COMPUTATIONAL APPROACHES FOR THE UNDERSTANDING OF MELODY IN CARNATIC MUSIC

Gopala K. Koduri, Marius Miron, Joan Serrà and Xavier Serra
Music Technology Group
Universitat Pompeu Fabra, Barcelona, Spain
gopala.koduri@gmail.com,miron.marius@gmail.com,joan.serraj@upf.edu,xavier.serra@upf.edu

ABSTRACT

The classical music traditions of the Indian subcontinent, Hindustani and Carnatic, offer an excellent ground on which to test the limitations of current music information research approaches. At the same time, studies based on these music traditions can shed light on how to solve new and complex music modeling problems. Both traditions have very distinct characteristics, specially compared with western ones: they have developed unique instruments, musical forms, performance practices, social uses and context. In this article, we focus on the Carnatic music tradition of south India, especially on its melodic characteristics. We overview the theoretical aspects that are relevant for music information research and discuss the scarce computational approaches developed so far. We put emphasis on the limitations of the current methodologies and we present open issues that have not yet been addressed and that we believe are important to be worked on.

1. INTRODUCTION

Though all music traditions share common characteristics, each one can be recognized by particular features that need to be identified and preserved. The information technologies used for music processing have typically targeted the western music traditions, and current research is emphasizing this bias even more. However, to develop technologies that can deal with the richness of our world's music, we need to study and exploit the unique aspects of other musical cultures. By looking at the problems emerging from various musical cultures we will not only help those specific cultures, but we will open up our computational methodologies, making them much more versatile. In turn, we will help preserve the diversity of our world's culture [26].

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The two classical music traditions of the Indian subcontinent, Hindustani [1] and Carnatic [2], are among the oldest music and most unique traditions still alive. There are excellent musicological and cultural studies about them, they maintain performance practice traditions and they exist within real social contexts. Thus, they are an excellent ground on which to build new information models and a way to challenge the dominant western-centred paradigms. In this article we focus on Carnatic music, the tradition of south-India.

Carnatic music shares with the Hindustani tradition some basic foundations, such as the basic elements of shruti (the relative musical pitch), swara (the musical sound of a single note), raaga (the melodic mode), and taala (the rhythmic pattern). Although improvisation plays an important role, Carnatic music is mainly sung through compositions, differently from Hindustani music where improvisation is fundamental. Carnatic music is usually performed by a small ensemble of musicians, consisting of a principal performer (usually a vocalist), a melodic accompaniment (usually a violin), a rhythm accompaniment (usually a mridangam), and a tambura, which acts as a drone throughout the performance. Other typical instruments used in Carnatic performances may include the ghatam, kanjira, morsing, veena and flute.

The computational study of Carnatic music offers a number of problems that require new research approaches. Its instruments emphasize sonic characteristics that are quite particular and not well understood yet. The concepts of raaga and taala are completely different to the western concepts used to describe melody and rhythm. Carnatic music scores serve a different purpose to those of western music. The tight musical and sonic relationship between the singing voice, the other melodic instruments and the percussion accompaniment within a song, requires going beyond the modular approaches commonly used in music information research (MIR). The special and participatory communication established between performers and audience in concerts, offers great opportunities to study issues of social cog-

[1] http://en.wikipedia.org/wiki/Hindustani_classical_music
[2] http://en.wikipedia.org/wiki/Carnatic_music

nition. Its devotional aim is fundamental to understand the music. The study of the song lyrics is also essential to understand the rhythmic, melodic and timbre aspects of Carnatic music. And many more interesting music aspects could be identified of relevance to music information processing.

In the next section we focus on the melodic aspects of Carnatic music, over-viewing the theoretical aspects that are relevant for MIR and discussing the scarce computational approaches that have been presented. In the last section we present open issues that have not yet been addressed and that we believe are important to be worked on.

