Flamenco music and its Computational Study

F. Gómez
Technical University of Madrid,
E-mail: fmartin@eui.upm.es

J.M. Díaz-Báñez
Dep. Applied Mathematics,
Universidad de Sevilla

E. Gómez
MTG,
Universitat Pompeu Fabra

J. Mora
Faculty of Psychology,
Universidad de Sevilla

Abstract

In this paper we present an example of interdisciplinary research through the work of the COFLA group. In the group there are researchers of various disciplines, including psychology, mathematics, engineering, and computer science, who work to understand a musical tradition as complex and rich as flamenco music. Several problems in the computational research of flamenco music are illustrated. Specifically, the problem of melodic similarity in a cappella flamenco songs is discussed. That problem requires the design of two distances, a melodic contour distance and a distance based on mid-level features. Both are combined into a unique distance that provides better results when trying to automatically distinguish different styles and variants.

Introduction

Music is a phenomenon that has always fascinated researchers of a wide range of disciplines. Music is complex, multidimensional and universal. Music can be seen as a phenomenon of people, society, and culture, as studied in anthropology and sociology [18]; as a physical phenomenon, and as such studied by physicists and engineers [1]; as a phenomenon of the mind, which is then an object of study of musical cognition [14, 23, 24]; as a purely musical phenomenon, and then questions such as melody, rhythm, and harmony organization are relevant; as an affective phenomenon, thus entering in the realm of psychology [22, 4]. However long this enumeration may seem, music has also sparked the interest of researchers of seemingly farther fields such as mathematics and computer science. The interest of mathematicians in music is by no means new; it can be traced back to the Greek. That interest has been renewed over the centuries as mathematics has progressed itself. New understanding in mathematics has sooner or later led to new interpretations of musical structures. Music is full of patterns and structures and that inexorably has attracted mathematicians' interest. This interest, however, should not be understood as an irrepresible desire to find patterns and structures in music irrespective of the object itself. That would provide an amiss, unfair impression of mathematics and its methods. In the mathematical research of music there has been a genuine interest to understand the nature of music. The reader can find a reasoned discussion about the scope and purpose of mathematics and computer science in music in [25]. Since computers allow such formidable ways to process musical data, a great wealth of mathematical research in music has served as theoretical foundations in musical technology. Music technology can be defined as the interdisciplinary science of computational description, analysis and treatment of music and music data. An important subfield of music technology is music information retrieval (MIR), the scientific discipline of retrieving data from music.

Over the last few years the use of computational tools in music research has grown rapidly, in music technology and especially in MIR. For example, Meinard [17] identifies four broad areas where audio-signal MIR techniques have intensively been applied to music, namely, audio retrieval, music synchronization, structure analysis, and performance analysis (although he himself acknowledges "this list only scratches the surface"). However, those tools are not intended to substitute traditional methods of research in music.

Nowadays computational tools are thought of to assist, complement, and increase the power of analysis of traditional methodologies, both in quantitative and qualitative terms.

The number of applications of music technology one can find in the literature is simply spectacular; just look at the papers presented at ISMIR [6], the main conference in the field, to obtain an idea of such variety of results. Surprisingly enough, most of research and applications were done for Western music, either popular music or classical music from the common practice. In 2010 Cornelis et al. [3] found that the problem persist, and in spite of all the substantial amount of research undertaken over the past few years, the amount of research done to understand and process ethnic music (non-Western, traditional, and folk music) is still scant and scattered. The challenges posed by the research in ethnic music are significant because of the particular musical features of a given tradition, which in many cases are markedly different from the Western one.

Research in music technology has mainly focused on written Western music, and only recently researchers have begun paying attention to oral traditions. In this respect, flamenco music is a case in point. Flamenco music is an non-Western, oral tradition with very particular musical features whose analysis certainly requires an interdisciplinary approach. A simple question such as musical transcription is by no means solved in flamenco music (see discussion below), just to name a central problem in musical analysis. Furthermore, other fundamental problems in flamenco music are still open, such as melodic and rhythmic similarity, style classification, singer identification, among others.

