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Methods to find Musical Compositions with grid Diagrams for Indian Classical (Hindustani) Notations

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Abstract— This thesis is a contribution to the concepts of Hindustani Magic, a module for the generation and application of musical grid structures, which is part of the mu-sic composition software presto (Atari ST), are generalized, abstracted and adapted for modern factorial mathematical music theory. Furthermore, an new implementation for the present day composition software Rubato Com[p]oser (Java) is provided.

The use of computers for music composition became more and more important by the end of last century. First of all, there are many commercial software products such as sequencing software [Logic] [Cubase], which are indispensable for the production of modern popular music, or notation software [Sibelius] [Finale]. However, already in 1991, Karlheinz Essl, one of today's leading computer music composers, said that for entering unknown musical territory, the widespread commercial products are not suitable . For such uses, since the early days of computer music, composers like Max Mathews, Gottfried Michael Koenig and Iannis Xenakis used to write their own software and this has not changed since then.

Index Terms—Hindustani Music, Computer Music, Music Composition,Gandharva Music, Bandish,Drupad Tarana, Tappa and Semiotics.

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Described as one of the most powerful music composition tools to date [Mazz89], a module in presto, namely the OrnaMagic module, allows to generate and use periodic grid constructions in an abstract way never seen since. Many other software products incorporate similar functions, which are in fact special cases of OrnaMagic applications, namely quantizing or tonal alteration.

Today, the Atari ST is outdated and modern mathematical music theory has made many steps forward [Mazz02] and now uses more abstract and versatile data types and operations. A new software product has been created according to these new theoretical foundations, namely Rubato Composer [Milm06a] [RubatoC]. It is a platform independent Java 1.5 application, featuring an extended mathematical framework as well as a modular design.

Hindustani classical music (Hindi: हिन्दुस्तानी शास्त्रीय संगीत, Urdu: کلاسیکی موسیقی) is the Hindustani or North Indian style of Indian classical music found throughout the northern Indian subcontinent. The style is sometimes called **North Indian classical music** or **Shāstriya Sangīt**. It is a tradition that originated in Vedic ritual chants and has been evolving since the 12th century CE, primarily in what is now North India, Pakistan and Bangladesh and to some extent in Nepal and Afghanistan. Today, it is one of the two subgenres of Indian classical music, the other being Carnatic music, the classical tradition of South India.

Characteristics

The tradition was born out of a cultural synthesis of several musical traditions: the Vedic chant tradition, dating back to more than three thousand years ago,[1] the ancient Persian tradition of Musiqi-e assil, and various folk traditions prevalent in the region.

1. Introduction:

It is traditional for performers who have reached a distinguished level of achievement to be awarded titles of respect; Hindus are usually referred to as*pandit* and Muslims as *ustad*. An aspect of Hindustani music going back to Sufi times is the tradition of religious neutrality: Muslim ustads may sing compositions in praise of Hindu deities, and vice versa.

Around the 12th century, Hindustani classical music diverged from what eventually came to be identified as Carnatic classical music. The central notion in both these systems is that of a melodic mode or raga, sung to a rhythmic cycle or tala. The tradition dates back to the ancient Samaveda, (*sāma* meaning "ritual chant"), which deals with the norms for chanting of srutis or hymns such as the *Rig Veda*. These principles were refined in the musical treatises *Natya Shastra*, by Bharata (2nd–3rd century CE), and *Dattilam* (probably 3rd–4th century CE).[2]

In medieval times, the melodic systems were fused with ideas from Persian music, particularly through the influence of Sufi composers like Amir Khusro, and later in the Moghul courts. Noted composers such as Tansen flourished, along with religious groups like the Vaishnavites. After the 16th century, the singing styles diversified into different gharanas patronized in different princely courts. Around 1900, Vishnu Narayan Bhatkhandeconsolidated the musical structures of Hindustani classical music, called ragas, into a number of thaats. Indian classical music has seven basic notes with five interspersed half-notes, resulting in a 12-note scale. Unlike the 12-note scale in Western music, the base frequency of the scale is not fixed, and intertonal gaps (temperament) may also vary; however, with the gradual replacement of the sarangi by the harmonium, an equal temperedscale is increasingly used. The performance is set to a melodic pattern called a raga characterized in part by specific ascent (aroha) and descent (avaroha) sequences, which may not be identical. Other characteristics include "king" (vadi) and "queen" (samavadi) notes and characteristic phrases (pakad). In addition each raga has its natural register (ambit) and portamento (meend) rules. Performances are usually marked by considerable improvisation within these norms.