2. COMPUTATIONAL APPROACHES TO MELODY

The most fundamental melodic concept in Indian classical music is raaga. Matanga is the first known person to define what a *raaga* is [28]: "In the opinion of the wise, that particularity of notes and melodic movements, or that distinction of melodic sound by which one is delighted, is raaga". Therefore, the raaga is neither a tune nor a scale [18]. It is a set of rules which can together be called a melodic framework. The notion that a raaga is not just a sequence of notes is important in understanding it and for developing computational models. Also the concept of raga has been changing with time. Nowadays a given raaga can be described by properties such as: a set of notes (swaras), their progressions (arohana/avarohana), the way they are intonated using various movements (gamakaas), and their relative position, strength and duration (types of swaras). In order to identify raagas computationally, swara intonation, scale, note progressions and characteristic phrases are used (Secs. 2.1 and 2.2). Unexploited properties of a raaga include gamakaas and the various roles the swaras play (Sec. 2.3).

2.1 Swaras and shrutis

In Indian music, swaras are the seven notes in the scale, denoted by Sa, Ri, Ga, Ma, Pa, Da and Ni [3] [27]. Except for the tonic and the fifth, all the other swaras have two variations each, which account for 12 notes in an octave, called swarasthanas. There are three kinds of scales that one generally encounters in Carnatic and Hindustani music theory: a 12-note scale, a 16-note scale and the scale which claims 22 shrutis [4] . The 16-note scale is the same as the 12-note scale except that 4 of the 12 notes have two names each, in order to be backward compatible with an older nomenclature.

Few musicians and scholars claim that there are more shrutis in practice than those explained above. Though many of them argue the total number to be 22, that itself is debated [9]. A more important question to be asked is whether they are used in current practice at all. Some musicologists say that they are no more used [21]. It is also said that they are wrongly attributed to Bharata, who used shruti to mean "the interval between two notes such that the difference between them is perceptible". Krishnaswamy [13] argues that the microtonal intervals observed in Carnatic music are the perceptual phenomena caused by the gamakaas, i.e. that these microtonal intervals are what few scholars and musicians claim as 22 shrutis. However, we believe that these claims need to be verified with perceptual and behavioural studies. In our encounters with most musicians, we can only conclude that they are unaware of the usage of 22 shrutis in practice. Few musicians who claim they are used, are not ready to demonstrate them in a raaga. In general, more empirical, quantitative and large-scale evidence needs to be gathered. Our preliminary research on this line shows no support for the usage of 22 shrutis [25].

The tuning itself, whether it is just-intonation or equi-tempered, is an issue of debate [5] [12, 25]. Since Indian classical music is an orally transmitted tradition, perception plays a vital role. For instance, tuning seldom involves an external tool. And even the tambura, which is used as a drone, and thus as a reference for tuning, has a very unstable frequency. Hence the analysis of empirical data coupled with perceptual studies are important. In [25] we have carried out an empirical analysis of the stable tunings employed by some Carnatic and Hindustani singers. The results suggest a clear tendency towards just-intonation in the case of Carnatic music while, at the same time, they point out to a strong influence of equi-tempered tuning in the case of Hindustani music.

Fixed tunings are not the whole story. In fact, it is a well accepted notion that a note (swarasthana) is a region rather than a point [7,27]. Thus, a fixed, stable tuning for each note is not as important as it is in, say, western classical music. In addition, Sa, the tonic, can be any frequency. It depends on the comfort of the singer or the choice of the instrument player. A given note can have several variations in intonation depending on the raaga. This variability in intonation arises from vocal articulations or the pulling of instrument strings. Even if two raagas have the same scale, the intonation of notes vary significantly. Belle *et al* [2] have used this clue to differentiate raagas that share the same scale. They evaluated their system on 10 audio excerpts accounting for 2 distinct scale groups (two raagas each). They showed that the use of swara intonation features improved the accuracies achieved with pitch-class distributions (c.f. [3]). This clearly indicates that intonation differences are significant to understanding and modeling raagas computationally. Levy [16] analyses the intonation in Hindustani raaga performances and notes that it is highly variable, and that it does not seem to agree with any standard tuning system. Subramanian [33] reports much the same for Carnatic music. These studies call for the need to understand the extent to which a given

[3] This notation is analogous to e.g. Do, Re, Mi, Fa, So, La and Ti.

[4] Shruti is the least perceptible interval as defined in Natyasastra [22].

