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# A Hybrid Symbolic–Acoustic Approach to Choro Analysis: Computational Modeling and Cross-Domain Integration in the Works of Garoto

## Uma abordagem híbrida simbólico–acústica para a análise de Choro: modelagem computacional e integração entre domínios na obra de Garoto

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**Abstract:** This article proposes a hybrid symbolic–acoustic computational framework for the analysis of Brazilian choro repertoire, integrating methods from computational musicology and musicological interpretation. The study focuses on works by Aníbal Augusto Sardinha (Garoto), a central figure in the development of Brazilian instrumental music, combining symbolic feature extraction from digitized scores using the Python library *music21* with acoustic descriptors derived from historical recordings through *librosa*. The symbolic corpus is based on the *Songbook Choros de Garoto* (SESC/IMS), while the acoustic corpus consists of selected historical recordings performed by the composer. Extracted features — including tonal organization, harmonic progressions, melodic patterns, MFCCs, tempo estimation, and energy curves — are integrated into a unified analytical structure using *pandas*, enabling cross-domain comparison between compositional and performative dimensions. The application of the model to the piece *Jorge do Fusa* reveals correspondences between formal structure,

harmonic mobility, timbral behavior, and dynamic shaping, suggesting a close interaction between compositional design and expressive performance practices. The study argues that computational descriptors gain analytical relevance when interpreted within musicological frameworks, contributing both to methodological discussions in computational musicology and to the analytical understanding of Brazilian popular music. The proposed framework offers a replicable approach for future stylistic investigations of choro and other repertoires that combine written and oral traditions.

**Keywords:** computational musicology; Music Information Retrieval; choro; Garoto; symbolic analysis; acoustic analysis; Python.

**Resumo:** Este artigo propõe um modelo computacional híbrido simbólico–acústico para a análise do repertório do choro, integrando métodos da musicologia computacional e interpretação musicológica. O estudo centra-se na obra de Aníbal Augusto Sardinha (Garoto), figura central no desenvolvimento da música instrumental brasileira, combinando extração de características simbólicas a partir de partituras digitalizadas por meio da biblioteca *music21* e descritores acústicos obtidos de gravações históricas com o uso da biblioteca *librosa*. O corpus simbólico baseia-se no *Songbook Choros de Garoto* (SESC/IMS), enquanto o corpus acústico é composto por gravações históricas selecionadas e interpretadas pelo próprio compositor. Os dados extraídos — incluindo organização tonal, progressões harmônicas, padrões melódicos, MFCCs, estimativa de andamento e curvas de energia — são integrados em uma estrutura analítica unificada com o uso de *pandas*, permitindo comparações entre dimensões composicionais e performáticas. A aplicação do modelo à peça *Jorge do Fusa* evidencia correspondências entre estrutura formal, mobilidade harmônica, comportamento tímbrico e modelagem dinâmica, sugerindo forte interação entre projeto composicional e práticas expressivas de performance. O estudo argumenta que descritores computacionais ganham

relevância analítica quando interpretados à luz de referenciais musicológicos, contribuindo tanto para discussões metodológicas em musicologia computacional quanto para a compreensão analítica da música popular brasileira. O modelo proposto oferece uma abordagem replicável para futuras investigações estilísticas do choro e de outros repertórios que articulam tradições escritas e orais.

**Palavras-chave:** musicologia computacional; recuperação de informação musical; choro; Garoto; análise simbólica; análise acústica; música popular brasileira.

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# 1. Introduction

In recent decades, advances in computational methods for music analysis have significantly transformed research practices in musicology, consolidating an interdisciplinary field that integrates music theory, data science, and signal processing (Müller, 2015; McFee et al., 2015). Within this context, Computational Musicology and Music Information Retrieval (MIR) have developed robust techniques for extracting, modeling, and interpreting musical features from symbolic representations and audio recordings, enabling large-scale analytical approaches that complement traditional musicological methodologies (Müller et al., 2019).

Libraries and frameworks such as music21 (Cuthbert & Ariza, 2010), designed for symbolic music processing, and librosa (McFee et al., 2015), widely used for audio feature extraction, have become standard tools in contemporary computational music research. These tools enable the automated investigation of harmonic progressions, melodic patterns, formal structures, timbral characteristics, and expressive performance parameters, opening new possibilities for integrating compositional and performative dimensions in musical analysis.

Despite these developments, the application of computational approaches to Brazilian popular music repertoires remains relatively limited compared to studies of Western classical or mainstream popular music corpora. Recent works have begun to explore harmonic and formal aspects of Brazilian genres such as choro using corpus-based methods, highlighting the potential of computational frameworks to reveal stylistic patterns and structural regularities (Moss, Souza & Rohrmeier, 2020; Almada, 2023). However, integrated approaches combining symbolic and acoustic analysis remain rare, especially in studies focused on historically significant Brazilian instrumental composers.

Within this scenario, the oeuvre of Aníbal Augusto Sardinha (Garoto) constitutes a particularly relevant case study. Widely recognized as a pivotal figure in the development of Brazilian instrumental music, Garoto's compositions are characterized by harmonic sophistication, melodic inventiveness, and formal flexibility that bridge popular and erudite traditions. For international readers, it is important to note that Garoto was not only an innovator in choro and in the development of Brazilian guitar language, but also a precursor to Bossa Nova and modern Brazilian popular music (MPB), establishing aesthetic and technical foundations that would influence later generations of composers and performers (Napolitano, 2002; Taborda, 2011). His work also occupies a historically strategic position in the evolution of Brazilian guitar language, influencing later developments associated with Bossa Nova and modern Brazilian popular music. Such characteristics make his repertoire especially suitable for hybrid analytical approaches that can address both structural and expressive dimensions.