History:

Music was first formalized in India in connection with preserving the sruti texts, primarily the four vedas, which are seen as *apaurasheya* (meaning "not created by man"). Not only was the text important, but also the manner in which they had been enunciated by the immortals. Prosody and chanting were thus of great importance, and were enshrined in the two vedangas (bodies of knowledge) called shiksha (pronunciation, chants) andchhandas (prosody); these remained a key part of the brahmanic educational system till modern times.

The formal aspects of the chant are delineated in the *Samaveda*, with certain aspects, e.g. the relation of chanting to meditation, elaborated in the*Chandogya Upanishad* (ca. 8th century BC). Priests involved in these ritual chants were called *samans* and a number of ancient musical instruments such as the conch (shankh), lute (veena), flute (bansuri), trumpets and horns were associated with this and later practices of ritual singing.

Sanskritic tradition[edit]

The Samaveda outlined the ritual chants for singing the verses of the Rigveda, particularly for offerings of Soma. It proposed a tonal structure consisting of seven notes, which were named, in descending order, *krusht*, *pratham*, *dwitiya*, *tritiya*, *chaturth*, *mandra* and *atiswār*. These refer to the notes of a flute, which was the only fixed-frequency instrument. This is why the second note is called *pratham* (meaning "first", i.e., produced when only the first hole is closed).

Music is dealt with extensively in the Valmiki *Ramayana*. Narada is an accomplished musician, as is Ravana; Saraswati with her veena is the goddess of music. Gandharvas are presented as spirits who are musical masters, and the gandharva style looks to music primarily for pleasure, accompanied by the soma rasa. In the *Vishnudharmottara Purana*, the Naga king Ashvatara asks to know the svaras from Saraswati.

The most important text on music in the ancient canon is Bharata's *Natya Shastra*, composed around the 3rd century CE. The *Natya Shastra* deals with the different modes of music, dance, and drama, and also the emotional responses (rasa) they are expected to evoke. The scale is described in terms of 22 micro-tones, which can be combined in clusters of four, three, or two to form an octave.

While the term raga is articulated in the *Natya Shastra* (where its meaning is more literal, meaning "colour" or "mood"), it finds a clearer expression in what is called *jati* in the *Dattilam*, a text composed shortly after or around the same time as *Natya Shastra*. The Dattilam is focused on gandharva music and discusses scales (swara), defining a tonal framework called *grama* in terms of 22 micro-tonal intervals (*sruti*[3]) comprising one octave. It also discusses various arrangements of the notes (*murchhana*), the permutations and combinations of note-sequences (*tanas*), and *alankara* or elaboration. Dattilam categorizes melodic structure into 18 groups called *jati*, which are the fundamental melodic structures similar to the raga. The names of the jatis reflect regional origins, for example *andhri* and *oudichya*.

Music also finds mention in a number of texts from the Gupta period; Kalidasa mentions several kinds of veena (Parivadini, Vipanchi), as well as percussion instruments (mridang), the flute (vamshi) and conch (shankha). Music also finds mention in Buddhist and Jain texts from the earliest periods of the Christian era.

Narada's *Sangita Makarandha* treatise, from about 1100 CE, is the earliest text where rules similar to those of current Hindustani classical music can be found. Narada actually names and classifies the system in its earlier form before the Persian influences introduced changes in the system.Jayadeva's *Gita Govinda* from the 12th century was perhaps the earliest musical composition sung in the classical tradition called Ashtapadi music.

In the 13th century, Sharngadeva composed the *Sangita Ratnakara*, which has names such as the *turushka todi* ("Turkish todi"), revealing an influx of ideas from Islamic culture. This text is the last to be mentioned by both the Carnatic and the Hindustani traditions and is often thought to date the divergence between the two.

Medieval period: Persian influence:

The advent of Islamic rule under the Delhi Sultanate and later the Mughal Empire over northern India caused considerable cultural interchange. Increasingly, musicians received patronage in the courts of the new rulers, who in their turn, started taking increasing interest in local music forms. While the initial generations may have been rooted in cultural traditions outside India, they gradually adopted many aspects from their kingdoms which retained the traditional Hindu culture. This helped spur the fusion of Hindu and Muslim ideas to bring forth new forms of musical synthesis likeqawwali and khyal.

