Microtiming in the rhythmic structure of Candombe drumming

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1. Introduction

The purpose of this study is to measure and analyze the micro-rhythmical characteristics of Uruguayan Candombe drumming, a rich tradition originated in Uruguay with African roots. The candombe rhythm is the result of the interaction of a group of drums, of three different types, each one with its specific register, rhythmic pattern and musical role. A data set of 54 annotated multitrack recordings (one drum per track) was used to analyze the rhythmic patterns of the *chico* drum, which is the time keeper of the ensemble. A variety of computational techniques were used for extraction, analysis and visualization of data from audio recordings. Methods and techniques used are described with some detail, in the hope that be useful in the analysis of microtiming in the musics of other drumming traditions.

This introduction includes a brief overview of the theoretical framework regarding meter and metrical structures, followed by a discussion of the concept of microtiming, and a basic description of the rhythm patterns of candombe drumming, its timeline and metrical structure.

The following section first describes the data set used in the experiments is described, and then discusses in more depth the elements of the analysis of microtiming in the pattern of the chico drum. Tools and techniques used for data extraction and visualization are also introduced in this section. The third section presents the analysis of several performances selected as case study. The chapter ends with a brief overview of the conclusions.

1.1. *Meter, metrical structure and timeline*

Metered rhythms are prevalent in the musics of a wide variety of cultures around the world, from traditional folk songs and dances, ritual music and work songs, to different genres of popular and "classical" musics.

Contrary to what happens in unmetered or "smooth" time (*temps lisse*, Boulez 1963), where music events occur in the chronometric continuum, in metered or "striated" time (*temps strié*), events are organized–and perceived–in relation to an underlying metrical structure.

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Meter is a mental construct inferred by the listener to accommodate the temporal distribution of events in the musical surface. Human listeners have the ability–and tend–to perceive temporal regularity in musical sequences, even when they are irregular, in a way that they can snap their fingers or tap their feet to a music without an explicit beat (Large and Palmer 2002).

At its most basic, meter can be defined as a regular, periodic sequence of beats, organized in a recurring pattern of alternating strong and weak beats (London 2002). In theory, beats do not have duration: they are points of expectation in time, produced by the predictability that results from the structural coherence in the sequence of events (London 2002; Jones and Boltz 1989).

To define the concepts of "strong" and "weak", however, a more complex model is necessary, of meter as a hierarchical structure of metrical levels, where at any given level, events that also belong to a higher level are stronger than those that do not. Tonal metrical structures have been formalized through a series of rules of two types: *well-formedness rules*, which specify the conditions that valid metrical structures must meet, and *preference rules*, which state the criteria that experienced listeners use to choose the correct metrical structure for a given piece out of all the possible ones (Lerdahl and Jackendoff 1985).

Although those rules were defined to describe the metrical structures of Western tonal music, the fundamental well-formedness rules–and some of the preference rules–also apply to other musics, including many rhythms of the African and African diasporic culture (Temperley 2000).

There are, however, many important differences, both in perception and in the conformation of the metrical structure. In Western tonal music several metrical levels are common, ranging from the lowest level of subdivision of the beat to hypermetrical levels spanning more than one measure. Beats at each level span either two or three beats of the level below it, resulting in metrical structures of up to five or six levels (Lerdahl and Jackendoff 1985, p. 23). Rhythm in the music of the Afro-Atlantic culture, on the other hand, is essentially cyclic, and metrical structures can be interpreted as having three levels: the main beat, the cycle and the beat subdivision, normally in either three or four pulses. Cycles comprising four beats are the most common on both sides of the Atlantic; ternary subdivisions of the beat are more common in Africa, while in America there is a clear prevalence of a subdivision in four of the beat, in what has been described as the result of a process of "binarization" of African rhythms in Latin America (Pérez Fernández 1987).

Apart from the three levels of the metrical structure, in the rhythmic analysis of Afro-Atlantic music it is very important the concept of "timeline" ("time line pattern", "standard pattern" or, in Latin America, "clave"): a short rhythmic pattern repeated cyclically serving as a reference for temporal organization (Jones 1959; Agawu 2006).

Figure 1 shows two well known timelines with their respective metrical structures: the standard bell pattern widely used in West and Central Africa, and the rumba clave very common in Afro-Cuban music. Both patterns have a length of four beats and very similar rhythmic characteristics. In fact, the rumba clave (and the related son clave) can be considered an adaptation to the subdivision in four of the beat, of the simplified five-stroke version of the standard bell pattern (Toussaint 2013).

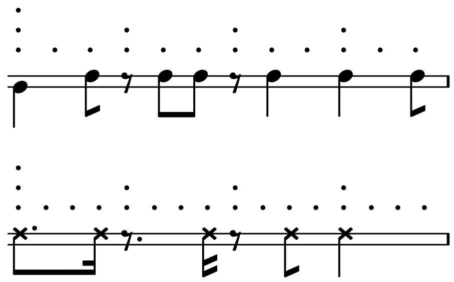

Figure 1. Standard bell pattern common in West and Central Africa (above), and Cuban rumba clave (below), with their respective metrical structures.

1.2. *The analysis of microtiming*

Essential to the theoretical framework discussed above is the assumption that, at each and all metrical levels, beats are distributed in a regular manner. However, this is a perceived regularity, not necessarily a strictly isochronal succession (Desain and Honing 2003). Actually, time-spans between beats are typically not equal when measured in physical time, meaning that the sequence of beats is not periodic in the mathematical sense of the term.

The discrepancy between a theoretically regular underlying metrical structure and the actual temporal distribution of events in the continuum of physical time is not relevant in the analysis of music as notation (Tagg 1982), since common music notation (CMN) implies equal subdivisions of note values.[1] For most of the twentieth century, all the established music analysis techniques focused almost exclusively on the corpus of academic Western music, and were based on the analysis of the musical score as symbolic representation of music (Cook 1987; Bent 1987; Dunsby and Whittall 1988). The last decades have seen the development of new methodologies applied to the analysis of music as sounding object (Cogan 1984; Leech-Wilkinson 2009), concomitant with a growing interest in the analysis of interpretation, as well as the analysis of music outside the standard canon of Western art music, including traditional, folk and improvised musics not based on notation.[2] This type of analysis has been facilitated by the development of powerful computational tools for extraction and processing of data from audio recordings.

The temporal deviation of events in the musical surface with respect to a theoretically isochronal metrical grid was generally referred to as "expressive timing" (Repp 1992; Desain and Honing 1994; Bilmes 1993; Windsor and Clarke 1997). The more generic terms "microtiming" and "microrhythm" began to be used, specially within the realm of computational musicology, but here again very often the concept was defined in terms of its supposedly expressive nature (Iyer 2002; Benadon 2006, 2009), although it is not clear why it should be considered more "expressive" (or less "structural") than any other musical dimension.

It has been noted that small deviations from the regular in timing, dynamics, articulation and intonation contribute to the perception of a more expressive performance (Kendall and Carterette 1990; Gabrielsson 1999), while an absence of variation tends to be perceived as "mechanical" and not accepted as a valid or adequate performance. However, this aspect is generally discussed in the very specific context of the

1. In American English, as well as in other languages like German, the names of the different note values suggest mathematical subdivisions of the main unit or "whole" note.

2. This trend was complemented by studies focusing on "music as heard" (Clifton 1983) or music as perception, in Tagg's terminology.

performance of notated compositions of the classical Western tradition; it is debatable whether–for example–the different approaches to “swing” eighth-notes observed in different jazz styles or different performers obey an expressive intent or rather constitute an inherent stylistic marker.

The analysis of micro-rhythmic aspects of music has received an increasing amount of attention in recent years, and has developed a more solid theoretical framework (Bilmes 1992, 1993). It has been established that microrhythm is an essential aspect of the rhythmic structure in many musics, and that only a very small part of it can be aptly referred to as “expressive timing” (Honing 2001). In this research, we will analyze microtiming as an integral part of the rhythmic configuration of candombe drumming, showing how certain time deviation patterns are inherent to the rhythm.