This article presents the initial stage of an ongoing doctoral research project aimed at proposing and validating a hybrid computational methodology for the analysis of choro repertoire. The approach integrates symbolic data extracted from digitized scores with acoustic descriptors derived from historical recordings, combining structural analysis with performance-oriented features. By employing Python-based tools — particularly music21 and librosa — the study seeks to establish a replicable workflow for the systematic investigation of stylistic traits in Brazilian popular music.

The contribution of this work is threefold. First, it proposes a methodological framework that bridges symbolic and acoustic domains within a unified analytical structure. Second, it applies this framework to a corpus centered on Garoto's works, contributing to the computational documentation of Brazilian musical heritage. Third, it explores the potential of data-driven techniques to support musicological interpretation,

emphasizing dialogue between algorithmic extraction and analytical interpretation rather than replacing traditional hermeneutic approaches.

The following sections present the theoretical foundations of the proposed model, describe the corpus and materials employed, detail the methodological procedures for feature extraction and data integration, and discuss preliminary results derived from the analysis of the piece *Jorge do Fusa*. Finally, the article outlines future perspectives for expanding the corpus and developing computational tools tailored to Brazilian music research.

## 2. State of the art

The development of computational musicology in recent decades is closely linked to the consolidation of the field of Music Information Retrieval (MIR), which investigates methods for the automatic extraction, representation, and analysis of musical information from symbolic and acoustic sources. Contemporary music analysis has significantly benefited from the integration of multimodal approaches; unlike other meanings that may be ascribed to the term, in our work, "multimodal" refers to the integration of symbolic and sonic data for a deeper and more contextualized understanding of music.

Hybrid and multimodal approaches integrating symbolic and audio representations have been increasingly explored in recent years, aiming to bridge compositional structure and performance-related information within unified analytical frameworks. Such approaches have been applied both to Western classical music and to popular music repertoires, demonstrating the potential of combining score-based and signal-based descriptors for enhanced musicological interpretation (MÜLLER et al., 2019; CANCINO-CHACÓN et al.,

2022; ORAMAS et al., 2025). Despite these advances, few studies explicitly apply such hybrid methodologies to historically significant Brazilian popular music repertoires, particularly in the context of choro.

This perspective is evidenced by systems that explore musical similarity through the fusion of symbolic and audio content, aiming to offer explainable and interpretable insights (POLTRONIERI, 2023). Similarly, cross-modal music information retrieval is enhanced by integrating visual sheet music and acoustic audio, utilizing mid-level feature representations, symbolic fingerprinting, and deep learning techniques to create joint embedding spaces (MÜLLER et al., 2019). In the field of symbolic music processing, the use of multimodal datasets, encompassing MusicXML scores, MIDI performances, and audio recordings with their respective alignments, is crucial for extracting relevant musical features (CANCINO-CHACÓN et al., 2022). Furthermore, the creation of datasets with detailed human musicological annotations, such as MGPHot, facilitates the analysis of popular music through attributes like rhythm, harmony, instrumentation, vocals, and lyrics, supporting multimodal representation learning (ORAMAS et al., 2025). Other notable examples include BPSD, which integrates digital sheet music and audio recordings with time-aligned annotations for the study of Beethoven's piano sonatas (ZEITLER et al., 2024), and MTD, which offers digital representations of graphical sheet music, symbolic encodings, and audio snippets, along with alignments, for research in cross-modal music information retrieval (ZALKOW et al., 2020).

In this context, considering the references cited above, the book *Fundamentals of Music Processing* (MÜLLER, 2015) provides succinct and introductory references on the main aspects of temporal representation, spectral analysis, structural segmentation, and the modeling of musical descriptors, emphasizing the convergence between score-based analysis and audio-based analysis as a pathway to a more comprehensive

understanding of musical phenomena. This literature offers principles capable of supporting hybrid methodologies that link compositional structure and performance, principles that are essential to the present study.

Within the domain of symbolic analysis, the music21 library, developed by Michael Cuthbert and Christopher Ariza (2010), has become widely adopted for the processing of digital musical scores. music21 enables the automatic extraction of tonalities, harmonic progressions, melodic patterns, and formal structures, making it a relevant tool for corpus-based stylistic analysis. By operationalizing concepts traditionally employed in music theory, the library bridges qualitative analytical practices and quantitative methodologies. In the present study, music21 provides the foundation for structural analysis, particularly regarding the identification of harmonic and formal patterns in Garoto's works.

Complementarily, in the acoustic domain, the librosa library, developed by Brian McFee and collaborators (2015), has established itself as a reference framework for musical audio analysis within the MIR community. The extraction of descriptors such as MFCCs, chromagrams, tempo estimation, and RMS energy curves allows researchers to examine timbral, dynamic, and rhythmic characteristics associated with musical performance. These descriptors, widely discussed in audio analysis literature, make it possible to capture expressive aspects not explicitly represented in musical notation, thereby expanding the analytical scope beyond compositional structures. The integration of music21 and librosa adopted in this article follows this methodological tradition, aiming to articulate symbolic representation and sonic realization within a unified framework.

Another relevant methodological element is the use of the pandas library, which enables the integration of heterogeneous data into unified tabular structures, facilitating exploratory and statistical analyses. Organizing extracted features into analytical

matrices opens possibilities for subsequent applications of dimensionality-reduction and machine-learning techniques, such as PCA and t-SNE, approaches frequently employed in contemporary studies of computational stylistic analysis.

Within Brazilian musicology, the work of Carlos Almada (2023, 1999) provides an essential theoretical basis for understanding the harmonic and formal language of Brazilian popular music. Almada highlights recurring procedures of formal organization, reharmonization practices, and melodic construction that characterize genres such as choro and Brazilian popular song, revealing levels of compositional sophistication often underestimated in traditional analyses. His analytical approach offers conceptual support for interpreting computationally extracted patterns from a musicological perspective, allowing quantitative findings to be contextualized within Brazilian compositional practices.