The most influential musician of the Delhi Sultanate period was Amir Khusrau (1253–1325), sometimes called the father of modern Hindustani classical music.[4] A composer in Persian, Turkish, Arabic, as well as Braj Bhasha, he is credited with systematizing many aspects of Hindustani music, and also introducing several ragas such as Yaman Kalyan, Zeelaf and Sarpada. He created the qawwali genre, which fuses Persian melody and beat on a dhrupad like structure. A number of instruments (such as the sitar and tabla) were also introduced in his time.

Amir Khusrau is sometimes credited with the origins of the khyal form, but the record of his compositions do not appear to support this. The compositions by the court musician Sadarang in the court of Muhammad Shah bear a closer affinity to the modern khyal. They suggest that while khyal already existed in some form, Sadarang may have been the father of modern khyal.

Much of the musical forms innovated by these pioneers merged with the Hindu tradition, composed in the popular language of the people (as opposed to Sanskrit) in the work of composers like Kabir or Nanak. This can be seen as part of a larger Bhakti tradition, (strongly related to theVaishnavite movement) which remained influential across several centuries; notable figures include Jayadeva (11th century), Vidyapati (fl. 1375 CE),Chandidas (14th–15th century), and Meerabai (1555–1603 CE).

As the Mughal Empire came into closer contact with Hindus, especially under Jalal ud-Din Akbar, music and dance also flourished. In particular, the musician Tansen introduced a number of innovations, including ragas and particular compositions. Legend has it that upon his rendition of a night-time raga in the morning, the entire city fell under a hush and clouds gathered in the sky, and that he could light fires by singing the raga "Deepak", which is supposed to be composed of notes in high octaves.

At the royal house of Gwalior, Raja Mansingh Tomar (1486–1516 CE) also participated in the shift from Sanskrit to the local idiom (Hindi) as the language for classical songs. He himself penned several volumes of compositions on religious and secular themes, and was also responsible for the major compilation, the *Mankutuhal* ("Book of Curiosity"), which outlined the major forms of music prevalent at the time. In particular, the musical form known as dhrupad saw considerable development in his court and remained a strong point of the Gwalior gharana for many centuries.

After the dissolution of the Mughal empire, the patronage of music continued in smaller princely kingdoms like Lucknow, Patiala, and Banaras, giving rise to the diversity of styles that is today known as gharanas. Many musician families obtained large grants of land which made them self-sufficient, at least for a few generations (e.g. the Sham Chaurasia gharana). Meanwhile the Bhakti and Sufi traditions continued to develop and interact with the different gharanas and groups.

Modern era

Until the late 19th century, Hindustani classical music was imparted on a one-on-one basis through the guru-shishya ("mentor-protégé") tradition. This system had many benefits, but also several drawbacks; in many cases, the shishya had to spend most of his time serving his guru with a hope that the guru might teach him a "cheez" (piece or nuance) or two. In addition, the system forced the music to be limited to a small subsection of the Indian community. To a large extent it was limited to the palaces and dance halls. It was shunned by the intellectuals, avoided by the educated middle class, and in general looked down upon as a frivolous practice.[5]

Then a fortunate turn of events started the renaissance of Hindustani classical music.

First, as the power of the maharajahs and nawabs declined in early 20th century, so did their patronage. With the expulsion of Wajid Ali Shah toCalcutta after 1857, the Lucknavi musical tradition came to influence the music of renaissance in Bengal, giving rise to the tradition of *Ragpradhan gan* around the turn of the century.

Also, at the turn of the century, two great stars emerged on the horizon: Vishnu Digambar Paluskar and Vishnu Narayan Bhatkhande. Independent of each other, they spread Hindustani classical music to the masses in general, and the Marathi middle class in particular. These two gentlemen brought classical music to the masses by organizing music conferences, starting schools, teaching music in class-rooms, and devising a standardized grading and testing system, and by standardizing the notation system.[6]

Vishnu Digambar Paluskar emerged as a talented musician and organizer despite having been blinded at age 12. His books on music, as well as the*Gandharva Mahavidyalaya* music school that he opened in Lahore in 1901, helped foster a movement away from the closed gharana system.