Broadly speaking, micro-rhythmic variations fall into two general categories: those occurring at the tactus level and taking the form of tempo variations, and those more appropriately represented by the time-shifting of events with respect to the steady beats of a constant tempo (Bilmes 1993). To the first category belong several types of tempo variations like *rubato*–a common practice in the performance of traditional Western art music from Baroque to Impressionism, (Botstein 2005; Martin 2002; Benadon and Zanette 2015) as well as in genres of popular music like tango (García Brunelli 2015; Alimenti Bel, Rocamora, and Martínez 2021) and jazz (Ashley 2002)–, the tempo arcs associated with melodic gestures (Repp 1992; Stowell and Chew 2013), and different forms of *accelerando* and *ritardando* (Sundberg and Verrillo 1980; Honing 2003).

However, not all microtiming phenomena can be adequately described by tempo curves (Desain and Honing 1993); some should rather be understood as the time-shifting of events at the sub-tactus level in the context of a locally stable tempo. This rhythmic effect, present e.g. in the performance of *notes inégales* in Baroque music (Moelants 2011), is an important characteristic of several traditional musics of the Afro-Atlantic culture (Gerischer 2006; Polak 2010; Polak and London 2014; Neuhoff, Polak, and Fischinger 2017; Naveda et al. 2011; Ferreira 2013; Jure and Rocamora 2016), and many genres of contemporary popular music, where it is important to infuse the music with rhythmic feelings such as “swing” or “groove” (Iyer 2002; Benadon 2006; Honing and Haas 2008; Butterfield 2011; Dittmar, Pfleiderer, and Müller 2015; Dittmar et al. 2017; Corcoran and Frieler 2021; Davies et al. 2013).

Global tempo variations during a performance in candombe drumming have been analyzed elsewhere (Jure and Rocamora 2018, 2020), this research will deal with the small time-shifting of events with respect to the regular, isochronous subdivision of the tactus.

1.3. *Candombe drumming*

With its deep African roots, candombe drumming is widely acknowledged as one of the most defining features of Uruguayan traditional culture. Internationally less known than other Latin American musics of African origin (such as Afro-Cuban or Afro-Brazilian), candombe drumming possesses a considerable rhythmic wealth and deserves wider recognition. In acknowledgment of its rich history and cultural value, in 2009 it was inscribed on the Representative List of the Intangible Cultural Heritage of Humanity by UNESCO (UNESCO 2009).

For generations candombe was practiced in the neighborhoods with larger concentration of black population in Montevideo, but now it has long been adopted by the larger society and is practiced by thousands of people all over the country. It remains, however, a symbol of the identity of communities of African descent in Uruguay (Ferreira 2007; Andrews 2010). The two neighborhoods with the longest tradition of candombe practice are *barrio* Sur and *barrio* Palermo, considered the cradle of the rhythm. Each has a distinctive and recognizable style of performing the rhythm, usually referred to with the names of the prominent streets in each neighborhood: Cuareim and Ansina respectively.

The most important and representative manifestation of candombe drumming is the *llamada de tambores*: a large group of drummers playing the characteristic candombe rhythm–also called *ritmo de llamada*–while marching on the street (see Figure 2). This is a traditional practice on weekends and holidays in specific points of the city. A parade of several of these groups of drummers, together with dancers and traditional characters, all in full costume, is a very important event during the Carnival festivities.

Essentially a folkloric form, its rhythm was also integrated in different ways into several genres of popular music, like tango, *canto popular* (folkloristic popular song), and most notably in all the genres derived from the so-called *candombe beat*.

Figure 2. Group of candombe drummers (*cuerda de tambores*) during a *llamada*.

The instrument of Candombe is called *tambor*, which is simply the word for “drum” in Spanish. There are three different sizes with their distinctive sound: *chico* (small, high-pitched), *repique* (medium size and pitch) and *piano* (large, low-pitched). Figure 2 shows in the first row, from the front backwards, a *repique*, a *chico* and a *piano*. All three drums are played with the dominant hand holding a stick and the other hitting the drumhead bare. The stick is also used to hit the shell, to produce a sound called *madera* (“wood”). This sound is used when playing the timeline pattern, which is called, precisely, *madera* or sometimes also *clave*, in analogy to the Afro-Cuban clave.

The ensemble of drummers is called *cuerda de tambores*, and in a traditional *llamada* it comprises typically between 20 and 60 drums (sometimes more in the Carnival parade), with proportional numbers of each of the three drums. In different settings, smaller groups are also common, and the minimal *cuerda* has one of each of the three drums (Figure 3).

Figure 3. A minimal *cuerda* of three drums. From left to right: *repique*, *chico* and *piano*. Note the *repique* playing *madera*.

Each of the three drums has a different function in the rhythm and specific patterns associated with its respective registers; the candombe rhythm results from the interaction between the patterns of the three drums. An additional pattern, shared by all three drums, is the *madera* pattern or *clave*, with functions similar to the timeline in Afro-Cuban and sub-Saharan African music traditions. It serves as a mean of temporal organization and synchronization, and is played by all the drums as an introduction to and preparation for the rhythm; during the *llamada* it is only played by the *repique* drum in between phrases. Figure 4 shows a simplified version of the patterns of the three drums and *madera*, together with the underlying metrical structure.[3]

Figure 4. Primary rhythmic patterns of the three drums with the timeline and the underlying metrical structure. The pattern of the *piano* drum is notated in a very simplified form.

It can be seen that it is a very regular and common metrical structure: a cycle of four beats, each with a subdivision in four pulses, very similar to other Afro-Latin

3. In all the examples, the lower line represents the hand and the upper line the stick, with an × representing the *madera* sound.

American musics. In fact, the primary *madera* pattern depicted here is isomorphic with the 3–2 *son* clave from Cuban music.

When transcribing into standard Western music notation, a common time signature (4/4) can be used for the cycle, with the quarter note representing the beat level and the sixteenth note the basic pulse. However, the distribution of events and accents differ in many ways from the preference rules of tonal meter, making the candombe rhythm difficult to decode for listeners not familiar with it, as well as for generic beat-tracking algorithms (Nunes et al. 2015). The *chico* pattern, with no events on the beat and a strong offbeat accent, as well as the syncopated character of the *repique* and the accents on weak metric points of the *piano*, may contribute to create a displaced sense of beat and downbeat on inexperienced listeners.

The *chico* drum is considered the cornerstone of the rhythm. It establishes the pulse by repeating a simple one-beat pattern throughout the whole performance (*chico de dos* or *chico liso*). The only possible variant is playing an alternate pattern (*chico de tres* or *chico repicado*), which is more common at slower tempos (Figure 5).

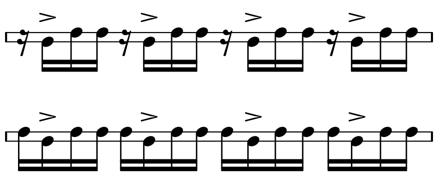

Figure 5. Standard *chico* pattern (*chico de dos*, top) and a common variant used at slower tempos (*chico de tres*, bottom).

The middle-sized *repique* drum, on the other hand, is regarded as a soloist and improviser, and has the greatest degree of variability among the three drums. During performance, a *repique* player typically interposes cycles of *madera* pattern in between *repique* phrases. These can be characterized by having a higher degree of syncopation and rhythmic and technical complexity. The *repique* has, however, a primary pattern (*repique básico* or *repique corrido*, see Figure 4), that may constitute a significant portion of the performance of a *repique* during the *llamada* (Jure 1992, 2013, 2018). The short excerpt transcribed in Figure 6 displays these three behaviors.