In addition, studies by Moss, Souza, and Rohrmeier (2020) contribute to the application of corpus-based methods to choro, investigating relationships between harmony and form within the genre. These works demonstrate the potential of computational approaches for uncovering structural regularities and suggest pathways toward large-scale stylistic analysis. Likewise, scholars such as Tamara Livingston-Isenhour (2005), and Carlos Sandroni (2001) provide historical and sociocultural perspectives essential for understanding choro as a hybrid practice situated between oral tradition and written notation, reinforcing the relevance of integrating symbolic and acoustic analysis.

The convergence of these perspectives — the technical foundations of MIR provided by Müller (2015), the computational tools developed within the Python ecosystem, and the analytical contributions of Brazilian musicology, particularly those of Almada (2023, 2019) — reveals a research gap that remains relatively underexplored: the effective integration of symbolic and acoustic analysis applied to historically significant

repertoires of Brazilian popular music. Despite the growth of computational music research, few studies propose models capable of simultaneously relating compositional structures and expressive dimensions of performance.

It is precisely within this gap that the present study is situated, proposing a hybrid approach that seeks to dialogue both with musicological analytical traditions and with contemporary computational methodologies, thereby contributing to the development of analytical frameworks and tools aimed at the study of choro and the works of Garoto.

## 3. Corpus and Materials

The construction of a musical corpus constitutes a central methodological step in computational musicology, as it determines the analytical scope and the validity of stylistic inferences derived from the data. In line with perspectives that emphasize the importance of systematic selection criteria for corpus-based research, the present study adopts a hybrid corpus designed to capture both compositional structure and performative expression within the choro repertoire.

The symbolic corpus is based on the *Songbook Choros de Garoto* (BELLINATI; PEREIRA, 2011), published by SESC in partnership with the Instituto Moreira Salles (IMS), comprising approximately fifty works by Aníbal Augusto Sardinha (Garoto). The scores were digitized and converted into MusicXML format, ensuring compatibility with the music21 library and enabling automated extraction of musical parameters such as tonal organization, harmonic progressions, melodic patterns, and formal structures. The curation process prioritized pieces containing complete notation — including dynamics, articulation markings, and metric indications — in order to maximize analytical reliability in symbolic processing.

The acoustic corpus consists of historical recordings performed by Garoto, obtained from remastered compilations and publicly available digital archives. These recordings originate from sessions conducted in 1950 and preserved in the personal collection of the researcher Ronoel Simões. Originally recorded under studio conditions and registered on acetate discs, these materials were not intended for commercial release, but rather functioned as private documentation of Garoto's performance practice. According to available documentation, the recordings were produced in São Paulo, likely at RGE studios, and later entrusted by the composer to Simões, who preserved them over several decades.

The original audio material was subsequently digitized from these acetate sources, ensuring its preservation and enabling computational analysis. All files used in this study were standardized in WAV format (44.1 kHz sampling rate, 16-bit resolution) in order to ensure compatibility with the librosa library. While this process allows consistent feature extraction, it also requires consideration of potential artifacts introduced during digitization, particularly in historical recordings.

Given the oral and performance-centered nature of choro, special attention was devoted to the correspondence between symbolic and acoustic materials. Score–audio matching was manually verified through detailed comparison of formal sections, melodic contours, and harmonic progressions, ensuring that equivalent versions of each work were analyzed across domains. This validation procedure is particularly relevant for repertoires in which multiple performance versions coexist and may significantly differ in structure or interpretation.

By integrating symbolic and acoustic sources, the adopted corpus seeks to capture both compositional elements encoded in notation and expressive nuances present in recorded

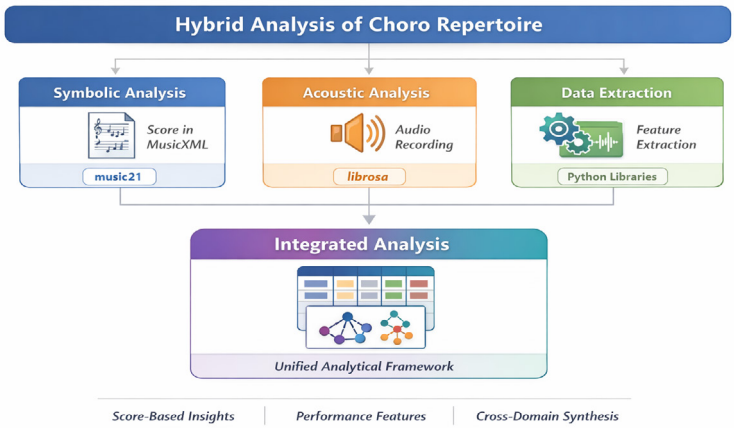
performances. This dual perspective provides the foundation for a more comprehensive understanding of Garoto's musical language, allowing the investigation of relationships between structural design and interpretative realization within a unified analytical framework.

## 4. Methodology

The methodology proposed in this study adopts a hybrid computational approach designed to integrate symbolic and acoustic perspectives in the analysis of choro repertoire. The analytical process is structured into three complementary stages: symbolic analysis of digitized scores, acoustic analysis of historical recordings, and cross-domain integration of extracted data within a unified analytical framework. This design seeks to explore relationships between compositional structures encoded in notation and expressive dimensions emerging in performance, following methodological perspectives that emphasize the complementarity between score-based and audio-based analysis in computational musicology.

The methodology integrates symbolic score-based analysis and acoustic audio-based analysis through the extraction of complementary musical descriptors. Symbolic features are obtained from MusicXML scores using *music21*, while acoustic features are extracted from audio recordings using *librosa*. The resulting data are integrated within a unified analytical framework for cross-domain musicological investigation.