[5] http://cnx.org/content/m12459/1.11

Raaga	Singer	Tested	Correctly identified
Sankarabharanam	Nithyasree	5	4
	Subbulakshmi	3	2
	Balamurali	2	1
Kanakangi	Nithyasree	8	6
	Ilayaraja	2	1
Karaharapriya	Nithyasree	10	6

Table 1. Results of Rajeswari & Geeta's raaga identification method.

note can be intonated. In particular, this could be of interest to differentiate artists and styles.

All these works indicate that a complete characterization of swarasthanas must go beyond static frequency measurements and that their dynamics need to be considered. The problem implies much more than trying to discriminate whether swarasthanas are tuned to just-intonation, equi-tempered or following 22 shrutis. Much empirical data like the one reported in [33] and [16] needs to be gathered to investigate the intervals, the range of intonations and the temporal evolution of each swarasthana.

2.2 Arohana and avarohana

Typically, a raaga is represented using ascending (arohana) and descending (avarohana) progressions of notes. There are certain note transition rules that are necessary to be followed when performing a raaga. The set of unique notes in these progressions form a scale. For raaga identification, Rajeswari *et al* [31] estimate the scale from the given tune by comparing it with template scales. Their test data consists of 30 tunes in 3 raagas sung by 4 artists. They use the harmonic product spectrum algorithm [15] to extract the pitch, giving the tonic manually. The other frequencies in the scale are marked down based on the respective ratio with the tonic. The results obtained are shown in Table 1, which depicts a 67% accuracy. The authors claim that such a low accuracy could be due to discrepancies in the manually fed tonic. But considering that their system identifies only the swaras that are used in a raaga and no other relevant data, the result shows that the swaras alone can be very useful. However, there are raagas which have the same swaras (since the scales of the raagas they considered are different, this is not an issue in their study).

Shetty *et al* [29] use a similar approach when they try to recognize raagas. The features extracted are the individual swaras and their relation in arohana-avarohana (swara pairs). The features are represented as bit sequences which are later converted to decimal values. These features are used for training a neural network. They report an accuracy of 95% over 90 tunes from 50 raagas, using 60 tunes as training data and the remaining 30 tunes as test data. However, such a high accuracy is questionable due to the few data per class used. Moreover, no cross-fold validation was done.

Sahasrabudde *et al* [23] model the raaga as finite automata. A finite automata has a set of states between which the transitions take place. In the case of raaga, the swarasthanas are the states and the note transitions are observed. This idea is used to generate a number of audio samples for a raaga, which they claim are technically correct and indistinguishable from human compositions. Inspired by this, Pandey *et al* [17] use HMM models to recognize the raagas. The rules to form a melodic sequence for a given raaga are well defined in the musicology literature [24] and the number of notes is finite. Therefore, intuitively, HMM models should be good at capturing those rules in note transitions imposed by arohana and avarohana patterns (at least the first-order, simpler ones).

Each raaga has also a few characteristic phrases. They are called swara sancharas in Carnatic and pakads in Hindustani. These phrases are said to be very crucial for conveying the feeling of the raaga [9]. Typically, in a concert, the artist starts by singing these phrases. They are the main clues for the listeners to identify which raaga it is. Pandey *et al* have complemented their approach with values obtained from two modules that match characteristic phrases, taking advantage of this information. In one such module, characteristic phrases are identified with a substring matching algorithm. In the other one, they are identified by counting the occurrences of frequency n-grams in the phrase.

The other important contributions by Pandey *et al* include two heuristics to improve the transcription of Indian classical music: the hill peak heuristic and the note duration heuristic. As mentioned, Indian music has a lot of micro tonal variations which makes even the monophonic note transcription a challenging problem [17]. The two heuristics proposed in their approach try to get through these micro tonal fluctuations in attaining a better transcription. The hill peak heuristic states that a significant change in the slope of a pitch contour (or the sign reversal of such slope) is closely associated with the presence of a note. The note duration heuristic considers only the notes that are played for at least a certain span of time. The approach was tested on two raagas. Table 2 shows the results obtained by using HMMs alone, and by complementing the models with characteristic phrase matching. Not much can be said about the reliability of the features they used since the number of classes considered were just two. But the advantage of characteristic phrase matching is evident.