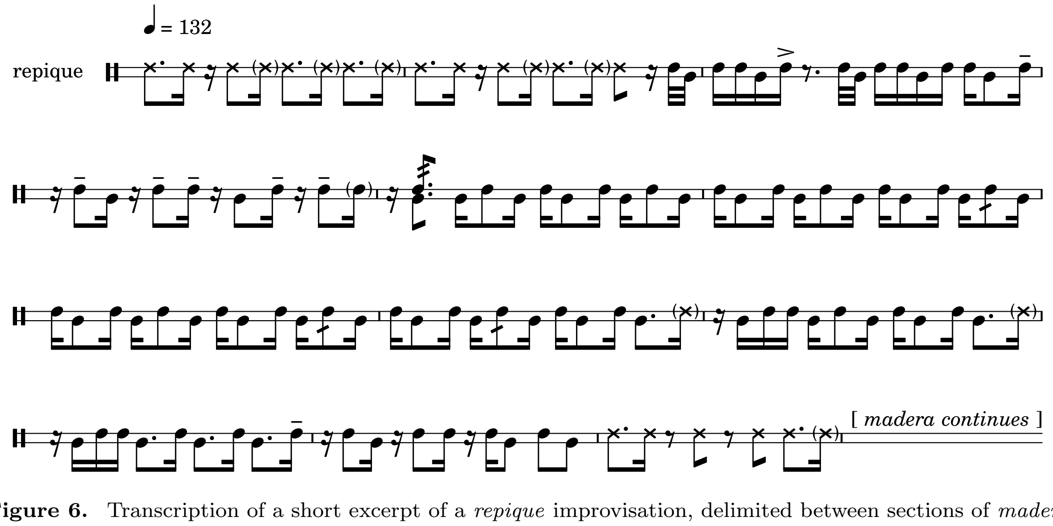

Figure 6. Transcription of a short excerpt of a *repique* improvisation, delimited between sections of *madera* patterns. The primary *repique* pattern (*repique básico*) alternates with more complex, improvised patterns.

The piano drum, the largest and lowest sounding of the three drums, has two different functions. The primary one (*piano base*) is to delineate the timeline with characteristic one-cycle patterns. There are many variants, that depend on both the style of each neighborhood and on the individual style of the performer. In all cases, the off-beat accent anticipating the second beat of the cycle is one of the most important features of the candombe rhythm. But the piano drum can occasionally interpose more ornamented *repique*-like patterns (*piano repicado*), typically one or sometimes two cycles long (Rocamora, Jure, and Biscainho 2014).

Figure 7 shows two examples of *base* and *repicado* patterns characteristic of the style of *barrio* Ansina. They are notated in their basic configuration;[4] during actual performance several subtle variants are introduced by means of added strokes and ghost notes.

Figure 7. Two examples of *piano base* patterns (above, compare with schematic pattern presented in Figure 4) and *piano repicado* (below, compare with the *repique* primary pattern).

In the transcriptions presented above, events are quantized to a regular, isochronous grid, with an equal subdivision in four of the beat. It has been noted, however, that in actual performance, the primary pattern of the *repique* presents a perceptible deviation with respect to the four pulses of the beat, towards a triplet feeling (Jure 1992; Jure and Rocamora 2016; Rocamora 2018). And although the *chico* drum is presented as the foundation upon which the whole metrical structure is built, its pattern presents a contraction of the inter-onset intervals (IOIs) (Ferreira 2013). The aim of this research is to assess the exact nature of these deviations in the chico drum, in particular when varying factors like tempo, performer and type of pattern.

2. Materials and methods

2.1. *Data set*

The data set used consisted of a collection of multi-channel audio recordings of 54 performances, recorded in eight different sessions during a period spanning 26 years, from 1992 to 2018. A total of 32 performers took part in the sessions, all of them distinguished players belonging to families of long-standing tradition in the community of the two most important neighborhoods where candombe is practiced: Barrio Sur and Palermo. In all cases, separate audio channels were obtained by close-miking each

4. The technique of the *piano* drum is more complex and requires some additional symbols: a cross represents a muted note (the hand and/or stick rest on the drum-head after striking it), and a stem without a note head means dampening the vibration with the palm without producing a sound. The triangular note head means palming the drum head with the fingers.

drum and recording them to independent tracks, in order to facilitate the analysis of the individual parts. Stereo takes and/or stereo mixes of the multi-channel recordings also exist for all performances. The collection includes beat and downbeat annotations for all the performances, as well as onsets annotations for individual tracks. Initial annotations were generated automatically using computational tools as described below in section 2.3. All labels were later manually checked and adjusted where necessary.

For the analysis of the patterns of the *chico* drum, a collection of 43 takes by 12 different players was used, totaling more than three hours of audio. Nine performances by five different players were finally selected to illustrate the configuration of the microtiming pattern when varying factors like performer, tempo and type of pattern (*chico de dos* or *chico de tres*).

2.2. *The analysis of the chico drum*

The chico drum repeats without pause or variation a simple one-beat pattern–either *chico de dos* or *chico de tres*–throughout the whole performance, establishing the lowest level of the metrical grid. It serves as a reference for the other drums upon which the rhythmic interplay is constructed. Therefore, it seems appropriate to concentrate on the behavior of the chico drum as a first step in the analysis of microtiming in candombe drumming.

The chico drum interlocks in a complex way with the primary pattern of the repique drum, with a quick alternation of in-phase points where the hand or stick of both drums are coincidental (see Figure 8), points of opposite phase (the hand of one of the drums coincides with the stick of the other) and points of no coincidence, where only one of the drums strikes an event.

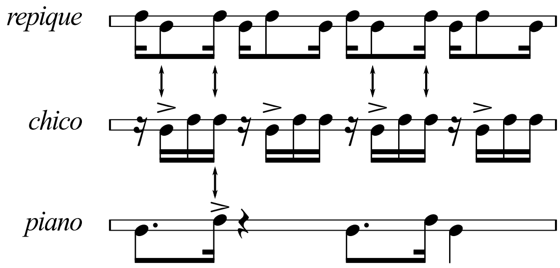

Figure 8. Important points of synchronism between the chico drum and the primary patterns of the repique and piano drums

Of particular importance is the coincidence occurring in the last pulse of the first beat between the chico and the piano drums (see Figure 8). The open stroke in the piano drum is the strongest accent in the cycle, and its location anticipating the second beat is essential in defining the rhythmic feel of candombe.

The chico drum is essentially anacrustic and always begins its pattern with the hand stroke. The primary chico pattern is thus constituted by a stroke with the hand (M) followed by two strokes with the stick (P1 and P2), while in the alternate pattern the hand is followed by three strokes with the stick (P1, P2 and P3)[5]. The primary pattern is an anacrusis without resolution, while in the alternate pattern P3 resolves on the beat, thus articulating the four pulses of the metrical grid.

5. The names *chico de dos* and *chico de tres* refer precisely to the number of strokes with the stick in each pattern.

For the analysis of the microtiming of the chico drum, two correlated but separate aspects will be analyzed: the location of the events within the beat as established by the whole ensemble, and the inter-onsets intervals (IOIs) between consecutive events in the pattern. The latter will be expressed as percentage of the beat duration and will serve as a measure of the degree of regularity/irregularity of the temporal distribution of events. The former will be expressed as a fraction of the normalized beat and is the factor that actually defines the characteristic "groove" of candombe drumming.

In this case, the equal subdivision in four of the beat (that will be referred to as I4) will be used as a reference, with the labels I4-1, I4-2, I4-3 and I4-4 for the points at 0, 0.25, 0.50 and 0.75 of the normalized beat, respectively. Occasionally, the analogous terminology for the subdivision in three of the beat (I3) will be used.

Figure 9 illustrates the basic elements of analysis and their terminology. The image shows the oscillogram of two beats of *chico de dos* (above) and *chico de tres* (below). The solid vertical lines represent the annotated beats, the dotted lines the isochronous grid of the subdivision in four of the beat (I4), and the red marks the location of the annotated onsets of each of the strokes in the pattern. The analysis will focus on the exact location within the beat of M, P1, P2 and P3 and their deviations with respect to the regular points of I4, as well as on the inter-onset intervals between them (IOI-1, IOI-2 and IOI-3).