Paluskar's contemporary (and occasional rival) Vishnu Narayan Bhatkhande recognized the many rifts that had appeared in the structure of Indian classical music. He undertook extensive research visits to a large number of gharanas, Hindustani as well as Carnatic, collecting and comparing compositions. Between 1909 and 1932, he produced the monumental four-volume work *Hindustani Sangeetha Padhathi*,[7] which suggested a transcription for Indian music, and described the many traditions in this notation. Finally, it consolidated the many musical forms of Hindustani classical music into a number of thaats (modes), subsequent to the Melakarta system that reorganized Carnatic tradition in the 17th century. The ragas as they exist today were consolidated in this landmark work, although there are some inconsistencies and ambiguities in Bhatkande's system.

The now tiny state of Goa has contributed a lot to Indian Classical music.Some of the renowned singers from 19th,-21st century hail from the state of Goa where the music was kept alive in the temples.[8]

In modern times, the government-run All India Radio, Bangladesh Betar and Radio Pakistan helped to bring the artists to public attention, countering the loss of the patronage system. The first star was Gauhar Jan, whose career was born out of Fred Gaisberg's first recordings of Indian music in 1902. With the advance of films and other public media, musicians started to make their living through public performances. As India was exposed to Western music, some Western melodies started merging with classical forms, especially in popular music. A number of Gurukuls, such as that of Alauddin Khan at Maihar, flourished. In more modern times, corporate support has also been forthcoming, as at the ITC Sangeet Research Academy. Meanwhile, Hindustani classical music has become popular across the world through the influence of artists such as Ravi Shankar and Ali Akbar Khan.

Principles of Hindustani music

The rhythmic organization is based on rhythmic patterns called tala. The melodic foundations are called ragas. One possible classification of ragas is into "melodic modes" or "parent scales", known as thaats, under which most ragas can be classified based on the notes they use.

Thaats may consist of up to seven scale degrees, or swara. Hindustani musicians name these pitches using a system called Sargam, the equivalent of the Western movable do solfege:

- Sa (Shadja) = Do
- Re (Rishabh) = Re

- Ga (Gandhar) = Mi
- Ma (Madhyam) = Fa
- Pa (Pancham) = So
- Dha (Dhaivat) = La
- Ni (Nishad) = Ti
- Sa (Shadja) = Do

Both systems repeat at the octave. The difference between sargam and solfege is that re, ga, ma, dha, and ni can refer to either "Natural" (*shuddha*) or altered "Flat" (*komal*) or "Sharp" (*tivra*) versions of their respective scale degrees. As with movable do solfege, the notes are heard relative to an arbitrary tonic that varies from performance to performance, rather than to fixed frequencies, as on a xylophone. The fine intonational differences between different instances of the same swara are called srutis. The three primary registers of Indian classical music are mandra (lower), madhya (middle) and taar (upper). Since the octave location is not fixed, it is also possible to use provenances in mid-register (such as mandra-madhya or madhya-taar) for certain ragas. A typical rendition of Hindustani raga involves two stages:

- Alap: a rhythmically free improvisation on the rules for the raga in order to give life to the raga and flesh out its characteristics. The alap is followed by a long slow-tempo improvisation in vocal music, or by the jod and jhala in instrumental music.
- **Bandish** or **Gat**: a fixed, melodic composition set in a specific raga, performed with rhythmic accompaniment by a tabla or pakhavaj. There are different ways of systematizing the parts of a composition. For example:
    - Sthaayi: The initial, rondo phrase or line of a fixed, melodic composition.
    - Antara: The first body phrase or line of a fixed, melodic composition.
    - Sanchaari: The third body phrase or line of a fixed, melodic composition, seen more typically in dhrupad bandishes
    - Aabhog: The fourth and concluding body phrase or line of a fixed, melodic composition, seen more typically in Dhrupad bandishes.

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The recent growth of musical applications of Peirce's general theory of signs, such as in the works of David Lidov (1986), Robert Hatten (1994), William Dougherty (1993, 1994), shows that this approach, once set properly in both musical and semiotic contexts, has great analytical power on questions of musical signification. In this paper I will present the structure of a semiotic theory of music, as demonstrated in my doctoral dissertation, ***Semiosis in Hindustani Music*** (Imatra: International Semiotics Institute), submitted and approved by the University of Helsinki in 1997.