**Figure 1 - Schematic representation of the hybrid computational workflow proposed in this study.**




*Source: Author's elaboration.*
*Image description: Data graph.*

The operational workflow was implemented using Python libraries widely adopted in music information retrieval and computational musicology, particularly *music21* for symbolic processing and *librosa* for audio analysis. The integration of these tools enables a methodological dialogue between structural analysis and performance-oriented descriptors, aligning computational extraction with musicological interpretation.

## 4.1 Symbolic Analysis with music21

Symbolic analysis was conducted using MusicXML files derived from the scores contained in the *Songbook Choros de Garoto*. These files were processed with the *music21* library, allowing automated extraction of musical parameters relevant to structural and stylistic investigation.

The symbolic analysis focused on four principal dimensions. First, global and sectional tonalities were identified to map tonal centers and modulation processes throughout each work. Second, harmonic progressions were obtained through automatic chord labeling, enabling the observation of functional relations and recurring harmonic patterns. Third, melodic *n-gram* analysis was applied in order to detect recurrent motifs and

thematic transformations, supporting inferences concerning Garoto's melodic vocabulary. Finally, formal segmentation was proposed based on harmonic and melodic continuity, allowing the identification of recurrent formal schemes commonly associated with choro repertoire, such as AABA and ABACA structures described in specialized literature.

The extracted symbolic features were organized into structured datasets using the *pandas* library, facilitating subsequent visualization and comparative analysis.

## 4.2 Acoustic Analysis with *librosa*

Audio analysis was conducted using the librosa library, which provides a set of tools for extracting meaningful features from audio signals. The recordings were loaded in WAV format with a sampling rate of 44.1 kHz, and preprocessing steps included normalization and trimming of leading and trailing silence to ensure consistency across samples.

Three groups of descriptors were considered. Chromagrams, which represent the distribution of energy across pitch classes over time and are commonly used for tonal and harmonic analysis (MÜLLER, 2015), and Mel-Frequency Cepstral Coefficients (MFCCs), which capture spectral envelope characteristics related to timbre perception (McFee et al., 2015), were employed to investigate spectral distribution and timbral variation throughout performances. Beat tracking algorithms provided tempo estimations and local temporal fluctuations, allowing analysis of rhythmic elasticity and expressive timing (Ellis, 2007). In addition, Root Mean Square (RMS) energy curves were used to examine dynamic shaping and emphasis patterns across musical sections, representing signal amplitude variations over time (McFee et al., 2015).

The extracted features were aggregated into statistical summaries, including mean and standard deviation values, in order to enable comparative analysis across different

sections of the piece. Temporal curves were also preserved for visualization purposes, allowing inspection of expressive variations throughout the performance.

This acoustic analysis complements the symbolic domain by providing insights into performance-related dimensions that are not explicitly encoded in musical notation, such as dynamics, articulation, and microtiming variations.

Beyond feature extraction, the analytical objective of this stage is to investigate how performance-related parameters interact with the structural elements identified in the symbolic domain. By examining relationships between timbral variation, dynamic shaping, and rhythmic flexibility, the study seeks to understand how expressive nuances contribute to the articulation of form and harmonic progression in Garoto's music.

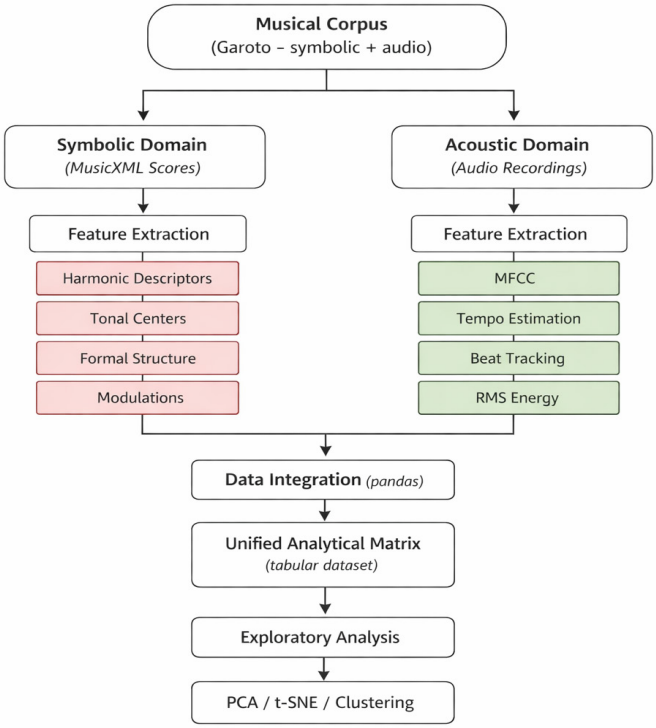
This perspective allows the interpretation of computational descriptors not merely as isolated numerical features, but as indicators of musical behavior that reflect interpretative choices. In this sense, the integration of acoustic analysis supports a more comprehensive musicological reading, in which performance is understood as an active dimension of musical structure rather than a secondary or purely ornamental layer.

## 4.3 Data Integration and Analytical Framework

The final stage of the methodology consists of integrating symbolic and acoustic descriptors into a unified analytical matrix. Using the *pandas* library, heterogeneous data from both domains were organized into a single tabular structure in which each work corresponds to one analytical instance.

The overall workflow of the hybrid symbolic–acoustic analytical framework adopted in this study is illustrated in **Figure 2**.