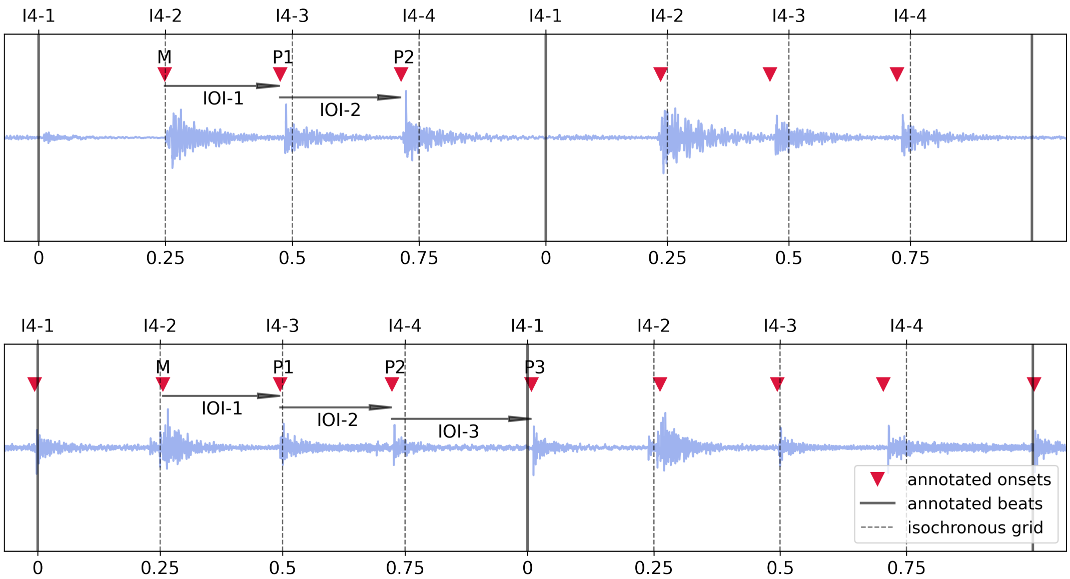

Figure 9. Microtiming terminology for *chico de dos* (top) and *chico de tres* (bottom).

The analysis of the exact location of the events with respect to the beats poses an important methodological problem: annotating the beat with the degree of precision required for analysis in microtiming. Due to the nature of the patterns of the three drums, in recordings of small ensembles of three of four drums it is not uncommon to find beats points without any onsets. Moreover, when there are more than one onset on the beat, they can be distributed within a window spanning in some cases up to a few hundredths of a second. In any case, the location of the onsets must not be mistaken with the location of the beat, since any drum can play "ahead" or "behind" the beat.

According to the definition given above, beats are "points of expectation in time", meaning that they are a subjective construction and not elements present in the signal, like onsets. It must be stressed, however, that beats are not strictly points, but rather small windows of uncertainty that are not negligible in the fine analysis of microtiming. In some cases, small adjustments in the beat annotations could result in differences of up to 1% in some of the values of the analysis.

2.3. ***Computational Tools***

For the analysis of several case studies, a variety of computational techniques were used for extraction, analysis and visualization of data form audio recordings. This section describes the computational tools used for beat and downbeat tracking, onset detection, and timing data extraction and analysis.

2.3.1. Onset detection

Automatic detection of onsets was carried out on the separate audio tracks by selecting peaks of a detection function based on the spectral flux (Simon Dixon 2006). It consists on seizing the changes in the spectral magnitude of the audio signal along different frequency bands, which is well-suited for dealing with the percussive events at hand.

The `carat`[6] (Rocamora and Jure 2019) software toolbox was used for implementing the onset detection. The spectral flux is obtained by firstly computing the Short–Time Fourier Transform of the signal for sequential 20 -ms duration windows in hops of 5 ms and then mapping it to the MEL scale using 80 sub–bands. The resulting sequences are time–differentiated (via first–order difference), half–wave rectified, and summed along the MEL sub–bands corresponding to frequencies between 500 and 3000 Hz. Onset are obtained by selecting peaks of the resulting detection function. To do that, the method used in Böck, Krebs, and Schedl (2012) is followed, in which onset candidates, apart from being a local maximum, have to exceed a threshold that is a combination of a fixed and an adaptive value. An example of the onset detection method is provided in Figure 10 for a short excerpt of a *chico de tres* recording. It depicts the adaptive threshold computed as a moving average, and the moving maximum condition that avoids the selection of peaks that are too close to each other.

2.3.2. Beat and downbeat tracking

Unlike onsets, metrical structures are not a feature of the signal but rather cognitive constructs inferred by the listener in response to the temporal distribution of events in the musical surface. Therefore, the labeling of metrical elements like beat and downbeat cannot be tackled only by means of low level signal processing techniques like the ones described above for onset detection and require instead a more complex approach.

Most classical algorithms for beat tracking follow a bottom-up approach with little prior information about the music under analysis (S. Dixon 2001; Klapuri, Eronen, and Astola 2006; Ellis 2007), often including some kind of preference rules (Lerdahl and Jackendoff 1985)—e.g. by aligning beats with onsets of stronger and/or longer events. Although they perform reasonably well for a considerable part of the European and North-American art and popular music with a steady beat, they usually fail on processing syncopated or polyrhythmic music, for instance, that of certain Turkish, Indian or African traditions (Srinivasamurthy, Holzapfel, and Serra 2014). Actually, candombe rhythm is also very challenging for these approaches (Rocamora 2018).

6. https://github.com/mrocamora/carat

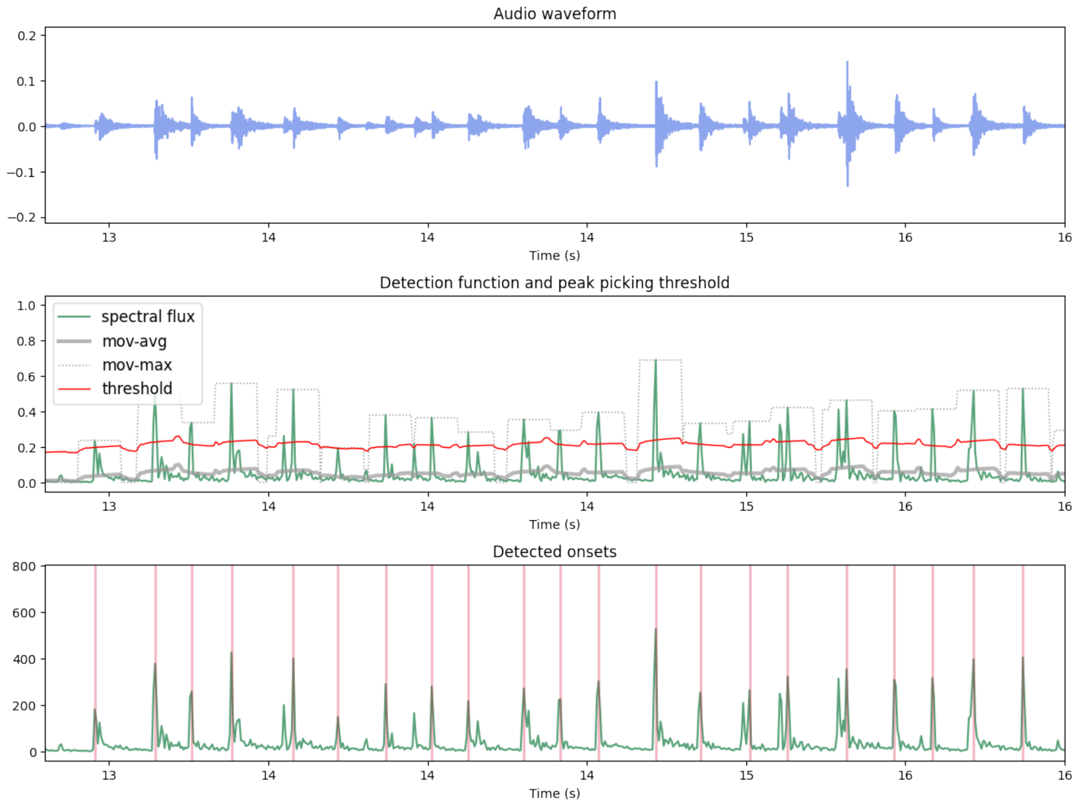

Figure 10. Example of spectral flux computation for a short excerpt of a *repique* performance.

In order to overcome the limitations of these techniques, other approaches follow a top–down process guided by high–level information, such as style–specific characteristics (Jehan 2005; Wright, Schloss, and Tzanetakis 2008). Among them, the explicit modeling of rhythmic patterns proposed in Krebs, Böck, and Widmer (2013) proved to be effective in properly dealing with candombe rhythm (Nunes et al. 2015; Rocamora 2018), so it is the technique applied in this work. It is based on the Bayesian approach referred to as *dynamic bar pointer model*, introduced by Whiteley, Cemgil, and Godsill (2006), and later extended by various authors (Whiteley, Cemgil, and Godsill 2007; Krebs, Böck, and Widmer 2013; F. Krebs et al. 2014; Florian Krebs et al. 2015; Srinivasamurthy et al. 2015; Krebs, Böck, and Widmer 2015; Nunes et al. 2015).