Sinith *et al* [30] also used HMMs of raagas to search for musical patterns in a catalogue of monophonic Carnatic music. They build models for 6 typical music patterns corresponding to 6 raagas (they report a 100% accuracy in iden-

Raaga	Samples	HMM	HMM + Phrase matching
Yaman Kalyan	15	80%	80%
Bhupali	16	75%	94%
Total	31	77%	87%

Table 2. Accuracy of raaga identification reported in [17].

tifying an unknown number of tunes into 6 raagas). HMMs are also used by Das and Choudary [6] to automatically generate Hindustani classical music.

Chordia and Rae [3] use pitch class profiles and bi-grams of pitches to classify raagas. The dataset used in their system consists of 72 minutes of monophonic instrumental (sarod) data in 17 raagas played by a single artist. Again, the harmonic product spectrum algorithm [15] is used to extract the pitch. Note onsets are detected by observing the sudden changes in the phase and the amplitude of the signal. Then, the pitch-class profiles and the bi-grams are calculated. It is shown that bi-grams are useful in discriminating the raagas with the same scale. They use several classifiers combined with dimensionality reduction techniques. The feature vector size is reduced from 144 (bi-grams) + 12 (pitch profile) to 50 with principal-component analysis. Using just the pitch class profiles, the system achieves an accuracy of 75%. Using only bi-grams of pitches, the accuracy is 82%. Best accuracy of 94% is achieved using a maximum a posteriori rule with a multi-variate likelihood model. Comparison to other classifiers is shown in [3].

2.3 Unexploited properties of raaga

2.3.1 Gamakaas

In Carnatic music the various forms of pitch movements are together called gamakaas. A sliding movement from one note to another or a vibrato are examples of gamakaas. There are various ways to group these movements, but the most accepted classification speaks of 15 types of gamakaas. Gamakaas are not just decorative items or embellishments, but very essential constituents of a raaga [9]. Each raaga has some characteristic gamakaas. Thus, the detection of gamakaas is a crucial step to model and identify raagas.

A gamakaa is often represented using discrete notes, but it does not necessarily mean that one plays them using discrete steps. The representation is only a handy expression of a more continuous sounding pattern, which is difficult to represent on the paper. A gamakaa is almost always a smooth change in the dynamics of a pitch contour. Similar concepts are used to describe the pitch inflections in Hindustani music [19]. Owing to their tremendous influence on how a tune sounds, the gamakaas and the related pitch inflections in Hindustani music are often considered the soul of Indian classical music.

There are two major issues that make identifying a gamakaa a challenging problem. First, it requires a very precise pitch transcription. Second, the variations found for different artists in performing a gamakaa complicate it further. Krishnaswamy [14] and Subramanian [33] report such variations across different artists performing the same gamakaa. They also propose some theoretical guidelines to resolve the second problem to some extent. These variations should be exploited in performers' computational modeling, a field that lacks much research in the case of Indian classical music.

2.3.2 Various roles played by the notes

In a given raaga, not all the notes play the same role. Though two given raagas have the same set of constituent notes, their functionality can be very different, leading to a different feeling altogether [34]. For example, some swaras occur frequently, some are prolonged, some occur either at the beginning or the end of the phrases, etc. In addition, there are alankaras, patterns of note sequences which are supposed to beautify and instil feelings when listened to.

Though emotion is a subjective issue, it gets into almost every discussion involving raagas. That is because each raaga is said to evoke characteristic emotions. To test this hypothesis, Chordia and Rae [4] have conducted a survey to check whether Hindustani raagas elicit emotions consistently across listeners. Positive results are reported, jointly with the musical properties like relative weight of the notes, which partially explain the phenomenon. Koduri *et al* [11] have conducted a similar survey with Carnatic raagas. Though not as significant as the pattern reported by Chordia *et al*, the results indicate that Carnatic raagas elicit emotions which are consistent across listeners. Wieczorkowska *et al* [35] tests if raagas elicit emotions, and also arrive at a mapping between melodic sequences of 3 or 4 notes and the elicited emotions. Their work suggests that different compositions in the same raaga might elicit different emotions, what is consistent with the observations made by Koduri *et al* [11]. Wieczorkowska *et al* note that these melodic sequences are related vaguely to the subjects' emotional responses. Another interesting observation is the significance in the similarity between the responses of people from various cultures, which is consistent with the observations made in a previous study conducted by Balkwill *et al* [1].