The main purpose of this paper is to make known the efforts of COFLA[10], a group of researchers from several disciplines who study flamenco music, as well as its results; the group was founded by the authors of this paper. Its goal is to analyze flamenco music from different disciplines, incorporating music technology in that analysis. To accomplish that goal COFLA is composed of an interdisciplinary team including experts from areas such as Musicology, Ethnomusicology, History, Literature, Education, Sociology, but also Mathematics, Engineering, and Computer Science. The structure of this paper is as follows. Next section gives a brief overview of the main musical features of flamenco music. Afterwards three problems the COFLA group is currently working on are presented. Next, the problem of melodic similarity in flamenco a cappella songs is tackled from an interdisciplinary perspective (which is original research). The paper finishes up with a conclusion section.

Flamenco music

Flamenco music is an eminently individual yet highly structured form of music. Indeed, on the one hand, in flamenco music there is a high degree of improvisation and spontaneity; on the other hand, there is an extremely stable organization of the musical material without which improvisation would not work. Flamenco music is the result of reciprocal influence of several cultures through time, which originated a unique combination of singing, dancing, and guitar playing. It has received influences of the Jews and Arabs, but also from the culture of the Andalusian Gypsies, who decisively contributed to its form as we know flamenco today. We refer the reader to the books of Blas Vega and Ríos Ruiz [2], Navarro and Ropero [21], and Gamboa [7] for a comprehensive study of styles, musical forms and history of flamenco.

According to Gamboa [7], flamenco music was mainly developed from the singing tradition. Therefore, the singer's role is dominant and fundamental in flamenco music. In the flamenco jargon, singing is called *cante*, and songs are termed *cantes*; in this paper we use this terminology. Next, we describe the main general features of flamenco *cante* (after [19]).

- Instability of pitch. In general, notes are not clearly attacked. Pitch glides or *portamenti* are very common.
- Sudden changes in volume (loudness). Those sudden changes are very often used as an expressive resource.

- Short melodic pitch range. It is normally limited to an octave and characterized by the insistence on a note and those contiguous to it.
- Intelligibility of voices. Lyrics are important in flamenco, and intelligibility is then desirable. For that reason, contralto, tenor, and baritone are the preferred voice *tessituras*.
- Timbre. Timbre characteristics of flamenco singers depend on the particular singers. As relevant timbre aspects, we can mention breathiness in the voice and absence of high frequency (singer) formants.

Since they will be used later for illustration purposes, we describe briefly a cappella *cantes*, which constitute an important group of styles in flamenco music. They are songs without instrumentation, or in some cases with some percussion. From a musical point of view, a cappella cantes retain the following properties.

- Conjunct degrees. Melodic movement mostly occurs by conjunct degrees.
- Scales. Certain scales such as the Phrygian and Ionian mode are predominant. In the case of the Phrygian mode, chromatic rising of the third and seventh degrees is frequent.
- Ornamentation. There is also a high degree of complex ornamentation, melismas being one of the most significant devices of expressivity.
- Microtonality. Use of intervals smaller than the equal-tempered semitones of Western classical music.
- Enharmonic scales. Microtonal intervallic differences between enharmonic notes.

These features are not exclusive to a cappella *cantes* and can be found to various degrees in other flamenco styles.

The COFLA group

The COFLA group has as its main goal the interdisciplinary study of flamenco music. In this section and as illustration, we present three problems the COFLA group is currently working on.

Musical transcription of flamenco music. As mentioned earlier, in other musical traditions the problem of transcription does not exist or is tractable. In flamenco music, unfortunately, it is not the case. As an oral tradition, performers never had the need to transcribe. Furthermore, flamenco has started to be studied from academia recently and available scores are scant, almost limited to guitar. In fact, consensus about which is the best method to transcribe flamenco music has not been reached among flamenco scholars. Whereas Donnier [5] advocates for the use of Gregorian neumes to annotate flamenco singing, Hurtado and Hurtado [15] and Hoces [13] argue in favor of Western classical notation. Emilia Gómez (COFLA) and collaborators have developed algorithms to automatically transcribe flamenco a cappella singing from audio input (see [8]). These transcriptions can be further tailored to obtain a melodic contour or detailed expressive features related to vibrato or ornamentation. A harder problem is that of the transcription of accompanied singing in polyphonic recordings, requiring a source separation method [9].