Peirce, in his studies of semiotics, concluded that thought is only possible by means of signs (vide CP 1.538, 4.551, 5.253). Music is a species of thought; and thus, the idea that music is sign and depends on significative processes, or semiosis, is obviously true. A musical sign can be a system, a composition or its performance, a musical form, a style, a composer, a musician, hers or his instrument, and so on. According to Peirce, signification occurs in a triadic relation of a sign and the object it stands for to an interpretant (CP 6.347), which - in music - is another sign developed in the mind of a listener, musician, composer, analyst or critic.

In Peirce's classification of the sciences, semiotics (or *semeiotic*) has three branches: Speculative Grammar, Critic and Methodeutic (or Speculative Rhetoric) (CP 1.192). According to Nathan Houser, the scholar who studies speculative grammar deals with the intrinsic nature of signs and semiosis. S/he examines relations among signs, the nature of the correlates taking part in semiosis, Peirce's sign trichotomies, and his ten or - broadly speaking - sixty-six classes of sign. The study of critic deals with signs in relation to their objects, and especially the condition of signs' references in relation to their signified objects. Consequently, critic deals with truth and the concept of truth. It encompasses the study of reasoning, or the three kinds of arguments (abduction, induction and deduction). Methodeutic studies signs in relation to their interpretants. Thus, semiosis is focused on the interpretant level, and how interpretants themselves can become signs during semiotic processes (Houser 1990: 210-11).

It seems to me that, just as Peirce divided formal semiotics into three areas, musical studies can also be understood as three interrelated fields, not as broad and abstract as speculative grammar, critic and methodeutic are, but still showing a concern for the following: (1) 'the general conditions of signs being signs' (CP 1.444), that is, the intrinsic nature of semiosis, or the study of signs and their systems of inner relationship; (2) 'the theory of the general conditions of the reference of Symbols and other Signs to their professed Objects' (CP 2.93), that is, the relation of signs to their objects; and (3) 'the necessary conditions of the transmission of meaning by signs from mind to mind, and from one state of mind to another' (CP 1.444), that is, the relation of signs to their interpretants, interpreters and systems of interpretation. On the microscopic level, the same division represents the basic relations of Peirce's model of semiosis: (1) the sign in itself, (2) the sign related to its possible objects, (3) the sign related to its possible interpretants.

2 Materials and Methods

2.1 Area of Study

Hindustani Music with all its Musical Journeys.

Mathematical music theory has become an indispensable basis for music informatics and computational musicology. It has been developed by mathematicians or composers like Leonard Euler [Eule39], Milton Babbitt [Babb92] or David Lewin [Lewi87][Lewi93]. The most recent advancement has been made by Guerino Mazzola in his work The Topos of Music [Mazz02]. His theorical achievements have been applied in several software products on different platforms, namely [Presto], [RubatoN], [RubatoX] and [RubatoC].

Two of these software products, presto and Rubato Com^{p}oser, facilitate music composition by providing composers with convenient mathematical tools. We describe both of them in this chapter, including their underlying theories. presto uses a geometrical representation of music, whereas Rubato Com^{p}oser, its present-day descendant, is based on modern functorial mathematical music theory.

It is interesting to note that the close affiliation of music and geometry has existed for centuries. The western score notation, for example, and its predecessor, the neumatic signs, can be seen as a grid, where notes are drawn as points and melodies as curves. This representation has been abstracted at the end of the last century and this is indispensable for music to be represented and processed by computers.

Some of the major abstractions in this field were made by Guerino Mazzola by the end of the 1980s and described in his book Geometrie der Töne [Mazz90]. The theoretical foundations were subsequently implemented in the music composition software presto, described in this section.

presto [Mazz89] [Presto] was published in 1989 for Atari ST computers. It provides a very elaborate interface

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(shown in Figure 2.2) to compose and manipulate music and also supports reading from and saving to standard MIDI files [MIDI96], recording music using a MIDI interface, drawing music using the mouse or printing the composed music.

These features are all wide spread among music software products, but what mainly distinguishes presto from other applications is its ability to generate and modify music by performing a variety of geometrical operations on it.

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2.4 Copyright Form

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3 Sections

Better than a hundred years lived in ignorance

without contemplation, is one single day of

life lived in wisdom and in deep contemplation'.