The model aims at the joint estimation of beats, downbeats, tempo, meter, and rhythmic patterns, by expressing them as hidden variables in a Hidden Markov Model (HMM) (Rabiner 1989). Thus, the relation between the temporal events in the musical surface and the rhythmic/meter structure is explicitly modeled as a latent state inference problem. The internal variables of the model are the tempo value, the position within the rhythm cycle and an index that selects one among the rhythmic patterns present in the data set (Krebs, Böck, and Widmer 2013). An observation feature based on the spectral flux is computed from the raw audio signal and an observation model relates this representation into a beat/downbeat likelihood that indicates which are the most likely candidates to be a beat or a downbeat in the temporal sequence. The observation models uses a Gaussian Mixture Models (GMM) which is fitted during training to the feature values of each bin in a one–bar grid (e.g. 64 bins for a 4/4 meter). In this way, rhythmic patterns are learned directly from the data. Several rhythmic patterns can be modeled, though a rhythmic pattern is assumed to remain constant throughout the whole audio signal. During inference, the beat/downbeat sequence is obtained by selecting the most likely candidates according to the likelihood given the sequence of observation features of the audio signal.

To apply the algorithm to candombe rhythm, the rhythmic pattern tracking is tailored towards the *piano* (i.e. the low–pitched) drum, since its pattern is the most informative on both tactus beat and downbeat locations. Using only the low-frequency band of the observation feature (<250 Hz), a single rhythmic pattern, and two components for the GMM, is sufficient to accurately track beats and downbeats in *candombe* recordings (Rocamora 2018).[7] In this work, the implementation of the model provided by the `bayesbeat`[8] software package was used. With the parameter configuration described above, it was trained on the 35 recordings of the data set released in Nunes et al. 2015, and then applied to the stereo mix of each recording of the data set described in Section 2.1 to obtain beat and downbeat annotations. Figure 11 shows the rhythmic pattern learned by the model in the low-frequency band from the whole data set. It depicts the normalized mean of the feature values for each of the positions within a bar in the 64th-bin grid. Note that the distribution of feature values is quite consistent with that of the primary rhythmic pattern of the *piano* drum introduced in Figure 4.

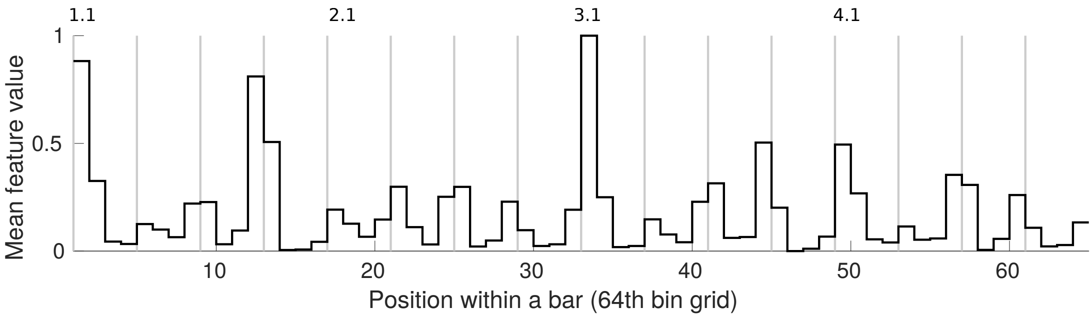

Figure 11. Rhythmic pattern in the low-frequency band learned from the training dataset.

2.3.3. Timing data extraction and analysis

Because of the different tempo of each recording, as well as the variations of the beat pace within a given performance, the timing data can not be analyzed as absolute duration values in seconds. As noted above, a reasonable option is to use the duration of the beat to normalize the timing data. So, beat durations are computed as the difference between consecutive annotated beats, and the location of each onset is normalized and expressed as a fraction of its corresponding beat duration, thus making it comparable across different recordings and distinct sections of a certain performance.

Then, each onset is grouped to the closest subdivision, considering the grid of equal subdivision in four of the beat (I4). Once the onsets are grouped, the mean and the standard deviation of each group is computed. This provides an estimate of the actual location of the events of the rhythmic pattern within the beat, as well as their amount of dispersion. For visualization purposes, the normalized onsets of each beat are represented as dots and stacked vertically with the rhythmic cycles increasing upwards, as shown in Figure 12 (middle). The histogram of the normalized onsets for

7. F-measure values of 99.3% and 100% for beat and downbeat respectively were reported in Rocamora (2018) using a leave-one-out scheme on the data set introduced in Nunes et al. (2015).

8. https://github.com/flokadillo/bayesbeat

each subdivision is depicted at the bottom. The mean of the normalized onsets within each subdivision is shown as a vertical dotted line and as a numerical value, and the standard deviation is represented as an error bar. The ticks at 0, 0.25, 0.50 and 0.75 correspond to the equal subdivision in four of the beat.

The analysis of the timing data also involves computing the inter–onsets intervals (IOIs) between consecutive normalized onsets, and representing them as a percentage of the beat duration. Recall that IOIs are computed using the hand stroke (M) as the first reference (see Figure 9). Therefore, note that IOI-3 corresponds to the difference between the second and third stick strokes (i.e. P2 and P3), the latter resolving on the next beat. The graphical representation of IOIs, as shown in Figure 12 (right), is similar to that of the normalized onsets, i.e. mean and standard deviation are represented, as well as the histogram of IOIs values.

The tempo curve of the performance is also shown in Figure 12 (left). Local tempo values at each beat point are computed from the annotations and the resulting sequence is smoothed with a Savitzky–Golay filtering (Savitzky and Golay 1964), with window of 15 points and polynomial of order 3. Note that the performance of Figure 12 exhibits a gradual tempo increase. It begins with a *chico de tres* pattern for the first 20 rhythm cycles, and then switches to the *chico de tres* pattern until the end.

All the timing data extraction, analysis and graphical representation is done using the `carat`[9] software toolbox (Rocamora and Jure 2019).

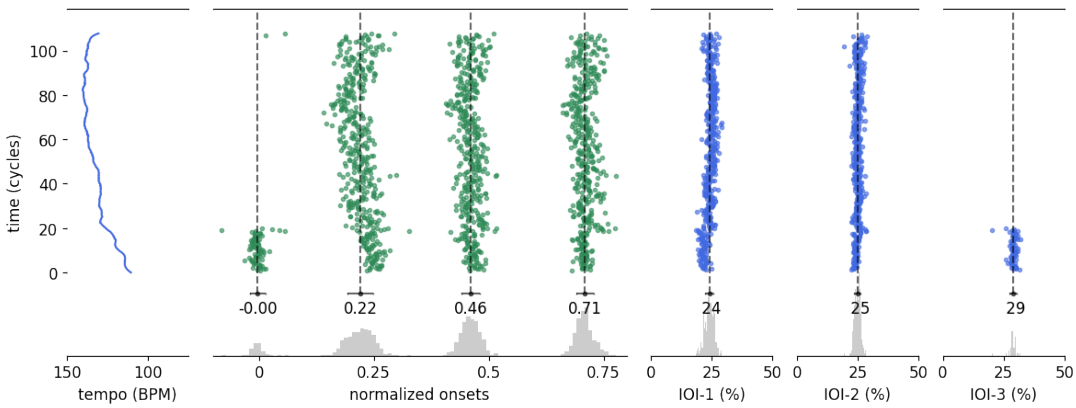

Figure 12. Example of the graphical representation of the timing data: tempo curve (left), normalized onsets (middle) and inter–onset intervals IOIs (right), for one of the *chico* drum performances of the data set.

3. Case studies

This section presents the analysis of nine performances by five renowned players from the two most important styles of candombe drumming, Ansina and Cuareim, in order to compare the microtemporal behavior of the pattern of the chico drum in different performers and when varying factors like tempo and type of pattern played.

The first two examples are by two players from Barrio Palermo, Ansina style: Edinson “Palo” Oviedo and Luis “Tierra” Nilo. In both cases the tempo remains stable during the performance at the characteristic fast tempo of Ansina, between ca. 130 and 135 BPM. The basic *chico de dos* pattern is played throughout the performance in both takes, as is the most common at that speed (Figure 13).