Melodic similarity in flamenco music. It is perhaps in this problem where flamenco proves to be an extraordinarily hard type of music to analyze. In other musical traditions, musical similarity is assessed through the sequence of notes and the order they appear in. Two *cantes* belonging to the same style may sound very different to an unaccustomed ear. Underlying each *cante* there is a melodic skeleton. Donnier [5] has termed that melodic skeleton as the "*cante*'s melodic gene." The singer may intersperse all kind of melismas, ornamentation and other expressive resources between the notes of the melodic skeleton. A flamenco aficionado would recognize two different fillings of the skeleton as being the *same song* as long as the skeleton is not changed. In order to help the reader understand this point, in Figures 1 and 2 we show a transcription of two version of the same *cante* to Western musical notation; the scores have not been transposed and reflect the actual pitches used by the singers. A flamenco aficionado recognizes both versions as the same *cante* because certain notes appear in a certain order. What happens between two of those notes does not matter regarding style classification, but does matter for assessing a performance or the piece itself. The main notes that the aficionado must hear have been highlighted in both Figures. See [19] for further information. By style here we mean pieces that share certain musical features; in flamenco every piece belongs to a specific style (sometimes a piece can be composed of sections in several styles).

Figure 1: Mairena's rendition of *En el barrio de Triana*.

Figure 2: Lobato's rendition of *En el barrio de Triana*.

In these transcriptions many melismas from the actual recording were removed for ease of reading. It is clear now that the problem in musical similarity in flamenco is quite complex and intricate. A line of research COFLA is pursuing consists of defining a melismas lexicon so that melismas could be discarded, and thus main notes could be identified.

Detection of distinctive melodic patterns in flamenco music. Since flamenco is orally transmitted, melody plays a central role. However, the way flamenco musicians memorize melodies is not note by note. For each style they learn a few melodic patterns, out of which later they will add their personal touch. Therefore, the identification of those patterns is of paramount importance. There are two approaches to the problem of finding distinctive patterns. The first one is an inductive method. Flamenco corpora are automatically analyzed in search of patterns that appear often or in certain positions in the piece. For further details on how this problem has been addressed by the COFLA group, see [12]. The other method, more interesting from a interdisciplinary point of view, is deductive. Flamenco experts define patterns that they consider meaningful or distinctive of a given style. Then their hypotheses are tested for searching those patterns in large corpora of flamenco music. Both approaches lead to many fascinating open questions;

here there is a short list: (1) What is the melodic pattern common to authoritative recordings of flamenco masters?; (2) What is the characteristic ornamentation of a given style?; (3) Which ornaments are mandatory in a given style?

An example of interdisciplinary research on flamenco music

As an example of the interdisciplinary research carried out by the COFLA group, we will study the problem of melodic similarity for style classification. One of the problems the COFLA group chose to tackle was that of a cappella *cante* classification. Three substyles, *deblas*, *martinete-1*, and *martinete-2*, from a style called *tonás* were selected to carry out this study. *Tonás* are *cantes* sung in free rhythm. Scale and melody type are modal. Frequent modes are major, minor, or Phrygian, though alternation of modes is also common. The lyrics of these songs range widely. This *cantes* possess a high degree of ornamentation; the *cantes* annotated in Figures 1 and 2 above are actually *deblas*.

Since scores were not available, the first step we took was to extract an automatic transcription from the audio files. The corpus was composed of 72 *tonás*, which included *deblas, martinete-1*, and *martinete-2*. We used the system proposed in [8], for the transcription task. Melodic transcription is usually structured into three different stages: low-level feature extraction, frame-based descriptor extraction (e.g., energy and fundamental frequency), note segmentation (based on location of note onsets), and note labelling. For more technical details, see [8] and the references therein.

The output of this first step is a MIDI-like file containing the sequence of notes and durations, representing the melodic contour. The corpus employed for our research can be found in [11]. In geometric terms, that sequence can be interpreted as a plane polygonal chain. The x-coordinate represents the duration of notes while the y-coordinate represents the pitch. From this point on, many mathematical techniques can be applied to the problem of determining the distance between two *cantes*. The problem of determining how similar two *cantes* has been transformed into the problem of determining the distance between the polygonal chains given by the melodic contours. There is a plethora of algorithms to compute the distance between two such chains (edit distance, n-grams, vector correlation). One of the most popular is the edit distance. Given two polygonal chains, we consider three basic operations to transform one chain into another: insertion of a note, deletion of a note, and substitution of a note. The edit distance between two polygonal chains is then defined as the minimum number of operations required to transform one chain into another. As a matter of fact, those operations have weights assigned, which depends on the specific problem.