The Dhammapada (The Path of Perfection)

It is evident that automatic content based music information retrieval greatly relies on a good indexing algorithm. The indexing algorithm should be time efficient and in addition to time efficiency should also aid in good precision and recall during the process of retrieval. Several algorithms have been proposed by various researchers for the process of information retrieval. A scalable P2P system for content based music information retrieval has been developed by George Tzanetakis [1]. This algorithm is based on Rendezvous points. The authors have extracted features based on the Short Time Fourier Transform and Mel-Frequency Cepstral Coefficients to represent sound texture, rhythm and pitch content. The means and variances are computed for the Spectral Centroid, Roll-off, Flux and Zero-Crossings and the first 5 Mel Frequency Cepstral Coefficients (MFCC) over a 1 second texture window are calculated for representing Spectral Texture. These features are called as rendezvous points. The authors have designed the algorithm to search based on only a selected quality or qualities of the music piece while ignoring all other parameters. This algorithm had a high time complexity for the process of search and retrieval, since focus was not given on the indexing process to aid in efficient retrieval.

In another algorithm proposed by Andreas Rauber et al, for the automatic indexing of music the genre of the music is used for indexing either directly or through the features conveying the genre of the music piece [3]. This algorithm used time-invariant features which are extracted based on psychoacoustic models for representing the genre of the input music signal. Based on the extracted features a clustering algorithm was used to group similar genre music together which are then used as indices for the given music piece. This algorithm used only the genre parameter for retrieval and hence has to be modified to include other features of the song.

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In another work by Hsuan-Huei Shih et al , the authors have assumed that the input file would be in MIDI representation and have modified a table driven algorithm for indexing using the tempo characteristics of the signal [4]. In this work a bar index table is built based on the tempo characteristics and then using the Lempel – Ziv algorithm retrieval is performed based on the bar indexes. This algorithm has given better results when the input is available in MIDI representation.

In another work by Cheng Yang a spectral indexing algorithm based on multiple hash tables have been proposed as a mode of indexing and then retrieval is performed based on Hough transform [5]. The authors have used minimal features like Short time Fourier transform and have tested for a total of 300 minute of audio input. The drawback of this approach is that it used a minimal feature set and hence did not a have a good precision and recall.

Indian Music is broadly divided into Hindustani music (North Indian music) and Carnatic music (South Indian counterpart). Both the systems are fundamentally similar and the differences arise in the style in which the notes are sung. Carnatic music can be thought of as a more systematized system as compared to Hindustani music [10]. The essential characteristics of Carnatic music are Ragam and Talam. Ragam is characterized by 'swaras'. There are essentially 7 swaras namely Sa, ri, ga, ma, pa, da, ni which is analogous to C, D, E, F, G, B, A in the keyboard. In an octave the 12 keys correspond to 12 frequencies. Normally, in a keyboard the C is played starting at 240 Hz. The next octave of C corresponds to a frequency of 480 Hz and therefore successive keys correspond to fixed frequencies, which follow a geometric progression. Carnatic music is based on a 22 interval per octave system as against Western music which is a 12 interval per octave system. Even if one chooses twelve keys to fill in an octave, there is no reason to tune them in a geometric progression. The seven swaras can be assigned frequencies between the frequency of the first chosen 'sa' and its harmonic frequency.

The starting frequency of the 'Sa' is called the fundamental frequency and can vary between singers, between songs and a combination of singers and songs. Western music system does not have the concept of Raga as compared to Carnatic music.

In addition, Western music is an even International Journal of Artificial Intelligence & Applications (IJAIA), Vol.1, No.3, July 2010 62 tempered system as against Carnatic music which is a just tempered system. Other characteristics of Carnatic music that are typically used for music information processing like Ragam, the variations of the swara, Talam, Gamakam are discussed by Rajeswari Sridhar et al . Hence these specific characteristics of Carnatic music make it impossible to adapt the algorithms available for Western music directly to Carnatic music. Hence in our algorithm we have used the concept of converting the frequencies to swara representation which in turn is dependent on fundamental frequency of the input being considered and used this swara string as one of the feature for indexing. In the indexing algorithms proposed for Western music, note representation, fundamental frequency usage, multiple parameters and a combination of signal level features are not used for indexing. It was observed from literature that multiple features had given good result in some situations but those algorithms did not have a good indexing mechanism .