9. https://github.com/mrocamora/carat

The contraction of the chico pattern is similar in both cases (within a ±1% margin), specially in the location of P2. At 0.70 of the beat duration, it falls somewhere in between I4-4 and I3-3. Although the total contraction is the same in average, in Oviedo the three strokes are more evenly distributed with IOIs of 23%, while in Nilo the IOIs are 21% and 24%. This means that in his case the contraction occurs mainly between M and P1, while the IOI between P1 and P2 is closer to I4.

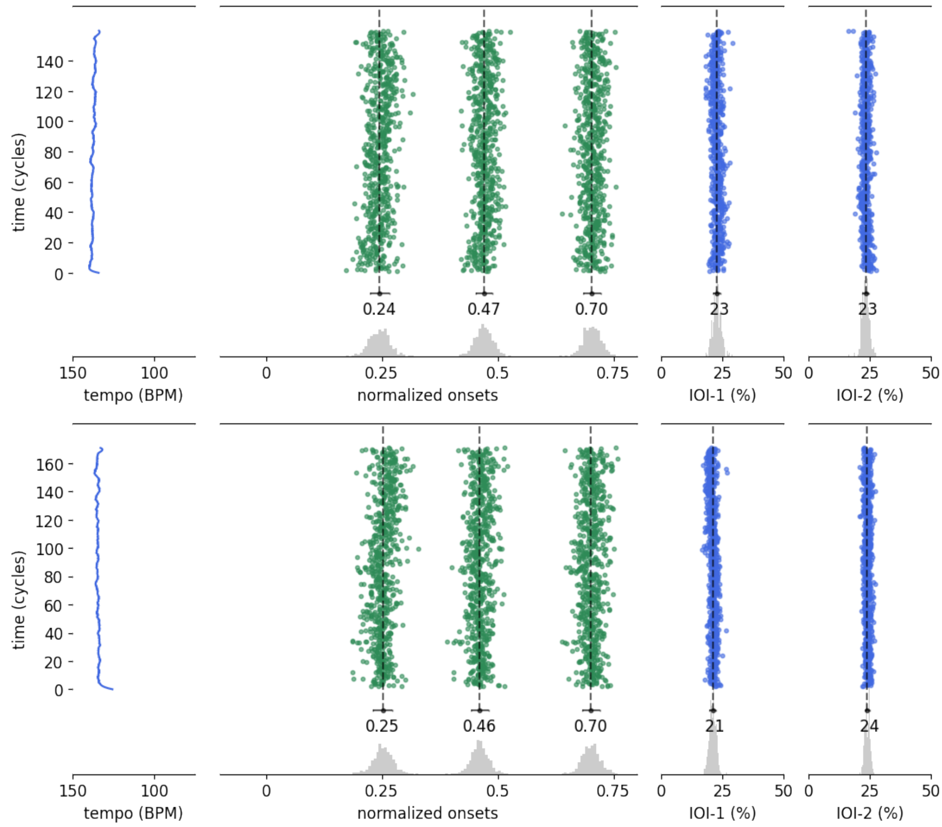

Figure 13. Microtiming pattern and IOIs of performances by two players belonging to the Ansina tradition: Edinson “Palo” Oviedo (top) and Luis “Tierra” Nilo (bottom).

The next two performances are by Luis Giménez, another player belonging to the Ansina style. The tempo curves in both cases have the same characteristics as the previous examples: stable fast tempo throughout the performance, with mean tempos of 130 and 134 respectively. In the first case (Figure 14, top) Giménez plays *chico de dos*, and the microtiming pattern is very similar to the previous examples.

In the second case (Figure 14, bottom) Giménez plays *chico de tres* throughout the whole performance, which is not very common at this tempo. It can be seen that the microtiming of M, P1 and P2 is very similar to the previous examples of *chico de dos*, although P1 and P2 are slightly less contracted. The new stroke–i.e., P3–falls quite precisely on the beat, which requires that IOI-3 is actually expanded–to 29%, in this case–to compensate for the contraction of the two other IOIs.

The microtiming pattern does not vary substantially in another performance of Giménez at a much slower tempo of ca. 100 BPM (Figure 15).

All the examples analyzed so far presented tempo stability. However, variations in tempo and dynamics are very idiomatic in candombe drumming (Jure and Rocamora 2018, 2020). A most common situation is to begin the performance at a slow or mod-

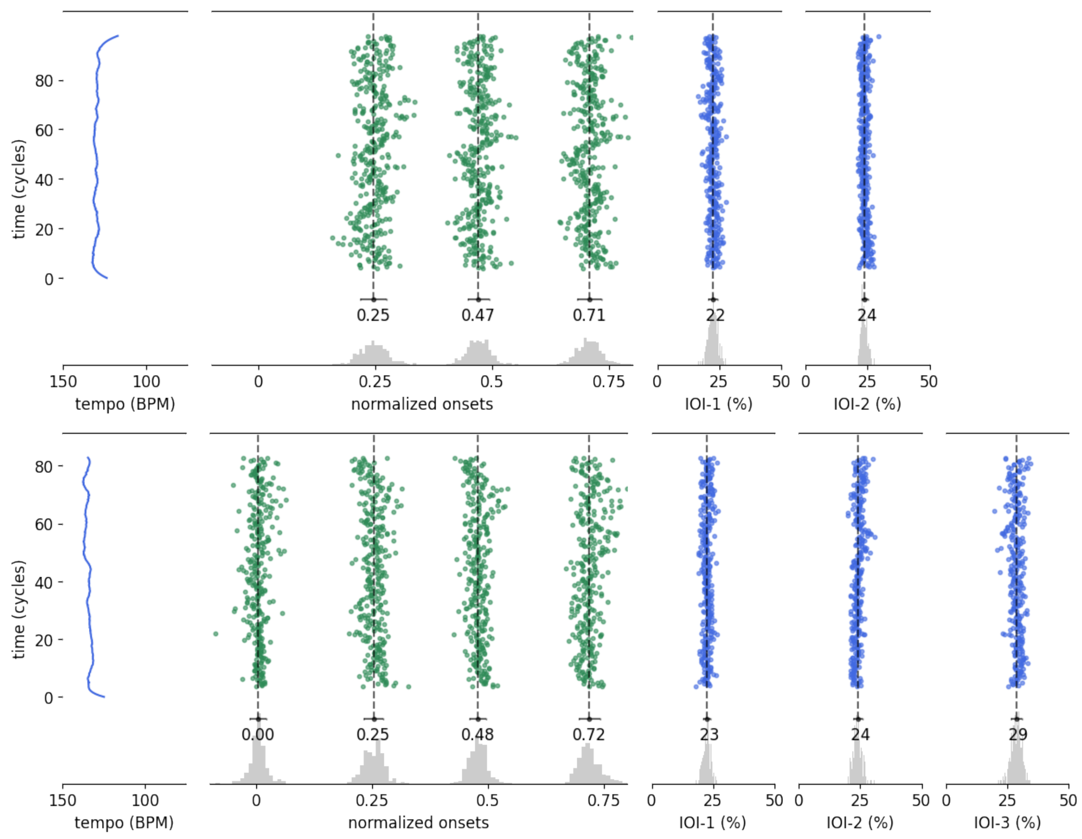

Figure 14. Comparison of two performances by Luis Giménez, another player from the Ansina tradition: *chico de dos* (top) and *chico de tres* (bottom).