However, most of those similarity measures lack perceptual validity, that is, they have not tested on subjects. In a 2004 paper Müllensiefen and Frieler [20] addressed this problem. Their first step was to establish some ground truth for melodic similarity under certain conditions; secondly, they analyzed 34 similarity measures (or dissimilarity distances) found in the existing literature to determine the most adequate measures in terms of perceptual validity. The best similarity measure was a linear combination between the raw edit distance and the n-grams, specifically $3.355 \cdot ED + 2.852 \cdot NG$, where ED is the edit distance and NG the n-grams distance. We followed their results to compute our similarity measures between *cantes*. The distance matrix obtained was used to feed an algorithm that computes phylogenetic graphs. Given a distance matrix from a set of objects, a phylogenetic graph is a graph whose nodes are the objects in the set and such that the distance between two nodes in the graph corresponds to the distance in the matrix; see [16] for more information. If possible, the phylogenetic graph algorithm tries to output a tree (a connected graph with no cycles). If that is not possible, then the algorithm introduces new nodes, which may create cycles, and outputs a more general graph. However, phylogenetic graphs are always planar graphs. Also, along the graph the algorithm outputs and index, $LSFit$, which is expressed as a percentage. It indicates how accurate the correspondence between the distances in the graph and the distances in the set of objects is. The higher the index is, the more accurate the correspondence between matrix and graph distances is. For our set of *cantes* that index is 99.19%; the resulting graph can be seen in Figure 3.