5. Objectives of the Proposed Study:

- A brief overview of modern mathematical music theory and the two related music composition applications presto and Rubato Com^{p}oser.
- The concepts of presto's OrnaMagic module and gives some common examples for its application.
- Limitations of OrnaMagic, proposes a structure for a new implementation and generalizes and formalizes concepts for functorial mathematical music theory.
- How the mathematical formalizations are implemented for Rubato Com^{p}oser and gives an overview of the implementation design.

- How our new implementation can be used to produce meaningful compositions and gives some examples for inspiration.
- Compares the new implementation with its predecessor. Furthermore, it provides an outlook on its future uses and further work.

Statistics :

It is interesting to note that the close affiliation of music and geometry has existed for centuries. The western score notation, for example, and its predecessor, the neumatic signs, can be seen as a grid, where notes are drawn as points and melodies as curves. This representation has been abstracted at the end of the last century and this is indispensable for music to be represented and processed by computers.

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presto [Mazz89] [Presto] was published in 1989 for Atari ST computers. It provides a very elaborate interface (shown in Figure 2.2) to compose and manipulate music and also supports reading from and saving to standard MIDI files [MIDI96], recording music using a MIDI interface, drawing music using the mouse or printing the composed music.

These features are all wide spread among music software products, but what mainly distinguishes presto from other applications is its ability to generate and modify music by performing a variety of geometrical operations on it.

Its unique tools are based on a geometrical representation of music, which we describe now.

In presto, notes are defined as points in a four-dimensional geometrical space spanned by the following coordinates:

- onset, the time when a note is played,
- pitch on the chromatic scale,
- duration in time and
- loudness.

All four coordinates have discrete values, where onset is between 1 and 11360 and the other three between 1 and 71. Additionally, one of 16 instruments can be chosen for every note in order to orchestrate a composition. However, this parameter is not included in the geometrical space and therefore not relevant with regard to the future explanations.

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5 Equations

- Simple: DiaF is a module M with FrameF = Hom(-, M) = @M. As previously stated, Simple is the basic type and it is comparable to the primitive data types in a programming language. However, the category of modules includes number rings such as Z, Zn, Q, C as well as word monoids hUnicodei or polynomial rings R[X] among others, which facilitate the construction of more complex mathematical structures than in a programming language.

  - Limit: the frame space FrameF is the limit lim(DiaF) of the form spaces of the given diagram. If the DiaF is discrete (i.e. no arrows), FrameF is the cartesian product, which is a conjunction of attributes. In OOP, the corresponding construction would be a class with several attributes.

  - Colimit: here, FrameF is the colimit colim(DiaF) of the given diagram's form spaces. In case DiaF is discrete, we have the disjoint union of a list of cofactors. To realize such a disjunction for a set of classes in OOP, a superclass can be defined for them.

  - Power: DiaF has a single vertex form G and no arrow. FrameF = $\Omega^{Space}G$, Ω being the subobject classifier (see [Mazz02] Appendix G, Section 3.1). This corresponds to an collection of instances of the specified form G. For this, we normally have predefined set classes in OOP.

6 Helpful Hints

6.1 Figures and Tables

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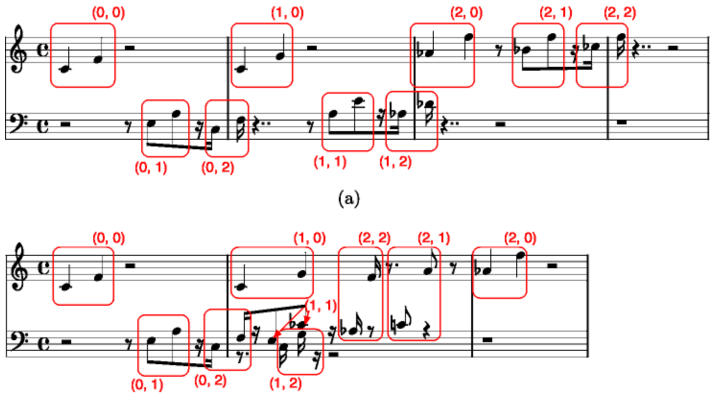

Two simple musical wallpapers generated from the two-note motif c^0-f^0, by commuting two morphisms f_1 and f_2, $r_1 = [0, 2]$, $r_2 = [0, 2]$. (a) $f_{\cdot 1} \sim f_{\cdot 2}$ (b) $f_{\cdot 2} \sim f_{\cdot 1.}$ (k_1, k_2) with k_i 2 r_i are the grid coordinates of the marked note groups.