**Figure 2. Workflow of the hybrid symbolic–acoustic analytical framework.**



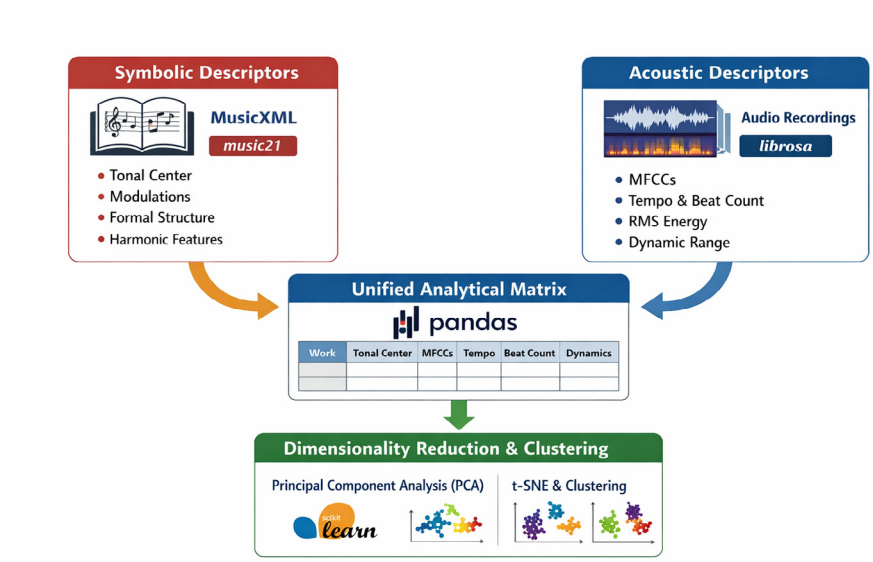

*Source: Author's elaboration.*
*Image description: Data graph.*

This matrix includes symbolic parameters — such as tonal centers, number of modulations, formal structure, and harmonic descriptors — alongside acoustic parameters, including average MFCC values, tempo estimates, beat counts, and dynamic statistics derived from RMS energy. The resulting dataset enables cross-domain analysis aimed at identifying relationships between compositional design and performance behavior.

Symbolic musical descriptors are extracted from MusicXML scores using the music21 library, while acoustic features are obtained from audio recordings using librosa. The resulting features are integrated into a unified analytical matrix with pandas, enabling dimensionality-reduction and clustering

techniques implemented with scikit-learn.The computational pipeline implemented for feature extraction and data integration is summarized in Figure 3.

**Figure 3 - Computational architecture of the hybrid symbolic–acoustic analysis framework.**




*Source: Author's elaboration.*
*Image description: Data table.*

Beyond supporting visual and exploratory analyses, this integrated framework establishes the foundation for future applications of dimensionality-reduction and machine-learning techniques, such as Principal Component Analysis (PCA) and t-Distributed Stochastic Neighbor Embedding (t-SNE), intended to investigate stylistic clustering and latent regularities within the corpus.

The analytical potential of this hybrid methodology is demonstrated in the following section through its application to the piece *Jorge do Fusa*.

The results presented herein can be explored or reproduced using the code available at: https://github.com/rafayasuda/analise_garoto

## 5. Application and Analytical Discussion: *Jorge do Fusa*

As an initial validation stage of the proposed hybrid methodology, the analytical framework was applied to the piece *Jorge do Fusa*, composed by Aníbal Augusto Sardinha (Garoto). This work was selected because of the availability of both a fully notated score and a high-quality historical recording, providing suitable conditions for integrated symbolic and acoustic analysis. The following sections present the results obtained through the hybrid model, emphasizing their analytical and musicological implications.

The results presented in this section are interpreted in light of the hybrid analytical framework proposed in this study, which seeks to relate structural features extracted from symbolic representations to expressive characteristics derived from audio analysis. Rather than treating these domains independently, the analysis emphasizes their interaction as a means of revealing stylistic and interpretative aspects of Garoto's musical language.

The symbolic analysis identified D major as the principal tonal center of the piece, with modulatory passages to F minor, A major, E minor, and D minor detected through automated tonal segmentation. Rather than functioning merely as structural transitions, these modulations suggest harmonic flexibility typical of the choro repertoire, where tonal movement often contributes to expressive contrast between formal sections.

Formal segmentation revealed an AABA structure, a recurring pattern within choro compositions and consistent with analytical descriptions in Brazilian musicological literature. The interaction between recurring formal sections and harmonic movement suggests a compositional strategy that balances structural regularity with expressive variation.

Automatic chord labeling revealed a predominance of functional harmonic relations centered around tonic, subdominant, and dominant functions, enriched by chromatic

resources such as secondary dominants and modal inflections. In particular, the predominance of the iii65 chord emerges as an unexpected feature, deserving specific attention, as it suggests a non-trivial role for mediant-related harmonies within the tonal framework of the piece. Additionally, the harmonic notation adopted in this study presents particular characteristics that extend beyond conventional Roman numeral analysis, incorporating inversions and contextual functional interpretations that aim to capture subtleties of harmonic behavior in the choro idiom. From an interpretative perspective, these harmonic features suggest that Garoto's compositional language extends beyond conventional functional expectations, incorporating mediant relationships and chromatic resources as expressive devices. The observed predominance of the iii65 chord, in particular, may indicate a strategy of tonal color expansion, contributing to subtle shifts in harmonic perception without fully destabilizing the tonal center.

In the melodic domain, *n-gram* analysis revealed recurrent patterns involving intervallic leaps such as major ninths, perfect fourths, and augmented seconds, suggesting a melodic language characterized by expressive sophistication and structural coherence.

Acoustic analysis revealed variations in tempo, timbre, and dynamics across different sections of the recording. Tempo estimation indicated fluctuations around an average value, reflecting expressive timing rather than strict metric regularity. Chromagram analysis demonstrated relative stability in tonal centers, while also capturing local harmonic deviations consistent with the modulations identified in the symbolic domain. MFCC descriptors revealed variations in spectral content, suggesting changes in timbral articulation, while RMS energy curves indicated dynamic shaping aligned with formal segmentation.