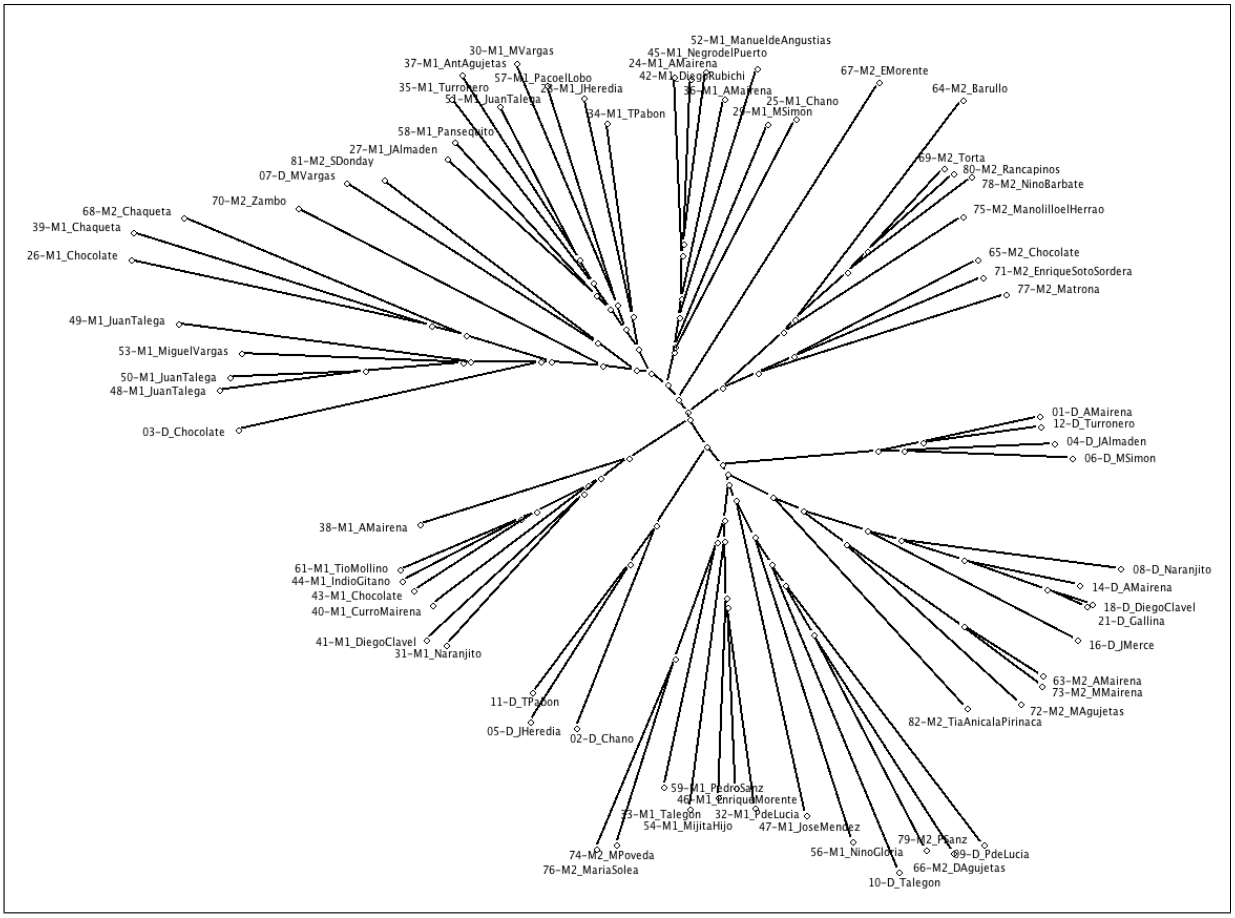

Figure 3: The phylogenetic graph for the melodic contour distance.

Because of the problem of ornamentation mentioned earlier, the phylogenetic graph produced poor results (there were many misclassified *cantes*). The *cantes* were classified a priori by the flamenco experts in the COFLA group. Then, once the distance matrix was computed, a *cante* was classified according to its k nearest neighbors (several values of k were tested, but they all gave poor performance). For example, if $k = 1$, a *cante* is classified as the style of its nearest neighbor. The main problem lies in the fact that two *cantes* may have the same main notes and very different ornamentations between them. However, an edit distance would give a high distance between them. More knowledge was required to obtain better results.

Typically, musical descriptors fall in three categories: low-level descriptors, mainly related to properties of the audio signal such as frequency, spectrum, or intensity; mid-level descriptors, associated to pitch, melody, chords, timbre, beat, meter, or rhythmic patterns; and finally high-level descriptors, typically linked to meaning and expressiveness such as mood, motor and affective responses. To circumvent the problem of ornamentation in the *cantes*, we defined a distance based on mid-level descriptors. The mid-level descriptors used for all *tonás* in our study were the following: (1) Initial note of the piece; (2) Symmetry of the highest degree in the second hemistich; (3) The frequency of the highest degree in the second hemistich (a hemistich is half of a line of poetry); (4) Clivis at the end of the second hemistich (a melodic movement consisting of two descending notes); (5) Final note on the second hemistich; (6) Highest degree in the *cante*; (7) Duration of the *cante*. As a matter of fact, just using features very peculiar to a given style would distort the analysis, as their discriminating power would be very high. Our intention was to select a set of a few features capable of discriminating between different *cantes*. Note that the variables chosen here are of a more musical nature.

The computation of these variables requires that ornamentation is taken into account and initially was done manually by flamenco experts. We are working on how to compute them automatically (some very hard computational problems arise here).

We defined a new distance that was a linear combination of the melodic contour and this mid-level distance. The results improved dramatically. The melodic contour accounted for local changes and the mid-level distance measured global changes. The clustering showed by the combined distance made sense according to flamenco experts and the number of misclassified *cantes* decreased to normal levels. Also, the distance allowed the study of intra-style characteristics; that study was not possible with the melodic contour distance.

Conclusions

In this paper we have presented an example of interdisciplinary research through the work of the COFLA group. In the group there are researchers of various disciplines, including mathematics, engineering, and computer science, who strive for understanding a musical tradition as complex and rich as flamenco music. At the outset we warned against doing mathematics for the sake of it (*the irrepresible desire to find patterns and structures*) and we believe we have escaped the danger. Indeed, in the example given, the problem of melodic similarity in a cappella *cantes*, we have seen that interdisciplinary methodology at work. The corpus was selected by flamenco experts; engineers, computer scientists, and mathematicians designed the algorithms to extract the melodic sequences from the audio files; mathematicians studied the problem of the similarity distance. As results were not satisfactory enough when the melodic contour distance alone was used, more research was in order. Flamenco experts designed the mid-level distance; again the scientists in the team were in charge of the computations and the assessment of results.

Many open problems remain to be considered. Our distance, although giving good results, can be certainly improved. In particular, we are working on the generalization of mid-level distance to other flamenco styles (the variables were specifically design for that corpus). An interesting question is what is the minimum set of variables that can be used to satisfactorily measure melodic similarity in flamenco music. The problem of automatically identifying ornaments in flamenco styles is still open and seems computationally hard. More research has to be done in the problem of the automatic detection of distinctive patterns. Although there are some studies, rhythmic similarity in flamenco music is a field waiting to be explored, particularly in hand-clapping rhythms.