Another interesting problem is to find a way to map a Power denotator d by any arbitrary morphism f . Also if for instance the codomain modules of d's Simple denotator value morphisms do not match f's domain modules. A rubette dealing with this problem offers great flexibility and security, since users can use a specific morphism for different purposes and cannot misapply it in any way.

In order to solve this problem, casting morphisms can be used to convert the Simple denotator's values so that they can be composed with the morphism. In this section we explain this procedure for a morphism f : V ! W and a denotator d : A@P(c_1,.. . c_n) of Power form P. The morphism's domain $V = V_1 \times .. . V_s$ and codomain $W = W_1 \times . . . W_t$ are assumed to be products of arbitrary modules.

We define two sequences of Simple forms G. = (G_1,.. . G_s), H. = (H_1,. . . H_t) with the elements G_j, H_k 2 S_P to specify, which denotators in c_1,. . . c_n 2 d are transformed by f . Moreover, we need three kinds of auxiliary morphisms:

- the injection morphisms i_1,. . . i_s, i_j : V_j ! V with $i_j(v) = v_0$ = (0,. . . v,. . . 0), where v is at the j-th position of v_0,
- the projection morphisms p_1,.. .p_t,p_k: W ! W_k with $p_k(w) = w_k$ for w=(w_1,...w_t)and
- the casting morphisms g_1,... g_s, g_j : G_j ! V_j and h_1,. . . h_t, h_k : W_k ! H_k.

In practice, a casting morphism is usually an embedding, if its domain module is contained by its codomain module. Otherwise, it is a rounding morphism. The previously defined morphisms are composed in the following way, to map denotator c_i 2 d by morphism f :

$$\varphi_f(c_i, (G_j)) = f(i_1 \sim g_1 \sim SA(G_1, c_i) + . . . i_s \sim g_s \sim SA(G_s, c_i)).$$

Finally, considering the Simple forms G., H., we are able to define our general mapping morphism $First_f$: P ! P for Power form P:

$First_f(d)$ is a copy of d, where every $SA(H_k, c_i)$ is replaced by $h_k \sim p_k \sim \varphi_f(c_i, (G_j))$ for 1 ~ k ~ t and every c_i 2 d.

7 End Sections

7.1 Appendices

Appendixes, if needed, appear before the acknowledgment. In the event multiple appendices are required, they will be labeled “Appendix A,” “Appendix B, “ etc. If an article does not meet submission length requirements, authors are strongly encouraged to make their appendices supplemental material.

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7.3 References

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4 Conclusion

The new implementation for grid structure generation and application is more flexible in many ways, as shown in Table 7.1. We summarize and discuss the improvements.

Due to its extendable structure and the rubette concept, Rubato Com^{p}oser promotes a modular way of thinking, where many functional parts act together in every conceivable way. To maximize the flexibility of use, the functionality of the OrnaMagic module has been separated in two main and three additional modules. The combination of these modules leads to new ways of using grid structures for composition.

Furthermore, the two main modules, the Wallpaper and the Alteration rubette can be used for processing any arbitrary structures, not just musical ones, since they accept any denotators of type Power as inputs.

All note coordinate values in presto are positive integers. Pitch, loudness and duration are moreover restricted to a maximal value of 72. In Rubato Com^{p}oser, the processed structures can have elements of many different modules as values. Our present implementation of wallpapers and alteration includes the modules Z, Q, R and Z_n.

5

	presto OrnaMagic	Rubato Composer
design	serial	modular
input	set of notes	any Power denotator
values	discrete integer values	$\mathbb{Z}$, $\mathbb{Q}$, $\mathbb{R}$ or $\mathbb{Z}_n$ values
space	onset ×pitch/loudness/duration	any arbitrary space
grid vectors	2-dim translations	n-dim morphisms

6

Table 7.1: Differences between the two implementations.

The space for grid structure generation and application is two-dimensional in presto and consisting of onset and a second coordinate. The new implementation allows the selection of any conceivable n-dimensional space.

This difference also applies to the grid vectors. In presto, these were in the two-dimensional and additionally restricted to simple translations. Our new implementation features affine and other morphisms of any dimension.

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