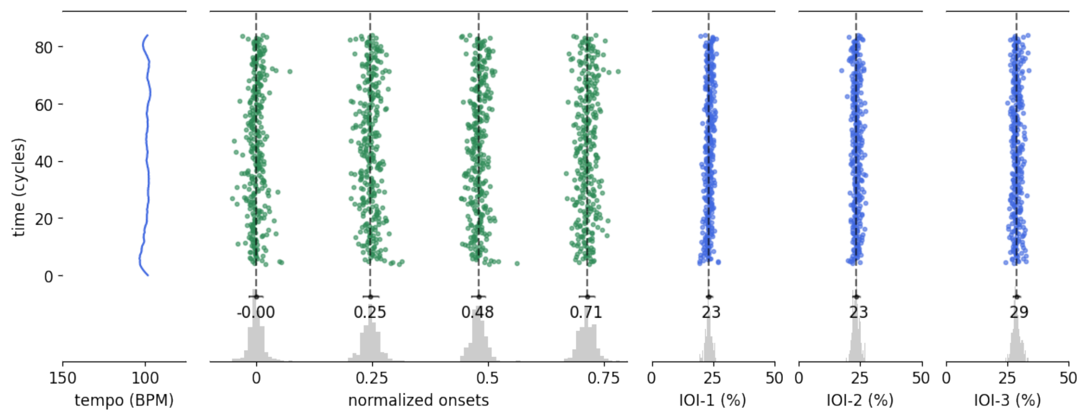

Figure 15. Performance of Luis Giménez playing *chico de tres* at a slower tempo.

erate tempo, and then accelerate to reach the standard fast tempo characteristic of the style, a little above 130 BPM in the case of Ansina.

In these cases, the accustomed procedure for the chico drum is to begin playing *chico de tres* in the slow section, and switch to *chico de dos* when tempo accelerates, which is usually accompanied by an increase in energy.

The next performance–also by Giménez–begins at a moderately slow tempo of ca. 105 BPM, with an accelerando between cycles 10 and 15 to reach fast tempos for the rest of the performance, varying around a mean of 135 BPM (Figure 16). The chico drum begins playing *chico de tres* in the slow section and switches to *chico de dos* during the accelerando. No significant variation in microtiming can be appreciated with the change of tempo and pattern.

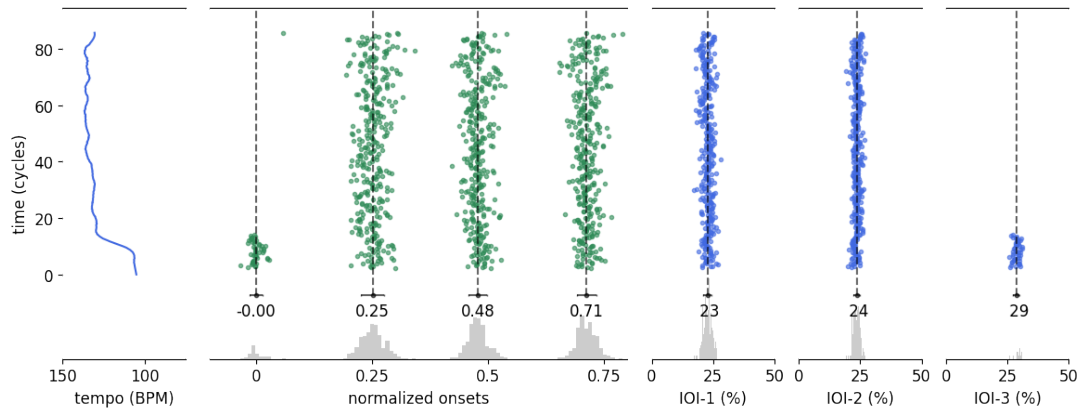

Figure 16. Performance of Luis Giménez with tempo variations and change of chico pattern.

The last examples by Giménez may suggest that factors like tempo and type of chico pattern have little or no influence in the microtiming pattern of an individual player. This is not typical, however, and it is more common to find more noticeable alterations in the microtiming of the events at different tempos, as will be illustrated below.

The following examples are by Jorge "Foqué" Gómez, a performer belonging to the style known as Cuareim associated with Barrio Sur, the other neighborhood with a long tradition in candombe drumming. Gómez is a player characterized by always employing *chico de tres*, even at very fast tempos.

The first example has a mean tempo of 136 BPM throughout the whole performance, and serves as reference of Gomez's microtiming at a stable fast tempo (Figure 17). The pattern is more isochronous than in similar examples analyzed so far, with P3, M and P1 coinciding with the points of equal subdivision of the beat. P2, on the other hand, presents a noticeable contraction at 0.7, in the range of the previous examples. This is compensated with a large IOI-3 of 30%.

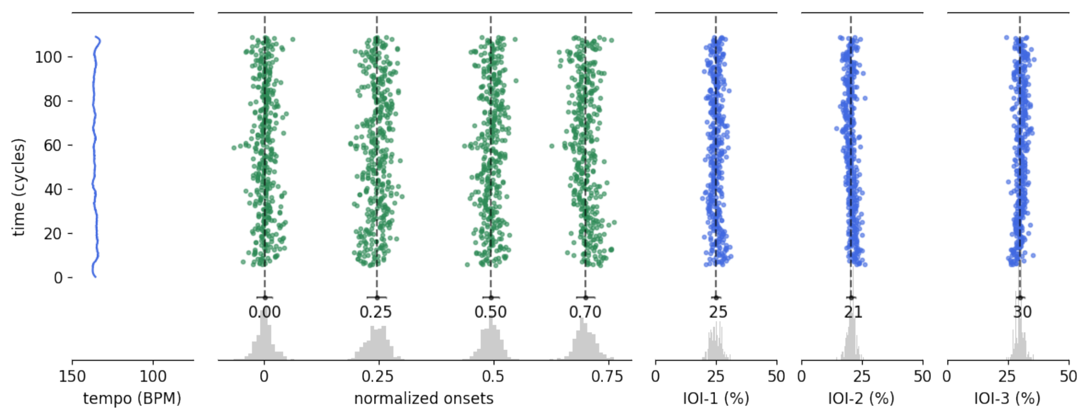

Figure 17. Performance of Jorge Gómez playing *chico de tres* at a fast tempo.

With that reference, it is interesting to analyze another performance by Gómez, now with variations in tempo. The next example begins at a very slow tempo with an irregular accelerando to reach fast tempos in the final section (Figure 18). As mentioned above, Gómez does not change the pattern to *chico de dos* when tempo accelerates, but there is a notorious change in the microtiming pattern, with the contraction of P2 increasing proportionally with tempo.

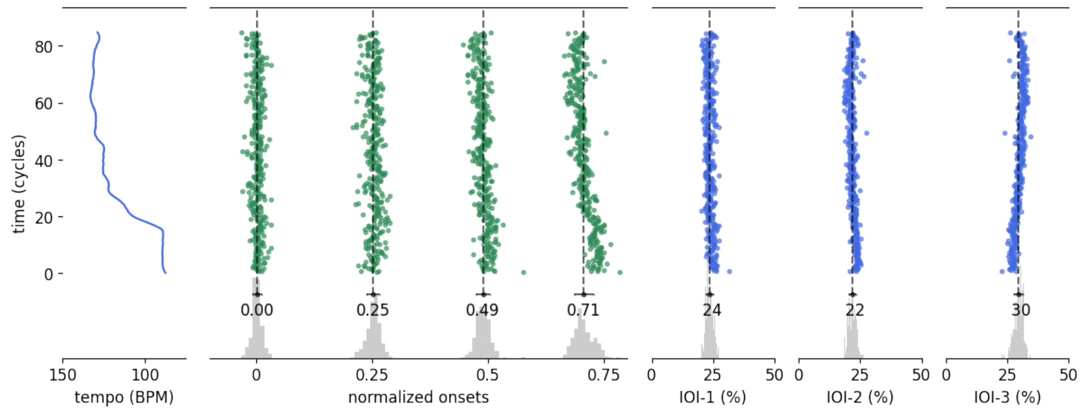

Figure 18. Performance of Jorge Gómez playing *chico de tres* with tempo variation.

From the beginning to ca. cycle 15 the tempo is stable at ca. 90 BPM. The chico pattern presents an almost isochronous distribution of events, with P3, M and P1 coincidental with the points of I4 and only a slight contraction of P2 at 0.73 (Figure 19, top). In the section from cycles 50 to 75 there are small variations in tempo around a mean of ca. 130 BPM (Figure 19, bottom). It can be seen that P3 and M remain on the points of I4, but there is a slight contraction of P1 from 0.50 to 0.48, and a more pronounced contraction of P2 from 0.72 to 0.69, leaving P2 much closer to I3-3 than to I4-4.