References

[1] R. Berg and D.G. Stork. *The physics of sound*. Addison-Wesley, 2004.

[2] J. Blas Vega and M. Ríos Ruiz. *Diccionario enciclopédico ilustrado del flamenco*. Cinterco, Madrid, 1988.

[3] Olmo Cornelis, Micheline Lesaffre, Dirk Moelants, and Marc Leman. Access to ethnic music: Advances and perspectives in content-based music information retrieval. *Signal Processing*, 90(4):1008–1031, 2010.

[4] Diana Deutsch. *The Psychology of Music*. Academic Press, 1998.

[5] P. Donnier. Flamenco: elementos para la transcripción del cante y la guitarra. In *Proceedings of the III Congress of the Spanish Ethnomusicology Society*, Spain, 1997.

[6] International Society for Music Information Retrieval. (ISMIR). http://www.ismir.net/, accessed in January, 2014.

[7] J. M. Gamboa. *Una historia del flamenco*. Espasa-Calpe, Madrid, 2005.

[8] Emilia Gómez and J Bonada. Towards computer-assisted flamenco transcription: An experimental comparison of automatic transcription algorithms as applied to a cappella singing. *Computer Music Journal*, 37:73–90, 2013.

[9] Emilia Gómez, F. Cañadas, J. Salamon, J Bonada, P. Vera, and P. Cabañas. Predominant fundamental frequency estimation vs singing voice separation for the automatic transcription of accompanied flamenco singing. In *13th International Society for Music Information Retrieval Conference (ISMIR 2012)*, Porto, 08/10/2012 2012.

[10] The COFLA group. The COFLA group. http://mtg.upf.edu/research/projects/cofla.

[11] The COFLA group. Corpus tonás. http://mtg.upf.edu/download/datasets/tonas, accessed in January, 2014.

[12] F. Gómez, A. Pikrakis, J. M. J. Mora, Díaz-Báñez, E. Gomez, and F. Escobar. Automatic detection of ornamentation in flamenco. In *Proc.of the 4th International Workshop on Machine Learning and Music. NIPS conference*, Granada, 2011.

[13] R. Hoces. *La transcripción musical para guitarra flamenca: análisis e implementación metodológica*. PhD thesis, Universidad de Sevilla, 2011.

[14] H. Honing. *Musical Cognition: A science of listening*. Transaction Publishers, 2013.

[15] D. Hurtado and A. Hurtado. El arte de la escritura musical flamenca. In *Bienal de Arte Flamenco*, Sevilla, 1998.

[16] Daniel H Huson and David Bryant. Application of phylogenetic networks in evolutionary studies. *Mol Biol Evol*, 23(2):254–267, 2006.

[17] M. Meinard. New developments in music information retrieval. In *Audio Engineering Society 42nd International Conference*, Ilmenau, Germany, July 2011.

[18] B. Merker and S. Brown. *The origins of music*. MIT Press, Cambridge, 2000.

[19] J. Mora, F. Gómez, E. Gómez, F. Escobar Borrego, and Díaz Báñez J.M. Characterization and melodic similarity of a cappella flamenco cantes. In *ISMIR (International Symposium on Music Information Retrieval)*, Utrecht, Netherland, August 2010.

[20] D. Müllensiefen and J. Frieler, K. Cognitive adequacy in the measurement of melodic similarity: algorithmic vs. human judgments. *Computing in Musicology*, 13:147–176, 2004.

[21] J.L. Navarro and M. Ropero, editors. *Historia del flamenco*. Ed. Tartessos, Sevilla, 1995.

[22] R. E. Radocy and D. J. Boyle. *Psychological Foundations of Musical Behaviors*. Charles C. Thomas, Springfield, Ill., 2003.

[23] J. Sloboda. *Exploring the musical mind: cognition, emotion, ability, function*. Oxford University Press, 2005.

[24] David Temperley. *The Cognition of Basic Musical Structures*. The MIT Press, Cambridge, Massachusetts, 2001.

[25] A. Volk and A. Honingh. Mathematical and computational approaches to music: challenges in an interdisciplinary enterprise. *Journal of Mathematics and Music*, 6(2):73–81, 2012.