3. OPEN ISSUES: GAMAKAAS, TAALAS, INSTRUMENTS AND IMPROVISATION

Little research has been carried out on Carnatic music and even less on the specific characteristics that makes it so special. Few proposed computational approaches have focused on raaga recognition and the results are quite preliminary given that the data used is not representative of the existing variety of raagas. The high accuracies reported might be due to the limited number of raagas used and the small sizes of the datasets. Moreover, important properties of the raagas, like their specific use of gamakaas, have not been exploited yet, and issues beyond recognition have neither been approached. We hypothesize that, as more representative datasets are gathered, the features used will not be sufficient to discriminate the raaga classes. Features such as pitch-class profiles and pitch-class dyad distributions infer partial information about the raagas. But the other roles of notes are not evident, which need to be exploited. Symbolic scores can also be used for building more complex models, especially to model the characteristic melodic movements of particular raagas.

While raaga is the fundamental concept related to melody, taala is the fundamental concept related to rhythm [34]. A taala is a rhythmic cycle, which is divided into specific uneven sections, each of them subdivided into even measures. The first beat of each taala section is accented, with notable melodic and percussive events. The characteristics of a taala are related to the main instrument used to emphasize the rhythmic aspect in a song, the mridangam. Understanding the acoustics of the mridangam and how it is played, is fundamental to model the taalas. Sambamoorty [24] lists all taalas and provides the description for each. The recognition of the different types of strokes to play the mridangam, bols, is an open topic. Current MIR research on drum transcription uses small numbers of drum stroke classes and each class is associated with a specific (single) drum, usually based on the typical western drum set. With mridangam, multiple bols are associated to each drum, and given that is a tuned instrument, the recognition of the bols have to take into account both timbre and pitch information. Some work has been done on the recognition of bols in Hindustani music, with the tabla [8] [5], but no research has been carried out in Carnatic music, with the mridangam. There is also no research focusing on the recognition or classification of taalas. As the musician always tries to embellish the taala, there is a strong variation from performance to performance, and the rhythmic complexity obtained is enormous. The main goal would be to gain insensitivity to these variations in order to classify taalas or, otherwise, to model these variations for understanding performance and improvisation. For this research we need to use top-down or other contextual information to make sense of the audio data, for example there is a well-defined structure to improvisation which should be exploited [9].

We have reported on previous work that has verified whether raagas elicit emotions and tried to map the musical features which are responsible for such phenomenon. Besides the note sequences, another important aspect of Indian classical music which could play a crucial role in eliciting emotions is gamakaa. However, there are no studies which report their effect so far. The kind of instruments used and the rhythmic aspects also need to be accounted when dealing with emotional aspects.

At the level of musical instruments there is practically nothing done. Physical modeling of their many non-linear behaviours is quite complex and the lack of instrument standardization does not help. Some research has been done on modeling north-Indian instruments like the tabla and sitar [10] and there have been a few attempts in developing sound synthesis systems [32]. The timbre of the tambura is at the basis of the Indian sound. It has a special overtone-rich sound, a sustained ”buzzing” resulting from the wide and arched bridge on which the strings rests and of the cotton thread placed between the strings and the bridge. This type of string termination results in a quite complex acoustic system first discussed by Nobel Prize winning physicists C V Raman [20] and for which current F0-detection methods perform very poorly.

The performance practice tradition has not been studied at all. Music performance is mainly learned by imitation, without much use of symbolic representations. The variability in performances of the same song is quite large, especially due to the importance of improvisation. The same composition sung by two artists can be different in many musical and expressive facets. These differences may challenge the version identification methods developed for western commercial music. In addition to the compositional forms, there are many improvisatory forms that are performed with well-defined structural criteria [9].

Through the article we have mentioned a number of characteristics of Carnatic music that deserve to be studied. Given that this music tradition is so different from the ones used to develop the current computational methodologies, there is a need to deal with some more fundamental issues related to music information processing. We need to study how the musical concepts and terms in Indian music are understood, specifying proper ontologies with which to frame our work. Also the cultural and community aspects of the music are so important that, without studying them, we will not be able to develop proper musical models. In summary, to approach the computational modeling of Carnatic music, making justice to its richness, it is fundamental to take a cultural approach and, thus, take into account musicological and contextual information.

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