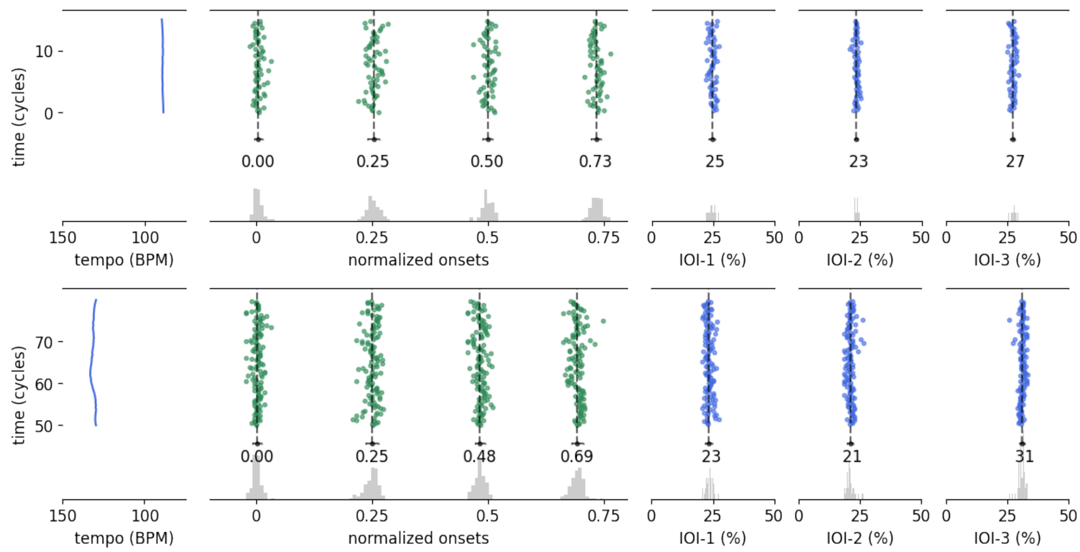

Figure 19. Microtiming pattern of Jorge Gómez in different sections: slow tempo (top) and fast tempo (bottom).

The last example is a performance by Javier "Cerdo" Martirena, another player from the tradition of Barrio Sur. Unlike Gómez, Martirena prefers *chico de dos* even at slow tempos. The performance shown here has a well-marked tempo curve: it begins at a stable medium tempo in the first half (ca. 125 BPM) and has a quick accelerando in the middle to a very fast tempo (ca. 140 BPM) until the end (Figure 20). The whole pattern is contracted and played somewhat "ahead" in the beat, with M and P1 at around 0.23 and 0.46 respectively.

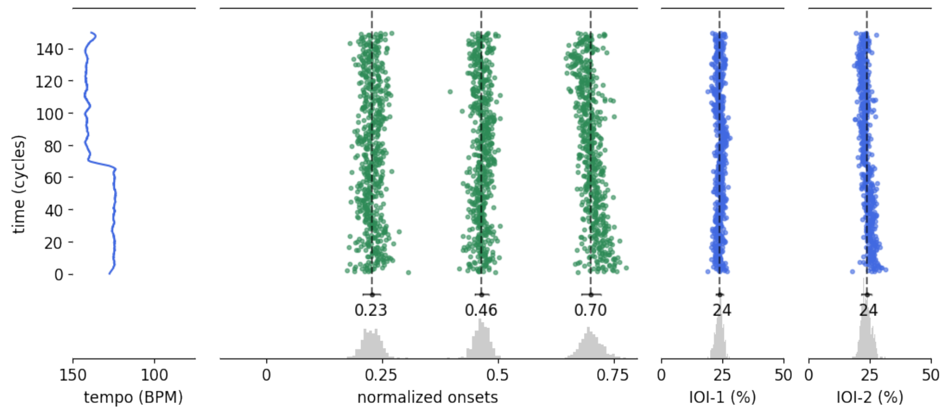

Figure 20. Performance of Javier Martirena with two sections of different tempo.

While M and P1 have little or no displacement when tempo changes, the contraction of the P2 increases proportionally with the tempo, moving from an average of 0.72 to 0.69 (Figure 21), again in this case leaving P2 much closer to I3-3 than to I4-4.

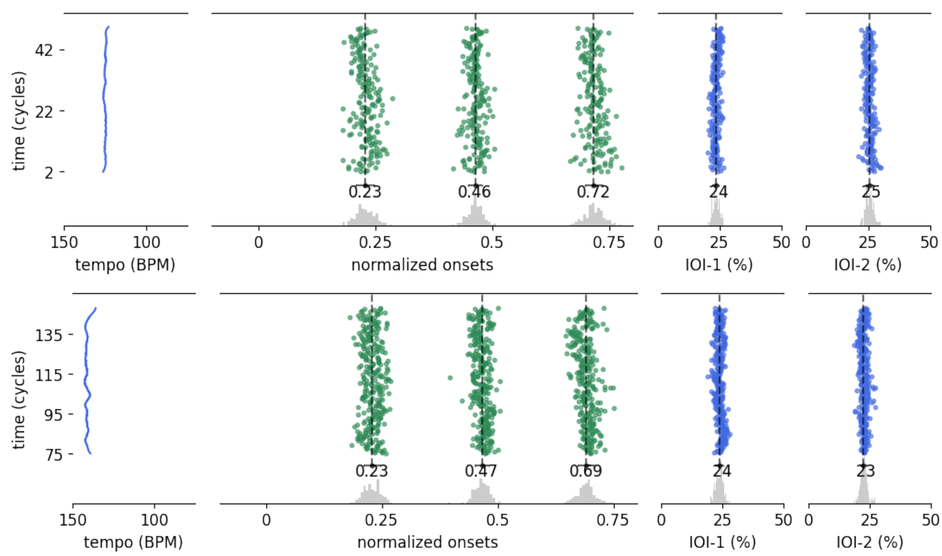

Figure 21. Comparison of the microtiming pattern in the two sections: beginning to cycle 60, slow tempo (top) and from cycles 75 to the end, fast tempo (bottom).

4. Discussion and conclusions

The analysis of several recordings by recognized players from the two main styles of candombe drumming revealed the systematic use of micro-rhythmical deviations in the patterns of the chico drum, indicating that microtiming is a structural component of the rhythm. The exact amount of the deviations of the events with respect to the isochronous metrical grid, as well as the nature of its distribution among the events, vary across performances. There are, however, general tendencies that are common to all the examples and reveal the essential characteristics of microtiming of candombe.

The most important and defining trait is the overall contraction of the pattern, specially of P2, that in all the analyzed performances is anticipated with respect to the isochronous grid.

The pattern begins with the hand stroke on or very close to I4-2, although in a few cases it can be slightly anticipated (Figures 20–21). The rest of the pattern is contracted, with both P1 and P2 played before their respective points in the isochronous grid. Only in the performances by Jorge Gómez P1 is coincidental with I4-3 (Figures 18, and 19 top, slow tempo).

As a rule, both IOI-1 and IOI-2 are less than 25%, and as a result the deviation of P2 is larger than the deviation of P1. The only exception is the performance by Martirena in the slow section (Figure 21, top).

In the performances analyzed here, the location of P2 range from 0.69 to 0.73, being the values between 0.70 and 0.71 the most frequent. These values are halfway between I3-3 and I4-4, giving to the last event of the beat a rhythmic feeling between ternary and quaternary subdivision.

In the *chico de tres* pattern, P3 is always on the beat (I4-1), meaning that the IOI with P2 (IOI-3) has to be expanded, in most cases to values around 30%.

Another recurrent and idiomatic performance practice is to increase the contraction of the pattern proportionally with tempo. Typical examples are shown in Figures 18–19 and 20–21, where it can be seen how IOI-2 decreases when tempo increases, bringing P2 closer to I3-3. This is not a fixed pattern, however, and an example was analyzed without noticeable variation in microtiming with tempo changes (Figure 16).

In conclusion, while all the examples exhibit systematic deviations of the events with respect to the isochronous grid, the only trait common to all the performances is a certain degree of contraction of the pattern, most noticeable in the location of P2, that is always played before I4-4, and in some cases closer to I3-3. The amount of this deviation, as well as the influence of tempo and the position of the other events, vary significantly across players and performances, revealing the absence of a predefined microtiming pattern in the rhythm.

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In memoriam Gustavo Adolfo Oviedo Gradín (1953–2021)

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