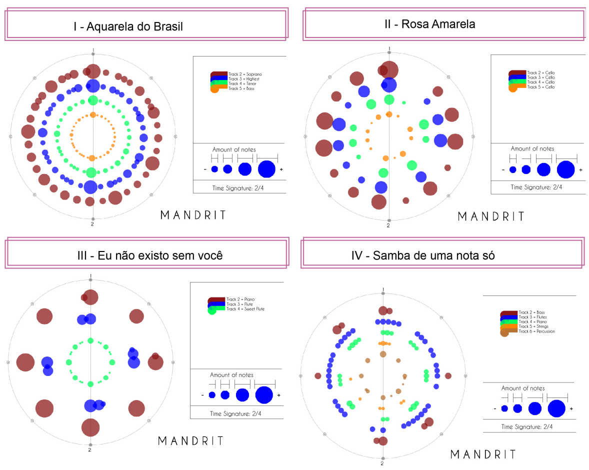

Figure 11: 2/4 Song Analysis

The song "Aquarelas do Brasil- Ary Barroso", one of the most recorded songs in Brazil, considered MPB classics, has a cyclic symmetrical signature about the musical performance, that is, it has a proportion and balance in the variation of the amounts of notes. 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 song II ”Rosa Amarela” by Villas Lobos, both structured around the theme of popular music, they emphasize culture and customs and about visualization, they explore the graphic area filled with musical information.

In the case of song II, we found its arrangement with all the Cello tracks, which brought us provocations about how to analyze songs more precisely, productions with instruments with the same timbre, because, 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 factor of the instrumental execution of the cello that provides the tempo and enriches the musical dynamic. In the songs (III) ”Eu não existo sem você” by Tom Jobim and (IV) we observe in the same metric 2/4 of the respective works, simplified visualizations with a clean visualization in keeping with its simple beat rhythm.

4. Discussion Results

Finally, we bring the quantitative data referring to the graphic results of the musical analysis of the Mandrit visualizations. Where 17 interviewees and potential users filled out the last evaluation form available online, with the presentation of the Mandrit application through text descriptions, tutorials, videos, and graphic models, views of 10 songs: Baião and Xote das Meninas - Luiz Gonzaga, Maracatu Atómico -, Girl from Ipanema - Antônio Carlos Jobim, Frevo Mulher - Zé Ramalho, Xote das Meninas - Take Five - Dave Brubeck, Yesterday - The Beatles, Machine Gun - Jimi Hendrix, Just Friends - John Klenner, Senorita - Shawn Mendes and Camila Cabello.

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

As shown in the graphic in the figure 12 58.8% of the public equivalent to 10 people perceive and identify the ”occurrences of notes” and ”metrics”. Only 3 (17.%) participants recognized the time signature by the views and 4 (23.%) were able to perceive accents, metrics, duration of silences, and the time signature itself. Two other interviewees are able to perceive the sequences and the notes played in syncopation and only one of them is able to understand all the musical information in the visualization.

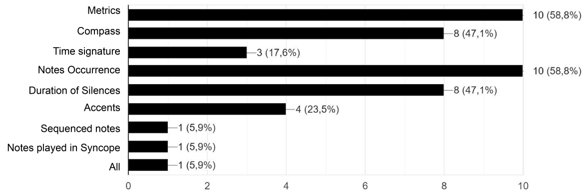

Figure 12: Findability Music Information

What we conclude from these data is that there is a notable difficulty for participants to perceive the properties in the first contacts with visualization, after a mental exercise of reading the visual properties associated with musical information they develop the ability to grasp the visualization and understand aspects of the visualization. rhythm accompanying the musical performance. But in general, they consider it a complex exercise to understand the rhythm in static views, because there is a lot of information in the graphic area and it is difficult to read and follow the rhythm. With a comparative evaluation in the figure 13 between the graphs generated by Mandrit: Polar Bubble Chart (Graph A), Polar Radar Chart (B) and Radial Collumn (C).

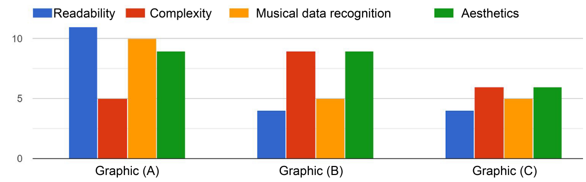

Figure 13: Comparative Evaluation

In summary (A), it is considered legible, not very complex and with good aesthetics and it is possible to recognize its musical data. In (B) its readability is little considered, so it is also more complex to analyze and consequently difficult to recognize some musical data, despite this its aesthetics is valued by most. However (C) has a rating with low relevance as a whole, one of the participant's reports that the cyclical bar chart becomes very confusing. So it is not considered legible, despite the aesthetics having been valued by some of the interviewees for its visual cleanliness and they consider it a little complex, but they do not recognize the musical data well.

When asked which of the three views generated by Mandrit are more communicative/informative, 58.8% of the participants selected the Polar Bubble chart, as shown in the figure 14 because they considered that it is possible to associate the musical information with the visual.

However, 23.5% of them also considered the Polar Radar Chart for its aesthetic that demonstrates the musical aspects in polygon format, even considering its chaotic

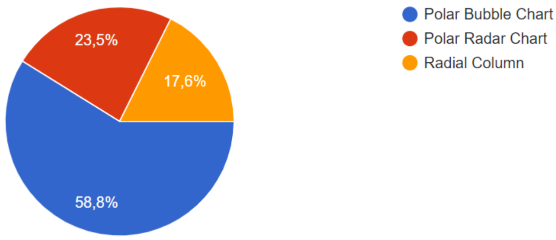

Figure 14: Mandrit Charts Evaluation

complexity, they claim that songs have a lot of information that matches the chart. And 17.6% of participants considered Radial Column as more communicative and informative according to the data collected.

During the development of the case study for the development of Mandrit, we noticed several barriers in this area, which is still maturing, which is the Musical Computer Visualization. Whether because of the representational challenge of transforming musical data to make them visually communicable, accessing musical files, and structured and organized information about Brazilian musical works. The need for database creations to enrich the study of rhythm through technologies.

In this same context, we consider crucial the formation of multidisciplinary teams, to contribute together to the growth and development of research that 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 that 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 the greatest difficulty in this interdisciplinary area is connecting and finding bridges with professionals in the area of Music, due to communication bottlenecks, which generate technical dependencies.

5. Final considerations

During this case study, we obtained as result discussions and qualitative data that stimulated the continuity of research in the area of 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 suggest directions in technical applications for automating instrumental sets that are the basis of musical arrangements, composition creations, mapping individual tracks to have a greater detail of micro variations of the information of each instrument. 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 to 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. Besides contributing to the documentation of the Computational Music Visualizations construction process, with tutorials, the database, and the rhythm visualizations developed with this project.

Acknowledgement

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