Taken together, these results reinforce the relevance of a hybrid analytical approach, in which symbolic and acoustic descriptors jointly contribute to the understanding of musical structure and performance. The integration of these domains allows the identification of relationships between compositional design and expressive realization, highlighting performance not merely as an execution of the score, but as an active dimension in the construction of musical meaning.

## 5.1 Symbolic Analysis: Tonality, Harmony and Formal Organization

The symbolic analysis identified D major as the principal tonal center of the piece, with modulatory passages to F minor, A major, E minor, and D minor detected through automated tonal segmentation. Rather than functioning merely as structural transitions, these modulations suggest harmonic flexibility typical of the choro repertoire, where tonal movement often contributes to expressive contrast between formal sections.

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numeral analysis, incorporating inversions and contextual functional interpretations that aim to capture subtleties of harmonic behavior in the choro idiom. This harmonic vocabulary indicates a dialogue between traditional functional practices and expanded harmonic language commonly associated with Garoto's style.

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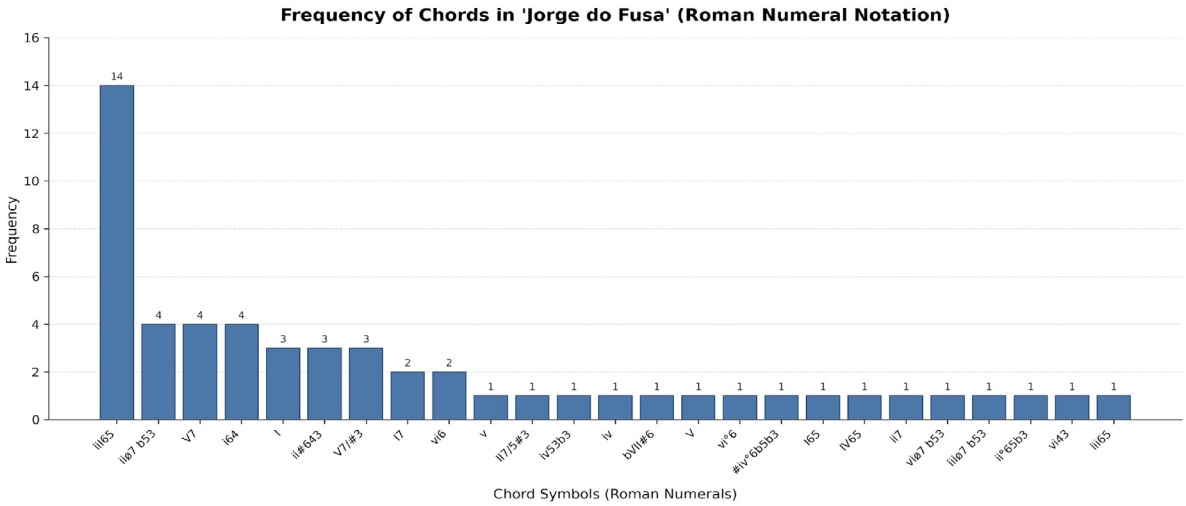
**Figure 4 - Frequency distribution of harmonic functions identified in *Jorge do Fusa* using Roman numeral notation.**




*Source: Author's elaboration.*
*Image description: Data graph.*

## 5.2 Acoustic Analysis: Performance and Expressive Parameters

The acoustic analysis focused on descriptors extracted from Garoto's recording using the *librosa* library, aiming to capture expressive aspects not explicitly represented in notation.

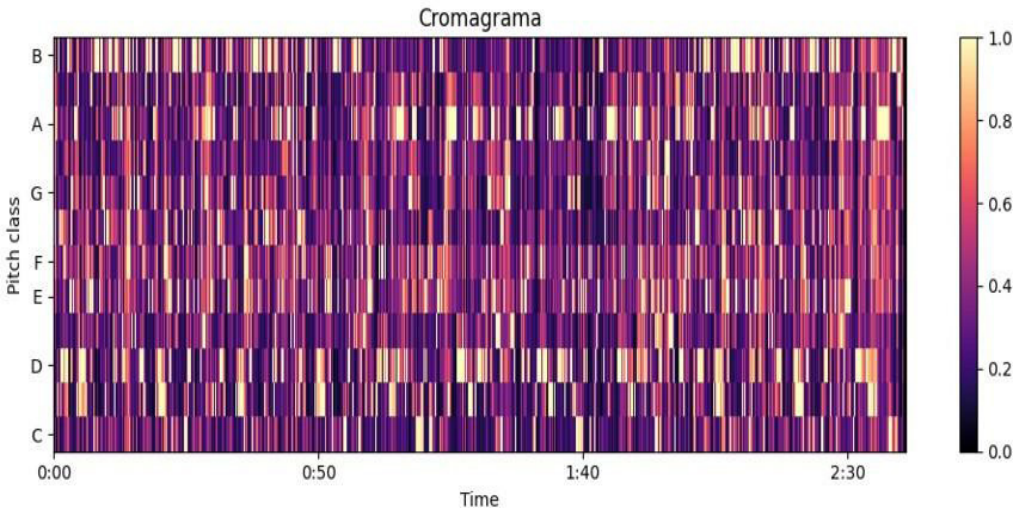
MFCC analysis revealed moderate timbral variation throughout the performance, indicating overall timbral stability consistent with solo instrumental interpretation. Local

oscillations suggest subtle changes in articulation and expressive emphasis rather than abrupt spectral transformations, reinforcing the perception of controlled interpretive nuance.

Tempo estimation indicated an average performance speed of approximately 129 BPM, with local fluctuations identified through beat-tracking algorithms. These variations suggest rhythmic elasticity characteristic of choro performance practice, where timing contributes to phrasing and expressive shaping.

The chromagram analysis confirmed tonal consistency throughout the performance, showing clearly defined pitch-class distributions aligned with the tonal centers identified in symbolic analysis.

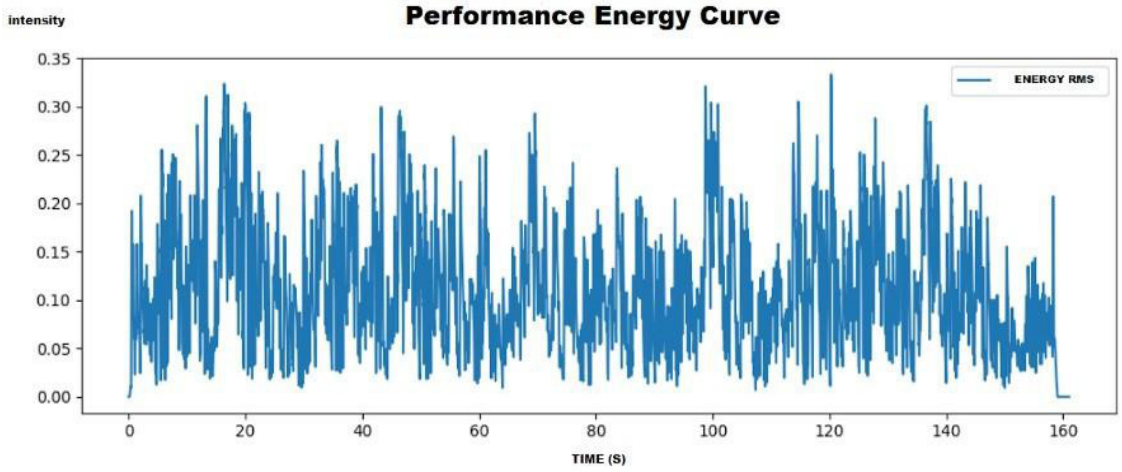
**Figure 5 - Chromagram of Jorge do Fusa**




*Source: Author's elaboration.*
*Image description: Data graph.*

The Root Mean Square (RMS) energy curve revealed alternating moments of intensity and repose throughout the recording. Higher energy levels tend to coincide with recurring A sections, while reduced energy appears in contrasting passages, indicating that dynamic shaping contributes to formal articulation.

Figure 6 - Energy Curve (RMS)




*Source: Author's elaboration.*
*Image description: Data graph.*

## 5.3 Cross-Domain Integration

Symbolic and acoustic data were integrated into a unified analytical table using the *pandas* library, enabling cross-domain correlations between compositional structure and performance behavior.

The integrated dataset indicates that dynamic and timbral variations align with formal sections. In particular, the progressive intensification of RMS energy in recurring A sections contrasts with attenuation in section B, suggesting interpretive differentiation aligned with formal design. Similarly, moments of harmonic transition correspond to slight increases in timbral variability, indicating interaction between tonal movement and performance expression.

Table 1 - Integrated Symbolic and Acoustic Data

| Work | Key | Form | Mods | MFCC | Tempo (BPM) | Beats | RMS Mean | RMS Std |
|---|---|---|---|---|---|---|---|---|
| Jorge do Fusa | D Major | AABA | 4 | 32.2 | 129.2 | 341 | 0.1129 | 0.0641 |

*Source: Author's elaboration.*
*Image description: Data table.*

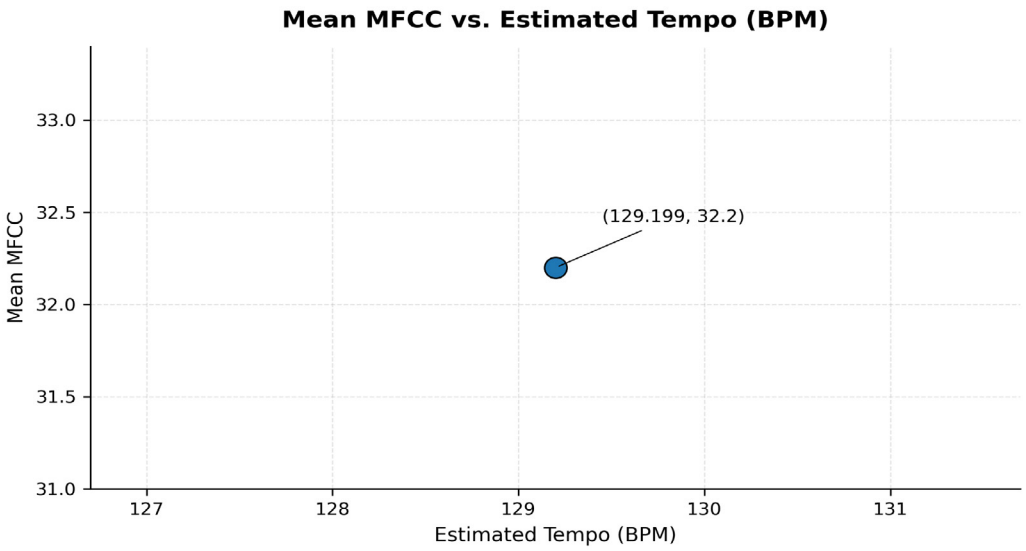
The table summarizes key descriptors extracted from the piece, including tonal center, formal structure, number of modulations, mean MFCC values, tempo estimation, detected beats, and RMS statistics. Together, these parameters illustrate how compositional structure and expressive performance characteristics interact within the hybrid analytical framework.

## 5.4 Musicological Interpretation of the Results

The integration of symbolic and acoustic descriptors reveals that structural repetition in *Jorge do Fusa* is not merely formal but continually recontextualized through performance strategies. Dynamic shaping, local timbral variation, and rhythmic flexibility contribute actively to the articulation of musical form, suggesting a close dialogue between compositional design and interpretive realization.

These results reinforce the perception of Garoto's musical language as balancing formal tradition and expressive innovation. More broadly, the case study demonstrates that computational descriptors gain analytical significance when interpreted within musicological frameworks rather than treated as isolated quantitative outputs.

**Figure 7 - Mean MFCC Vs. Time Estimated**




*Source: Author's elaboration.*
*Image description: Data graph.*

The temporal evolution of MFCC values illustrated in Figure 4 reinforces the interpretation of overall timbral stability combined with localized expressive variation throughout the performance. Rather than indicating abrupt changes in sonic identity, the observed fluctuations suggest subtle adjustments in articulation and phrasing that coincide with formal transitions and harmonic movement. This behavior supports the hypothesis that expressive nuance in Garoto's performance emerges through controlled microvariations within a stable timbral framework.

From a musicological perspective, these findings indicate that performance parameters actively contribute to the articulation of musical structure. The correspondence between symbolic features — such as formal segmentation and harmonic transitions — and acoustic descriptors suggests a close interaction between compositional design and interpretive realization. In this sense, the MFCC trajectory functions not merely as a timbral measurement but as an indicator of expressive shaping aligned with the formal logic of the piece.

These observations demonstrate how the integration of symbolic and acoustic analyses enables the identification of stylistic characteristics that would remain less apparent through single-domain approaches, reinforcing the analytical potential of the proposed hybrid framework for the study of choro repertoire.

Taken together, the findings highlight the potential of hybrid computational approaches for the analysis of Brazilian popular music repertoires, particularly those situated between written notation and performative flexibility, such as choro.

## 6. Final Remarks and Future Perspectives

The hybrid analytical approach developed in this study demonstrates the potential of integrating symbolic and acoustic perspectives for the computational analysis of the

works of Aníbal Augusto Sardinha (Garoto). By combining symbolic parameters extracted from musical notation with acoustic descriptors derived from historical recordings, the methodology enables a unified analytical perspective that bridges compositional structure and performance practice. The combined use of the Python libraries *music21* and *librosa*, together with data organization through *pandas*, allowed the construction of a coherent analytical framework suitable for visualization, comparison, and interpretive correlation.

The application of the model to *Jorge do Fusa* illustrates how hybrid analysis can reveal relationships between formal structure, harmonic behavior, timbral variation, and dynamic shaping, reinforcing the importance of interpreting computational descriptors within musicological contexts. Rather than functioning merely as quantitative measurements, these descriptors become analytically meaningful when related to stylistic conventions and performance practices characteristic of choro.

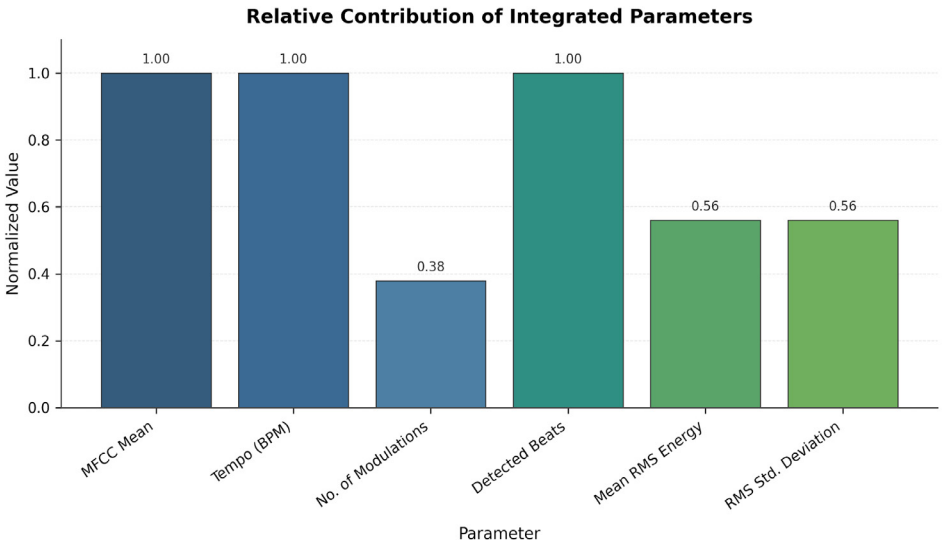
At the same time, some methodological limitations must be acknowledged. The automation of symbolic analysis still encounters challenges, particularly in the identification of formal structures in works presenting ambiguous or incomplete notation. Likewise, acoustic descriptor extraction remains sensitive to recording quality and to the presence of noise or non-musical artifacts, especially when working with historical sources. These limitations highlight the importance of continuous methodological validation and musicologically informed intervention when necessary.

Future stages of the research will expand the analysis to the full *Songbook Choros de Garoto* corpus, enabling broader comparative studies across works and stylistic contexts. Planned developments include the implementation of interactive visualization interfaces to support exploratory analysis by researchers and performers, as well as the application of dimensionality-reduction and machine-learning

techniques aimed at identifying stylistic clusters and recurrent compositional patterns.

In a broader perspective, the methodological framework proposed here may contribute to the construction of computational models capable of describing stylistic traits of choro repertoire through the integration of quantitative descriptors and music-theoretical concepts. Such developments may support comparative analyses involving other composers and contribute to the systematization of formal and expressive characteristics of Brazilian instrumental music.

**Figure 8 - Graphical Conclusion with Visual Summary of Integrated Analyses**




*Source: Author's elaboration.*
*Image description: Data graph.*

Ultimately, this study highlights the value of interdisciplinary collaboration between musicology, data science, and signal processing in addressing analytical questions that transcend traditional methodological boundaries. As part of an ongoing doctoral project, this research seeks to contribute both to computational musicology and to the understanding of choro as a significant component of Brazilian musical heritage.

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